REmap

A Renewable Energy Roadmap

IRENA

International Renewable Energy Agency

ROADMAP FOR A RENEWABLE ENERGY FUTURE

2016 EDITION

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.

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Disclaimer

In an era of accelerating global change, the adoption of the Paris Agreement at COP 21 marks a turning point in the global energy transition. The imperative of decarbonising energy is now seen as a central element of global efforts to deeply reduce greenhouse-gas emissions.

Substantial growth in renewable energy deployment has already taken place, but the next step-change must include accelerated deployment coupled with energy efficiency. This approach is also embedded in the Sustainable Development Goals, which call for a substantial increase of renewables in the global energy mix by 2030 and to double the rate of improvement in energy efficiency.

The second edition of IRENA's global renewable energy roadmap – REmap – shows how the world can double the share of renewable energy in the energy mix within this timeframe, reducing global CO_2 emissions from energy use as much as 35%. We know that doubling the share of renewables by 2030 is possible, and a review of the best practices among different countries shows how it can be done. Realising these goals can help fulfil the ambition of the international community to achieve sustainable development and climate change mitigation.

REmap provides an important and authoritative perspective on the opportunities and challenges that lie before us. The report specifies solutions and actions needed today to accelerate a transition to a sustainable future. It shows that progress in the power sector has been remarkable, but that to reach broader sustainability objectives, more action is needed in the transport, heating and cooling sectors, and with all sources of renewable energy. Continuous innovation is required, both to modernise traditional energy uses and to enhance the innovation and deployment of new technologies.

This roadmap provides a global assessment of different pathways, as well as an actionable source of information and advice to countries and other stakeholders. It supports those looking to contribute to the common goal of accelerating the deployment of renewable energy worldwide. Ultimately, it charts a path to a secure and sustainable future through a positive, growth-oriented and economically beneficial energy transformation.

Adnan Z. Amin

Director-General

International Renewable Energy Agency

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- Annual national REmap expert workshop, Abu Dhabi, 5 November 2014
- Side-event at the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP), formed under the United Nations Framework Convention on Climate Change (UNFCCC), Geneva, 15 February 2015
- Africa Renewable Energy Roadmap workshop, Abu Dhabi, 8 June 2015
- Annual national REmap expert workshop, Abu Dhabi, 25 November 2015
- Several side-events at the 8th, 9th and 10th Sessions of IRENA's Council and 4th and 5th Sessions of IRENA's Assembly, Abu Dhabi, 2014-2015
- Launch events and preparatory meetings for REmap country reports on China, Germany, Mexico, Poland, Ukraine, the United Arab Emirates and the United States of America, 2014-2015

The level and scope of REmap and IRENA's ability to engage with countries benefited greatly from voluntary contributions provided by Germany and Japan.

Sole responsibility for the analysis, findings and conclusions lies with IRENA.

ROADMAP FOR A RENEWABLE ENERGY FUTURE

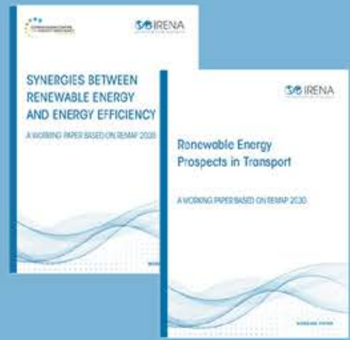
RECENT REMAP-RELATED PUBLICATIONS, BACKGROUND DATA AND METHODOLOGY

First edition of IRENA's global roadmap (2014)

The first study of worldwide renewable energy potential assembled from country plans and data, outlining how the world can double the share of renewables in the energy mix.

Comprehensive country reports (2014—)

Detailed studies – done in collaboration with countries – outlining REmap analysis, the potential of renewables and applicable policy frameworks, with suggestions and recommendations to accelerate uptake.



Action team working papers (2015—)

REmap action teams explore subjects including RE/EE* synergies and renewable transport technologies.

* renewable energy / energy efficiency
** forthcoming

Further studies and tools

REmap has provided the analytical basis for IRENA's REthinking Energy and Renewable Energy Benefits reports, as well as Sustainable Energy for All Global Tracking Framework and G7, G20 and UNFCCC frameworks.

Regional analyses (2015—)

Detailed regional perspectives based on REmap findings.

Country background papers (2015—)

Concise analysis of specific issues, sectors and technologies in REmap countries.

Technology roadmaps for manufacturing, bioenergy and electricity storage (2014—)

In-depth technology and sector-based roadmaps featuring the technologies needed to enable the global energy transition.

All publications, background data and methodology overviews can be downloaded from **www.irena.org/remap**

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ABBREVIATIONS

°C	degrees Celsius
ASEAN	Association of Southeast Asian Nations
BECCS	bioenergy with carbon capture and storage
bln	billion
BNEF	Bloomberg New Energy Finance
CCGT	combined cycle gas turbine
CCS	carbon capture and storage
CH_4	methane
CHP	combined heat and power
CO_2	carbon dioxide
COP21	21^{st} Conference of the Parties
CSP	concentrated solar power
DH	district heat
DSM	demand side management
EE	energy efficiency
EIA	Energy Information Administration
EJ	exajoules
ETS	emissions trading system
EU	European Union
EUROSTAT	Statistical Office of the European Union
EV	electric vehicle
FAO	Food and Agriculture Organization of the United Nations
G20	Group of Twenty
G7	Group of Seven
GDP	gross domestic product
GEA	Global Energy Assessment
GFC	gross final consumption
GHG	greenhouse gas
GJ	gigajoule
Gt	gigatonne
GW	gigawatt
ICE	internal combustion engine
IEA	International Energy Agency
INDC	Intended Nationally Determined Contribution
IOREC	International Off-Grid Renewable Energy Conference
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
kWh	kilowatt-hour
LNG	liquefied natural gas
LPAA	Lima to Paris Action Agenda
LULUCF	land use, land-use change, and forestry
m^2	square metres
m^3	cubic metres
MJ	megajoule
MW	megawatt
MWh	megawatt-hour
NDC	Nationally Determined Contribution
NPS	New Policy Scenario (IEA WEO)
OECD	Organisation for Economic Co-operation and Development
PJ	petajoule
p-km	passenger kilometre
ppm	parts per million
PV	photovoltaic
R&D	research and development
RE	renewable energy
SAIREC	South Africa International Renewable Energy Conference
SDG	Sustainable Development Goal
SDG7	Sustainable Development Goal 7: Ensure access to affordable, reliable, sustainable, and modern energy for all
SE4All	Sustainable Energy for All
SHP	small hydro power
SME	small and medium enterprises
TFEC	total final energy consumption
TPES	total primary energy supply
TWh	terawatt-hour
UAE	United Arab Emirates
U-HVDC	ultra high-voltage direct current
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environmental Program
US	United States
USD	United States dollar
VRE	variable renewable energy
WEC	World Energy Council
WEO	World Energy Outlook
WHO	World Health Organization
yr	year

EXECUTIVE SUMMARY

THE WORLD CAN REACH ITS SUSTAINABLE ENERGY AND CLIMATE CHANGE OBJECTIVES BY DOUBLING THE SHARE OF RENEWABLE ENERGY BY 2030

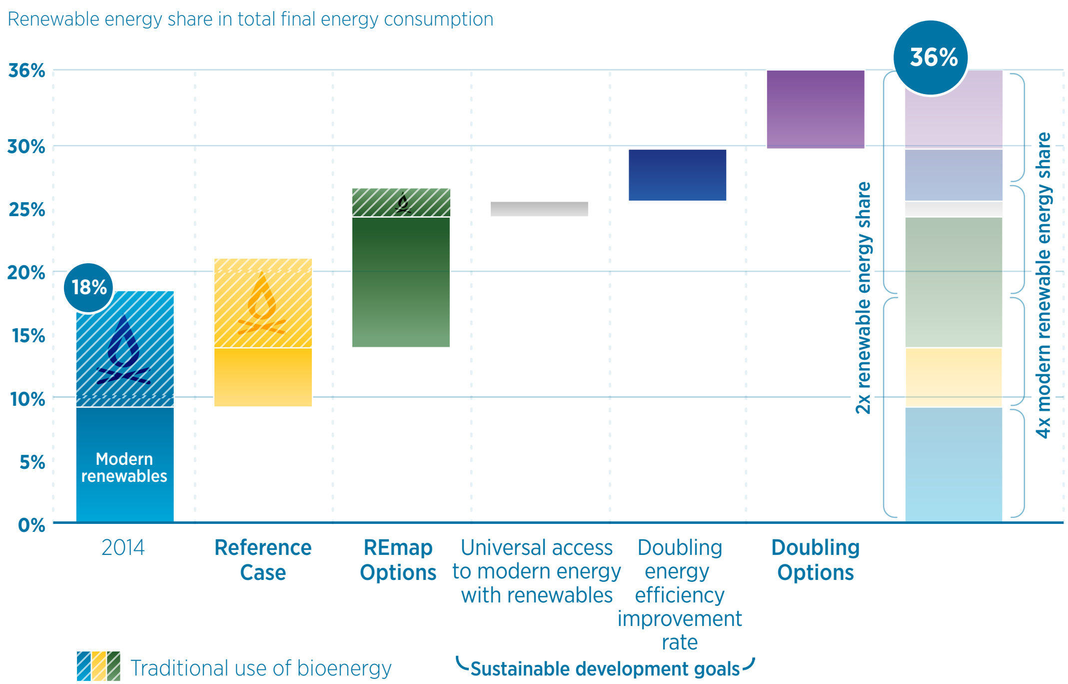
The 2015 United Nations Climate Conference in Paris was a watershed moment for renewable energy. It reinforced what advocates have long argued: that a rapid and global transition to renewable energy technologies offers a realistic means to achieve sustainable development and avoid catastrophic climate change. Now that renewable energy is recognised as central to achieving climate and sustainability objectives, the challenge facing governments has shifted: from identifying what needs to be done, to how best to achieve it.

REmap offers a global plan to double the share of renewables in the world's energy mix by 2030. This edition updates some of the key findings of its 2014 predecessor. Yet the core message remains consistent: doubling the share of renewables is possible, cost-effective and economically beneficial, even as global energy demand grows. Doing so is one of the main ways countries can meet their international climate-change targets, as well as the Sustainable Development Goals.

The drop in oil prices over the past 18 months has not affected the prospects for renewables. The year 2015 saw record highs in renewable energy investments, with solar photovoltaics (PV) and wind capacity additions at all-time highs. Renewable energy technologies are today among the most cost-competitive options for power generation.

The continued growth of renewables is driven by falling costs. Prices for equipment and installation and project finance all continue to decline. The banking sector has recognised the reliability and low operational costs of renewables and has responded by offering interest rates at record lows. Investors appreciate that wind and solar power can balance out their energy portfolios and hedge against tightening regulations on fossil fuels.

Figure ES1: Doubling the world's renewable energy share requires concerted action, reinforcing growth in renewables with energy efficiency and universal access.



REFERENCE CASE: DEPLOYMENT BASED ON EACH COUNTRY'S PLANS AND POLICIES TODAY

REMAP OPTIONS: THE DEPLOYMENT POTENTIAL OF ADDITIONAL RENEWABLE ENERGY TECHNOLOGIES BY 2030 ON TOP OF TODAY'S EXISTING POLICIES

DOUBLING OPTIONS: ADDITIONAL RENEWABLE ENERGY DEPLOYMENT COMBINED WITH DEEPER STRUCTURAL CHANGES

Doubling the renewable energy share by 2030 will be easier if energy demand growth slows. Greater energy efficiency will rein in demand growth.

Renewables, meanwhile, are essential to extend energy access to all. Off-grid renewable solutions offer the most cost-effective way to expand electricity access. For people in less developed countries, the transition also means replacing traditional, and often unsustainable uses of bioenergy with modern renewable options for cooking and heating.

Doubling the renewable energy share means accelerating the deployment of current technologies as well as investing in innovation. Some 60% of the world's renewable energy potential can be achieved by implementing what this roadmap calls "REmap Options". The remaining 40% can be realised through accelerated energy efficiency along with an investment push to achieve universal energy access with renewables. Described here as the "Doubling Options", these combine new technologies with deeper structural changes.

Doubling the renewable share is vital to achieve a carbon-free energy system in the next 50 years. It would also reduce the challenges of global energy security and risks to the environment and human health.

DOUBLING THE SHARE OF RENEWABLES BY 2030 IS FEASIBLE, BUT ONLY WITH IMMEDIATE, CONCERTED ACTION TO JUMP-START THEIR USE IN TRANSPORT, BUILDINGS AND INDUSTRY

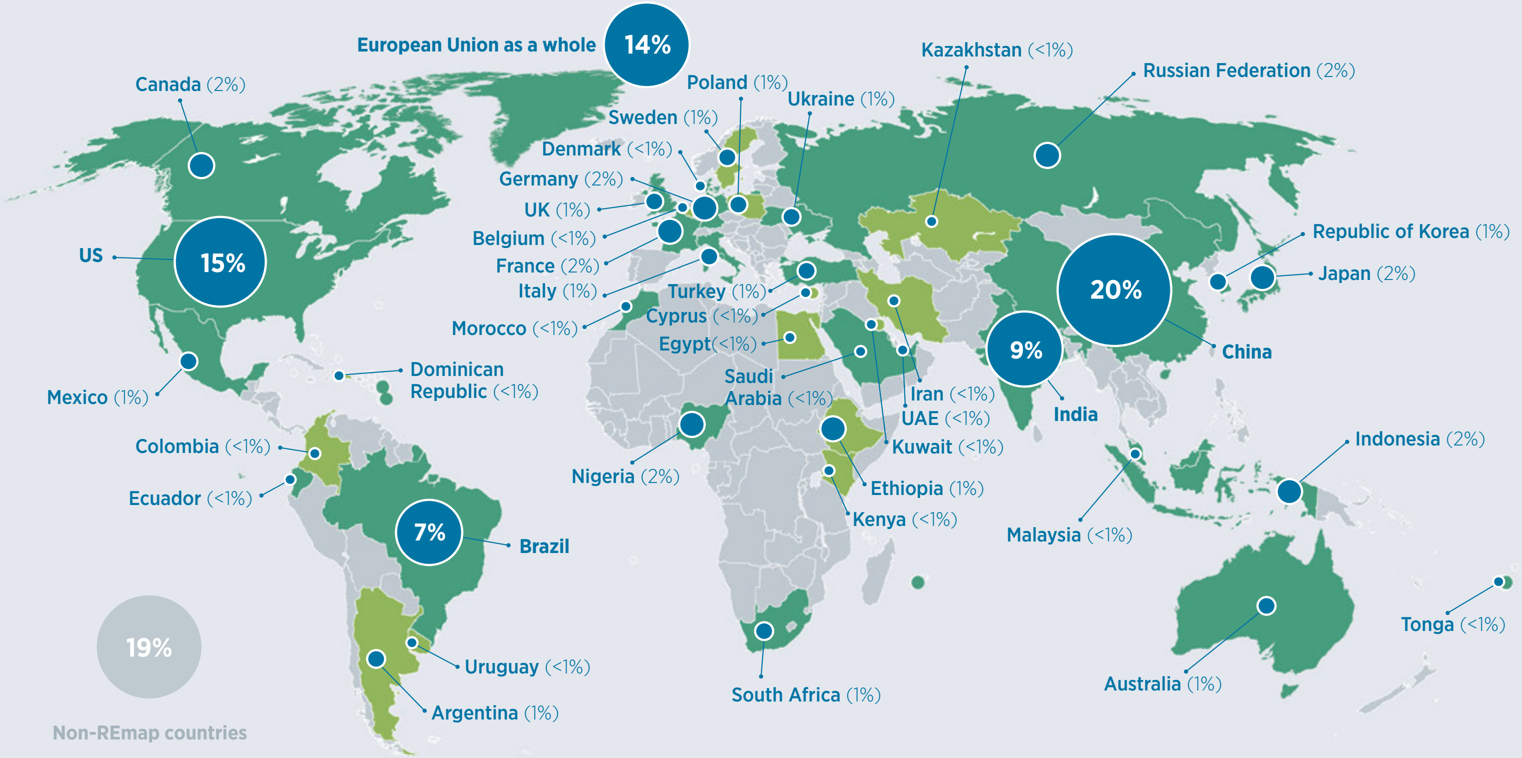
Policies now in place would increase the renewable share in the global energy mix to only 21% by 2030. Starting with the 18.4% renewable share in 2014, average annual growth would amount to 0.17 percentage points, far short of the 1 percentage point a year required. Global energy demand continues to grow – it will rise 30% in 2030 compared to the level today – and the pace of renewable deployment is only slightly higher. To achieve the necessary doubling, therefore, urgent and concerted action is needed, both nationally and through greater international cooperation. REmap aims to equip policy makers, business leaders and civic organisations with the information to make that happen.

Global doubling does not imply doubling in every country. While some countries have raised their outlook for renewable energy adoption in the last two years, others have postponed investments. Projections for many countries show energy demand rising faster than renewable energy adoption. Growth rates and renewable energy deployment potential will always differ, reflecting differences in national circumstances. As of 2010, the modern renewable share in energy consumption in the 40 countries that participate in REmap ranged from a low of 1% to around 50% for modern renewable energy, and up to 90% if traditional use of bioenergy was included. But while the pace varies, every country can achieve some growth.

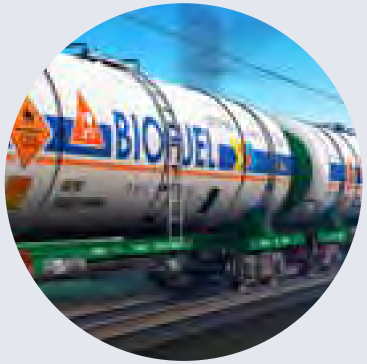
Implementation of all REmap Options would increase the renewable share between 20% and 70% in most countries by 2030. In several developed countries, renewables have grown because of successful policies, and most have the potential for significant growth. Energy demand in developing countries is growing faster, creating many opportunities for deployment.

The share of renewables in the energy consumption of REmap countries in 2030 varies, from just 10% to over 60%. REmap takes a country-specific approach to doubling the global share, and addressing the specifics of each market or region. Nonetheless, a global energy transformation requires targeted action by all.

Figure ES2: Country opportunities vary, but each country has a role to play in scaling up renewables.



Note: Percentage indicates how much renewable energy each country consumes in 2030 if the REmap Options are deployed.



While the outlook for renewables in the power sector is highly positive, advances in transport, heating and industry have been slower. An electric-transport revolution may be drawing closer, but liquid biofuel uptake is hurt by low oil prices. Renewable energy adoption for buildings has also slowed, and industry, in particular, is often overlooked in country plans. To accelerate overall uptake enough, renewable power generation will have to increase still more. The electrification of heating and transport will further boost power demand.

Countries must accelerate their uptake of renewables in buildings, industry and transport without delay. Consumption of renewable power will account for around half of the total renewable energy use in 2030, while the rest would come from direct uses, such as biofuel-based heating, cooking, cooling and transport, as well as district heating.

Planning must start now to ensure the successful integration of variable renewable power. Wind and solar PV power generation are influenced by weather and daylight patterns, resulting in variable output. With higher shares of wind and solar, the power system needs more flexibility. Coupling excess renewable power generation with heating and transport demand is one way to provide such flexibility.

Limited deployment in some government projections stems from a lack of incentives for renewables in buildings and industry. Renewable-heat policies often receive less attention than those for electricity, in part because renewables are more easily deployed in new buildings. Standing capital stock with long lifespans is an impediment to change. Renewable energy is more difficult to deploy in refurbishment and renovation schemes than in new buildings. Other barriers can also play a role. For example, in the aviation sector, the use of renewable fuel is negligible, because price plays a bigger role in competition between airlines compared to environmental performance.

Bioenergy will have to account for half of renewable energy use in 2030 for a high enough renewable share overall. Bioenergy must be reinvigorated in all its forms, including advanced liquid biofuels for aviation, freight and shipping applications. Enough sustainable bioenergy is available to reach this target. Consistent with many other global estimates, IRENA finds that sustainable primary bioenergy use can increase by nearly 70% between today and 2030.

For renewables other than bioenergy, the growth potential is even higher. Solar PV power generation can grow sevenfold, from 230 gigawatts (GW) of capacity at the end of 2015 to between 1 600 GW and 2 000 GW by 2030. Wind power can more than quadruple, from 400 GW in 2015 to over 1 800 GW.

If the steps outlined in this roadmap are followed, nearly half of global power generation will be renewable by 2030, compared to less than a quarter in 2015. The renewable energy share would also surge in others, with increases to as high as 57% in buildings, 35% in industry and, 16% in transport.

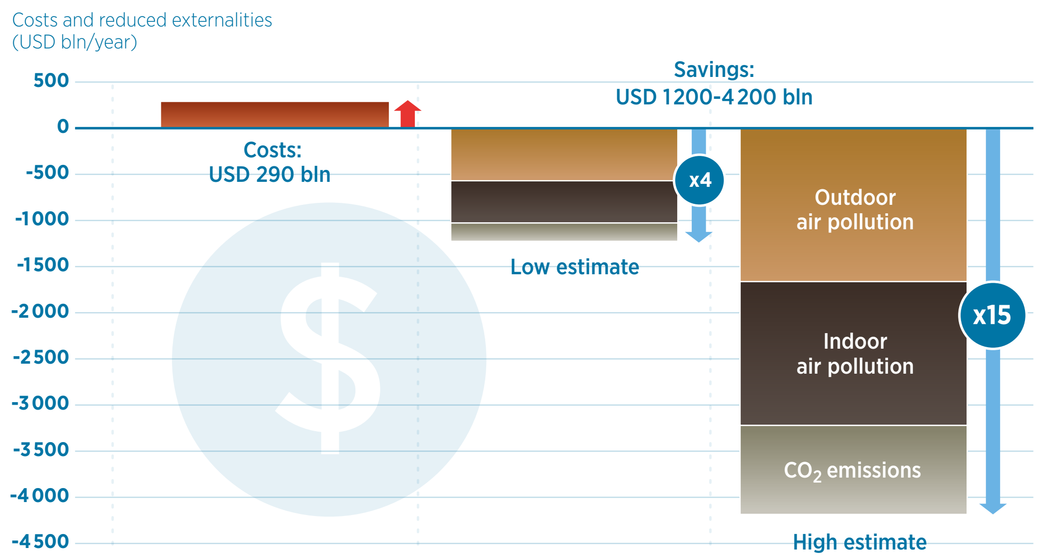
DOUBLING RENEWABLES WILL SAVE UP TO 15 TIMES MORE THAN IT COSTS

Doubling the renewable energy share requires annual investments in power generation, heating, cooling and biofuel capacity to rise from USD 360 billion in 2015 to USD 1 300 billion by 2030. Renewables generally require steeper upfront investment than non-renewable energy technologies, but without ongoing fuel costs later. After those factors are taken into account, REmap Options require USD 100 billion more of investments each year in 2015-2030 compared to a business as usual (the Reference Case in this report). In terms of the global economy, this equals 0.1% of annual investment.

Cost of doubling the renewable energy share by 2030 would be USD 290 billion per year. According to REmap analysis, this is at least 4 and up to 15 times less than the external costs avoided. In other words, the reduction of CO_2 emissions and air pollution damage on human health and agricultural crops can produce annual net savings between USD 1 200 billion and USD 4 200 billion. Nearly two thirds of the *REmap Options* outlined in this report are already cost-competitive without considering externalities. However, those options result in a share of only 30% for renewables, short of the 36% needed to reach international climate goals. The more costly *Doubling Options*, which would increase renewables to 36%, become competitive when these externalities are accounted for.

The reduction of air pollution both indoors and outdoors promises the largest savings, between USD 1 050 billion and USD 3 200 billion per year in 2030 with the share of renewable energy doubled in the world's energy mix by 2030. Indoor air pollution caused by traditional uses of bioenergy accounts for the largest share of reduced externalities, followed by outdoor air pollution and climate change. The reduction of air pollution can save up to an estimated 4 million lives per year with the share of renewables doubled in the world's energy mix by 2030. Higher shares of renewable energy will also bring significant energy security benefits, either through reduced import dependence or enhanced trade balances.

Figure ES3: Reducing human health damage and CO_2 emissions would save at least four times more than the cost of doubling renewable energy use.



Fossil-fuel subsidies and taxes continue to distort energy markets. Currently, subsidies and market structures continue to tip the scales in favour of fossil fuels. Encouraging investments through market restructuring should therefore be a priority. Reducing market discrimination against renewables can eliminate the need for investment support, otherwise estimated at USD 400 billion per year in 2030 to implement *REmap Options* and *Doubling Options*.

Renewable energy can sustain 24.4 million jobs worldwide by 2030 if its share in the global energy mix is doubled. Implementing *REmap Options* and *Doubling Options* would increase the number of jobs (direct and indirect) related to renewables from 9.2 million in 2014 to 24.4 million in 2030 – almost 11 million more than business as usual.

RENEWABLES, COUPLED WITH GREATER ENERGY EFFICIENCY, CAN KEEP AVERAGE GLOBAL TEMPERATURES FROM RISING MORE THAN 2°C ABOVE PRE-INDUSTRIAL LEVELS.

Renewables are essential to realise long-term climate targets. Reaching a 30% share by 2030 *(REmap Options)* should be enough to prevent global temperatures from rising more than 2 °C above pre-industrial levels. Going below the 2 °C target called for in the Paris Agreement will require a doubling of renewable energy share to 36%. Investments in renewables and energy efficiency must also accelerate further beyond 2030.

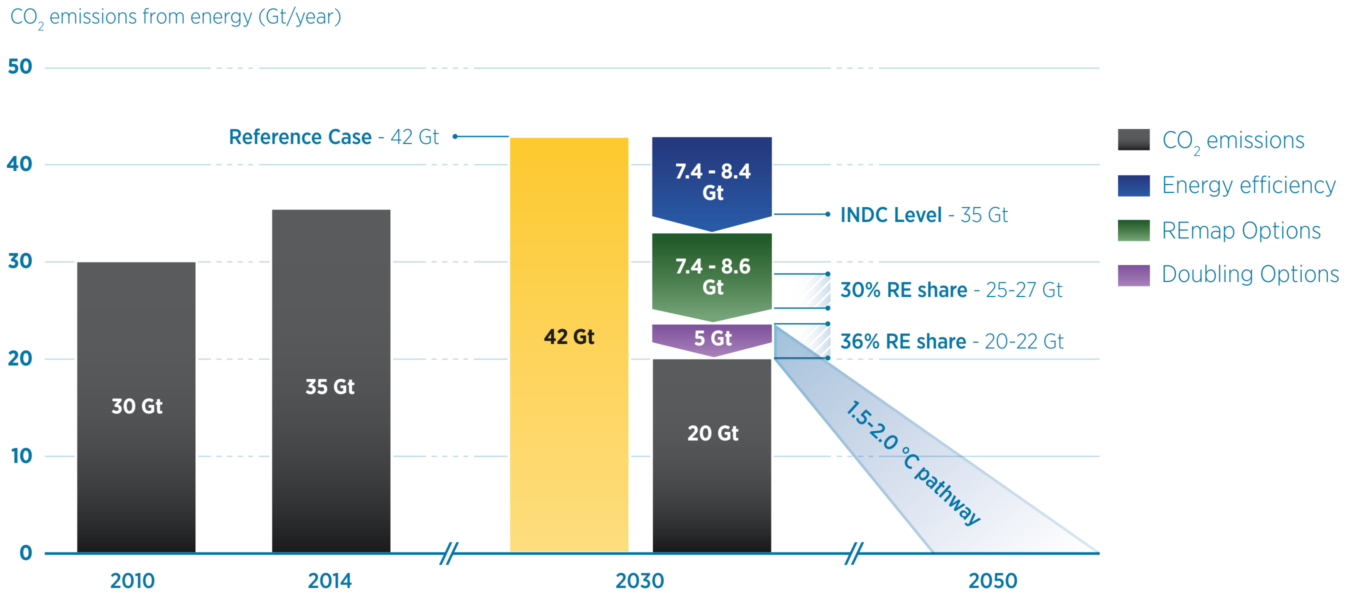
Doubling the share of renewables would avoid up to 12 gigatonnes (Gt) of additional CO_2 emissions per year in 2030 compared to business as usual, while energy efficiency measures would avoid a further 8 Gt. Greenhouse gas emissions in the form of methane and black carbon would also be avoided.

Renewable energy policy needs to be more closely coordinated with climate policy. Although many governments have increased their efforts to promote renewable energy, the Nationally Determined Contributions (NDC) analysed in this roadmap have underestimated the potential for renewable energy in 2030 by a factor of five. To affect change at the national and regional levels, more emphasis must be put on how renewables can mitigate greenhouse gas emissions. Renewables and energy efficiency can end demand growth for coal, oil and gas.

A streamlined system of energy governance is needed at the national level. Currently, the benefits of renewable energy tend to be understood only within specific areas of government. Yet accelerated deployment would address multiple Sustainable Development Goals, from health to resilience and poverty alleviation. For maximum impact, the commitment to renewables must be infused into all dimensions of national planning.

The last two years have seen the emergence of new initiatives, institutions, alliances and centres to promote renewable energy in different countries and regions. Aligning these with global development and climate objectives will strengthen the international-cooperation framework.

Figure ES4: Global energy-related CO_2 emissions between today and 2050



CLIMATE AND SUSTAINABLE ENERGY OBJECTIVES WILL NOT BE MET WITHOUT IMMEDIATE, CONCERTED ACTION TO DOUBLE THE RENEWABLE ENERGY SHARE IN THE GLOBAL ENERGY MIX BY 2030

To double renewable energy share in the global energy mix in the next 14 years, policy makers must accelerate their efforts today and achieve significant progress within five years. Time is running out to achieve the international targets agreed upon in 2015.

Transforming the energy system cannot be left to markets and investors alone. In some cases, the main obstacle is policy and regulation; in others, market design, institutional frameworks or local renewable-resource quality. In a few instances, a lack of commercially viable renewable solutions requires technological innovation. The public sector must do its part to surmount all these obstacles.

Legislators and policy makers must lay the necessary foundations. Five areas are especially critical:

- planning transition pathways for development of national plans and targets,
- creating an enabling business environment, with energy prices that recover external costs;
- ensuring the smooth integration of renewables into existing infrastructure;
- creating and managing renewable energy knowledge; and
- promoting continuous innovation.

REmap has identified five key action areas that must be addressed in order to enable the significant scale-up of renewables »

REMAP IDENTIFIES THE FOLLOWING ACTION AREAS:

1 Correct for market distortions to create a level playing field. This could be achieved by intro-ducing carbon prices to reflect the external costs of fossil fuels, as well as improving the regulatory framework for the renewable energy market. Governments also need to account for externalities related to human health and climate change in energy pricing. Risk-mitigation mechanisms will be important to mobilise investment.

2 Introduce greater flexibility into energy systems and accommodate the variability of key renewable energy sources. The availability of solar and wind energy is predictable, despite daily and seasonal variations. Interconnectors between national or regional grids help to balance supply and demand for power. Demand-side management, electricity storage and smart grids also strengthen the integration of variable renewables, while real-time market pricing helps to assess the value of power generation at different times. New regulatory frameworks must allow new entrants into the power market and reflect the evolving roles of utilities and consumers.

3 Develop and deploy renewable heating and cooling solutions for urban development projects and industry. Cities, local governments and municipalities need to encourage the uptake of renewables and adopt efficient, centralised district systems. Sector coupling allows surplus electricity to provide heating and cooling for buildings and industry.

4 Promote transport based on renewable power and biofuels. Urbanisation is occurring rapidly worldwide, and clean transport is necessary to keep cities liveable. Trams, buses, freight and passenger vehicles powered by renewable-based electricity must become the predominant forms of city transport. This can be achieved through smart city planning and the rollout of recharging and supply infrastructure. Government support is needed to commercialise advanced liquid biofuels for widespread use, especially in aviation, freight and shipping.

5 Ensure the sustainable, affordable and reliable supply of bioenergy feedstocks. Bioenergy can come from agricultural and forestry residues, waste and other sustainable feedstocks. It is particularly important in applications for which no other renewable energy technology is suitable, such as high-temperature process heat in industry. Depending on the feedstock type, either markets need to be expanded or vertical integration of the fuel chain is needed to guarantee supply of reliable and affordable bioenergy products. New international trade and infrastructure policies are needed to facilitate local, regional and global trade in bioenergy commodities.

Policy makers are encouraged to consider solutions in these areas as part of a comprehensive approach to enabling the energy transition. If the international community fails to seize the opportunity offered by renewable energy, there is a serious risk that international energy and climate targets will be missed.

This roadmap offers ten technology and innovation solutions (see Chapter 3) that will be crucial to take action in the recommended areas. In sum, this roadmap is meant to foster ambitious, sustainable and commercial-scale renewables growth in a climate-constrained world.

RENEWABLES AND ENERGY SYSTEM TRANSFORMATION

Renewable energy is crucial in mitigating climate change, but that will not be its only benefit. These technologies will also yield a cleaner environment and job opportunities. This suite of benefits will require policies and efforts beyond what is planned today, however, and no single policy package can be applied everywhere. Policymakers will need to tailor solutions to local, national and regional conditions. Chapter 1 of this report, the second edition of International Renewable Energy Agency's (IRENA) REmap global renewable energy roadmap, provides a starting point.

The chapter begins by explaining the REmap country process and then looks at what the doubling of the renewable energy share entails at a global level. This crucial overview is based on a combined assessment of 40 countries that represent 80% of global energy use.

It also looks back at the policies that have changed and the progress made since the 2014 edition of this report. The underlying data and methodology used in this report have evolved and improved over the past two years; this chapter sheds light on those changes as well. The same section explains how changes in energy prices over the past two years have impacted investments in both renewable and non-renewable energy technologies. The updates that follow it are important because REmap is becoming one of the reference works for public- and private-sector leaders, and the underlying data and methodology used have evolved and improved.

Finally, special attention is paid to the climate debate, which made great strides at the 21st Conference of Parties (COP21) in Paris[1]. REmap's key instruments – the REmap Options and the Doubling Options – are aligned with the climate targets of 2 degrees Celsius.

1) The 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC).

KEY POINTS

- IRENA's REmap programme now covers 40 countries, representing 80% of the world's total final energy consumption.
- Doubling of the renewable share in global energy use by 2030, compared with today's levels, would result in significant savings to society. By reducing externalities related to air pollution and climate change, it would set the world on a course towards limiting temperature rise to no more than 2 degrees Celsius. It would also boost economic growth and employment.
- The renewable energy share must increase by 1 percentage points annually up to 2030 as a worldwide average. Growth by country will vary according to local conditions. The current growth rate is just 0.17 percentage points per year, meaning a six-fold increase is necessary to realise a doubling.
- Together with efficiency solutions that slow down demand growth, the renewable-energy technologies identified in this analysis – the **REmap Options** – can boost the global share for renewables to 30% by 2030. Without those options, the renewable share would rise just 3 percentage points by 2030, to 21%. That is in line with the national plans of countries today – the **Reference Case** in this report.
- **Doubling Options** – or stronger additional actions – could close the gap to 36% through electrification of industry, buildings and transport; by coupling power generation with heat and transport where possible; and with strategies such as early retirement for non-renewable energy power plants.
- Global leaders can limit global temperature rises to 2 degrees Celsius, but reaching the ideal target of 1.5 degrees Celsius requires more than a doubling of the renewable share. While this report identifies the need for significant effort to reduce energy-related carbon dioxide emissions, a similar effort will be required to reduce emissions of other greenhouse gases.
- Depending on the degree to which the renewable energy share increases, up to 12 gigatonnes of energy-related carbon dioxide emissions can be eliminated beyond the Reference Case. This is higher by a factor five than the emission reductions that would be achieved when the Intended Nationally Determined Contributions of all countries are aggregated.
- Despite falling prices of fossil fuels, investments in renewable energy continue to increase: 2015 was a record year for solar photovoltaic and wind power installations.

REMAP: COUNTRY PROCESS AND ANALYTICAL APPROACH

IRENA is an intergovernmental organisation that supports countries in their transition to a sustainable-energy future. In that capacity it is also acting as the renewable energy hub of the United Nations' (UN) Sustainable Energy for All (SE4All) initiative. IRENA created its REmap programme in 2012, within the SE4All framework, to work toward a doubling of the renewable energy share in the global total final energy consumption (TFEC) between 2010 and 2030 (UN and The World Bank, 2016). Today REmap works in support of the UN's seventh Sustainable Development Goal (SDG) of affordable and clean energy, and the project also identifies the role renewables can play in realising long-term climate targets. For these goals and for others, IRENA's contributions include researching the potential and costs for renewable energy deployment, externalities related to climate change as well as the human health and agricultural crop impacts of air pollution, and the socio-economic impacts of renewables.

Cooperation and consultation with countries is the cornerstone of the REmap approach. The outcome of the REmap programme is not to set renewable energy targets – instead the IRENA process is to first collect data from countries about their national plans and goals, and the next step is to produce a global baseline for renewable energy that has been compiled for the period 2010-2030. This is IRENA's Reference Case. Subsequently technology pathways that reap the rewards of the realistic potential of renewable energy technologies beyond the Reference Case are prepared, and these are the REmap Options. They are customised for specific countries and sectors, and aim to close an important knowledge gap for many countries by helping policy makers to a clearer understanding of the opportunities that lie before them. However, the political feasibility and challenges to implement each option in different sector and countries will vary depending on countries national circumstances as well as the level of commercialization technologies have reached. Targets are great starting points, but policymakers need to know more: how to get there and go beyond.

A number of factors are considered in estimating REmap Options, including resource availability; access to finance; human-resource needs and supply; manufacturing capacity; policy environment; the age of existing capital stock as well as the costs of technologies by 2030. Reference is made to other publications where relevant, to make results comparable with other approaches.

In terms of renewable energy share, some countries are close to 30% already or above, while others are at low levels of renewable energy integration but increasing fast. The quality and availability of resources across countries is an important factor to determine the REmap Options. The United States (US), for example, has significant potential for all resources (IRENA, 2015a), whereas in others potential is mostly found in one or several – such as the high quality of the solar resource in the United Arab Emirates (UAE) (IRENA and Masdar Institute, 2015). Depending on the situation of the country, some can easily finance the transition, whereas others require assistance.

IRENA has developed a spreadsheet tool that allows country-level experts to evaluate and create their own REmap analyses. These are clear and dynamic accounting frameworks to evaluate and verify Reference Case developments and REmap Options within a country. All results are displayed in a REmap-specific energy balance, and thus far the results for 40 countries are available online (**www.irena.org/remap**).

Each REmap Option is characterised by its substitution cost, which is expressed in United States dollars (USD) per gigajoule (GJ) of final renewable energy. The substitution cost is the difference between the annualised costs of the REmap Option and a non-renewable energy technology used to produce the same amount of energy (*e.g.,* electricity, heat), then divided by the total renewable energy use in final energy terms. It is based on the capital and operation and maintenance (O&M) costs in 2030, and considers technological learning as well as energy-price changes between now and 2030. In IRENA's REmap analysis, costs are estimated from the perspective of both business and government, accounting for the commercial focus of the former and broad societal goals of the latter.

Modern Energy Access and **Energy Efficiency:** Pursuing and meeting SDG7 and SE4ALL objectives would increase the renewable energy share.

REmap Options: These refer to the deployment of renewables in countries beyond the Reference Case. REmap Options were identified in consultation with countries and, if implemented globally in combination with energy-efficiency measures and access to modern energy alternatives, would boost the renewable share in the global energy mix to 30% by 2030.

Doubling Options: In the terminology of the REmap analysis, these are additional efforts at renewable energy deployment and energy efficiency that would bring the renewable share in the global energy mix to 36%, or double the current amount. These options were identified by IRENA without country consultation.

1 Gigajoule (GJ)
= 0.0238 tonnes of oil equivalent (toe)
= 0.0341 tonnes of coal equivalent (tce)
= 0.238 gigacalories (Gcal)
= 278 kilowatt-hour (kWh)
= 0.175 barrel of oil equivalent (BoE)
= 0.947 million British thermal units (MBtu)

All energy quantities presented in this report are based on lower heating value (net calorific value).

01

IRENA's REmap programme now covers 40 countries, representing 80% of the world's total final energy consumption.

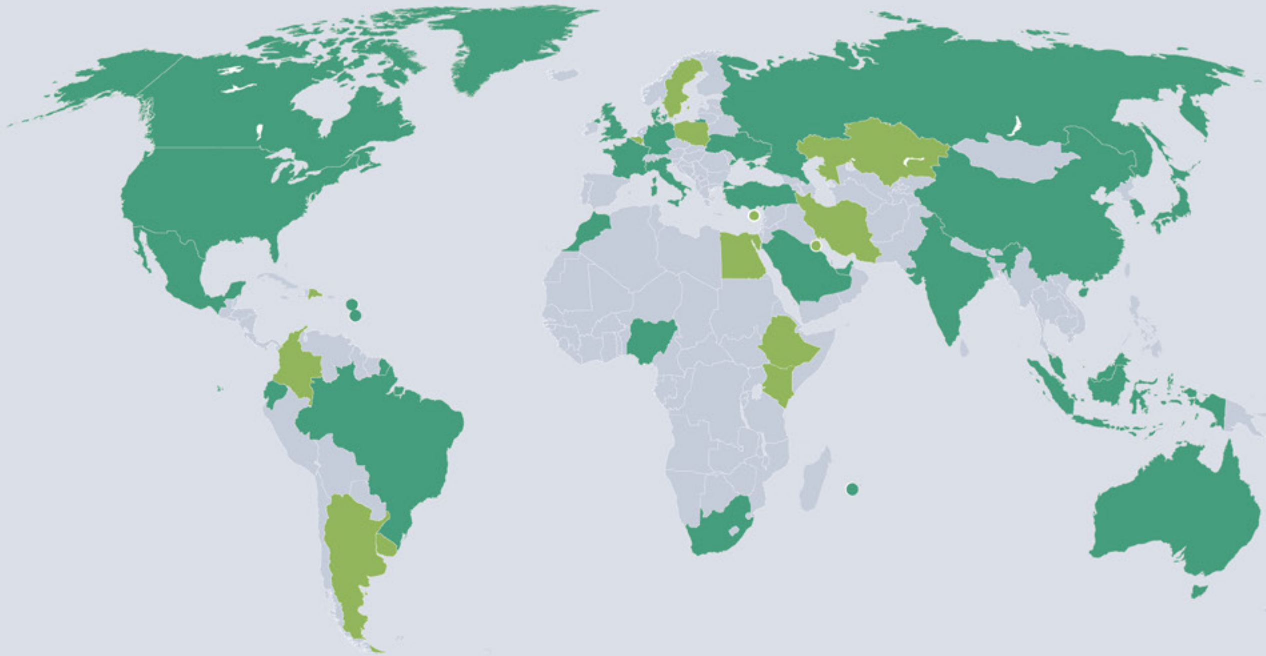
The **business perspective** provides a view on how investors would evaluate technology choice. Here, energy prices include taxes, subsidies, and 44 country-specific discount rate (based on the anticipated cost of capital to private sector investors).

The **government perspective** takes a broader societal view, and includes the reduced externalities related to renewable energy. Selected externalities considered in REmap include carbon dioxide (CO_2) and other air pollutants, as well as their impact on human health and agricultural crops. A range of USD 17-80/t CO_2 is assumed

REmap

As of end of 2015, the 40 REmap countries are: Argentina, Australia, Belgium, Brazil, Canada, China, Colombia, Cyprus, Denmark, the Dominican Republic, Ecuador, Egypt, Ethiopia, France, Germany, India, Indonesia, Iran, Italy, Japan, Kazakhstan, Kenya, Kuwait, Malaysia, Mexico, Morocco, Nigeria, Poland, the Republic of Korea, the Russian Federation, Saudi Arabia, South Africa, Sweden, Tonga, Turkey, Ukraine, the United Arab Emirates, the United Kingdom, the United States and Uruguay.

Figure 1: Map of REmap countries



Note: 26 countries participated in 2013 (dark green), 14 countries joined in 2014/2015 (light green)

Definition of energy sectors in REmap:
transport, buildings (where residential, commercial and public sectors are combined throughout this report), and industry, the three sectors where energy is consumed. Electricity is consumed in all these three, but the power and district heating sectors are discussed separately, in particular because power sector deserves special attention.

The energy use of agriculture, forestry and fishing as well as non-energy use is excluded from this roadmap.

Total final energy consumption (TFEC):
is the energy delivered to consumers, whether as electricity, heat or fuels that can be used directly as a source of energy. This consumption is usually sub-divided into that used in: transport; industry; residential, commercial and public buildings; and agriculture; and it excludes non-energy uses of fuels.

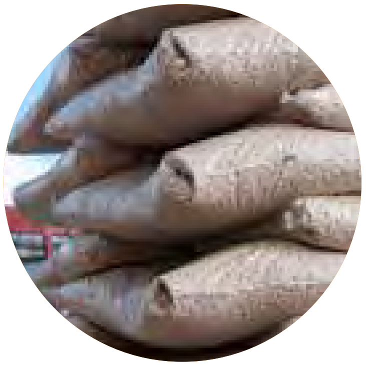
for carbon prices and a wide range of unit external costs for air pollutants (IRENA, 2016f; US Government, 2013). Energy prices exclude taxes, subsidies, and carbon pricing. A standard discount rate for investments is used: 7.5% for countries of the Organisation for Economic Co-operation and Development (OECD) countries and 10% for non-OECD countries.

When the **substitution cost** is multiplied by the potential of each option (in petajoules (PJ) per year), the result is a realistic figure for the system cost associated with the increases in renewable energy deployment featured in the REmap Options.

A detailed explanation of the REmap methodology is also provided online at **www.irena.org/remap** as well as in the Appendix of this report.

FIVE STEPS TO DOUBLE THE RENEWABLE SHARE IN GLOBAL ENERGY USE BY 2030

In the next 14 years, the share of renewables in the world's total final energy mix needs to increase by just over 1 percentage point annually. That means doubling the share to 36% in 2030, from today's 18.4%. Replacing traditional (and unsustainable) uses of bioenergy with modern alternatives is also crucial. Along with doubling the renewable energy share, this entails quadrupling the use of modern renewables.



REmap analysis has identified technologies and policies to make this feasible. It has also found that the reduced externalities related to human health and climate change impacts of fossil fuels by far outweigh the additional cost of a doubling. This further strengthens the argument in favour of doubling the global renewable energy share. The main steps to achieving this are:

- Deployment of renewables potential (the REmap Options and the Doubling Options),
- Enabling universal energy access through the choice of modern renewable energy technologies for cooking, water heating and electrification, and
- Higher rates of energy efficiency (EE) beyond what is envisioned in the Reference Case according to national government plans.

SE4All's Global Tracking Framework 2015 (IEA and the World Bank, 2015) estimates a global renewable energy share of 18.1% for the year 2012. According to the REN21 2015 Global Status Report, while some estimates put the share at more than 19% in 2013, IRENA estimates for 2014 a share of 18.4% (REN21, 2015).

In the Reference Case compiled by IRENA based on national plans of 40 countries for this report, the projected 21% share of renewable energy by 2030 includes significant uses of traditional bioenergy. These are defined according to the International Energy Agency (IEA) as wood, animal dung, and agricultural residues that are burned in simple stoves at low rates of efficiency. Their use is most common outside OECD countries (IEA, 2012), and are an important source of energy for many. However, given the health risks and environmental impacts, a transition away from their use is important. The estimate made in this report to substitute traditional uses of bioenergy is subject to uncertainty. In addition to challenges for doing so in reality, data available to make the related estimates are subject to large

Together with efficiency solutions that slow down demand growth, the renewable-energy technologies identified in this analysis – the REmap Options – can boost the global share for renewables to 30% by 2030. Without those options, the renewable share would rise just 3 percentage points by 2030, to 21%. That is in line with the national plans of countries today – the Reference Case in this report.

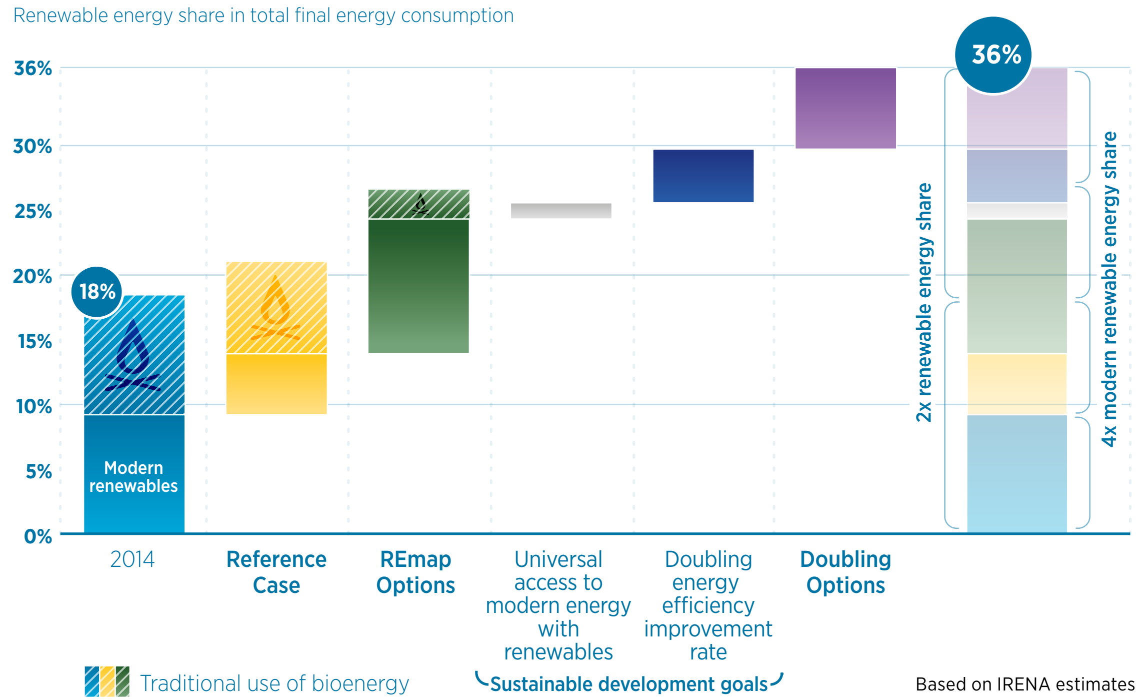
uncertainty. Hence the estimates in this report should be regarded by considering the limitations of the analysis.

In the Reference Case the use of traditional use of bioenergy would decline significantly, with modern energy forms, including both fossil fuel and renewables as a substitute. Deployment of the REmap Options would increase the share of modern renewable energy alone to around 25%. These efforts are, however, still not enough to bring the global renewable energy share to a doubling by 2030.

REmap Options need to be complemented with energy efficiency and modern energy access (electrification and substitution of the remaining uses of traditional bioenergy) in line with the SDG and SE4All objectives, which could bring the renewable energy share to 30%. Energy efficiency reduces overall demand, which in turn reduces the total renewable energy needed to achieve higher renewable energy shares. Since energy efficiency also means saving money, a focus on it would make it easier overall to reach the goal of doubling the renewable share of the global energy mix by 2030, and at a lower cost. The costs for these measures, and for modern energy access, are outlined in SE4All's Global Tracking Framework 2015 (IEA and the World Bank, 2015). Specific challenges related to each one of these steps and technology solutions to overcome them are discussed in Chapter 3.

Doubling is made possible by deploying "Doubling Options". These have been identified by IRENA and focus on applications that have been overlooked by REmap Options as well as strategies that allow "thinking outside the box". For example, they include scaling up renewables in the aviation sector, earlier retirement of aging coal power plants that will still be in operation in 2030, carbon pricing, and new power market designs that are not covered in existing plans.

Figure 2: The renewable share in global energy between today and 2030



The share representing modern renewable energy, which excludes traditional uses of bioenergy, stood at just above 9% in 2014. A doubling would therefore mean a quadrupling of the modern renewable energy share in the same time frame. However, this requires action in multiple areas, not only in renewables.

Doubling Options – or stronger additional actions – could close the gap to 36% through electrification of industry, buildings and transport; by coupling power generation with heat and transport where possible; and with strategies such as early retirement for non-renewable energy power plants.

01

THREE MAIN TRENDS FOR COUNTRIES

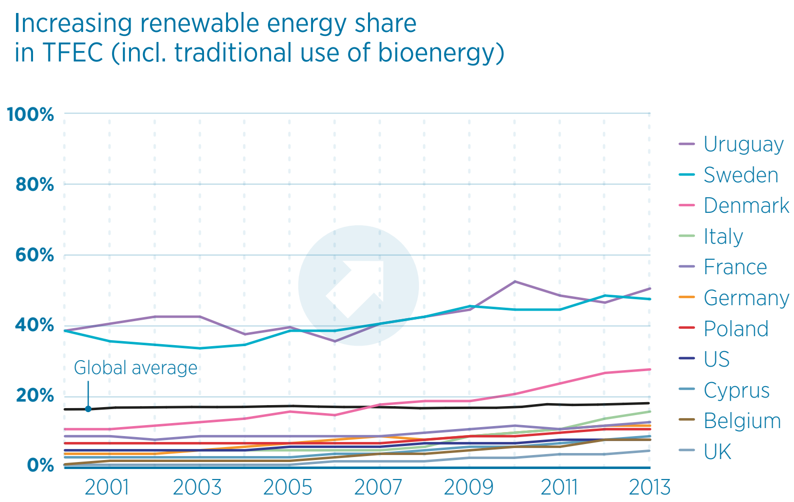
The overall renewable energy share has remained constant since the 1990s at about 18% of global TFEC. The increase in renewable energy shares in developed economies has been insufficient to raise the global total because the share of traditional use of bioenergy is decreasing elsewhere, as consumers move to using other fuels such as modern petroleum products, but also renewables.

In the past decade, the amount of renewable energy produced has increased but not outstripped growth in energy demand. Therefore, the share of renewable energy has only increased slightly. Figure 3 shows the development of renewable energy shares in TFEC for REmap countries from 2000 to 2013 (IEA, 2015a). In most REmap countries renewable energy use has grown in absolute terms over the period. Nonetheless, at a country level, renewable energy shares of TFEC decreased in 11 out of 40 countries included. The decreases are found mostly in developing and emerging economies, primarily because overall energy demand growth outstripped renewable energy deployment and in some cases because non-renewable fuels substituted the use of traditional bioenergy.

By comparison, the renewable energy share has grown in most developed economies and a few others with great renewable energy potential. Countries such as Belgium, Cyprus, Denmark, Germany and Italy saw two- to three-fold renewable energy share growth in the period, a result of successful policies to support renewable electricity and heat deployment.

Finally, the largest REmap group of 16 countries saw their renewable energy shares remain largely unchanged. In three of them, Ethiopia, Kenya and Nigeria, renewable energy remained static but at very high levels, at between 80% and 95%, explained by high levels of hydropower and/or traditional uses of bioenergy. The other countries with stagnant renewable energy shares are large fossil fuel producers, or face other constraints to exploiting renewable energy resources.

Figure 3: Renewable energy developments in REmap countries, 2000-2013

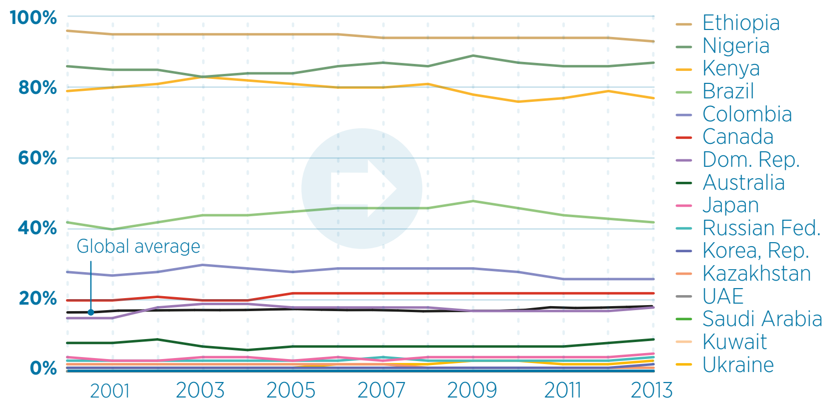


In countries where traditional use of bioenergy makes up a majority of final renewable energy consumption, the modern renewable energy share is significantly lower. If the trends in renewable energy shares were estimated based on only modern renewables (as an alternative to what is depicted in the figures below, which includes the traditional use of bioenergy), in many cases the renewable energy development over the period 2000-2013 would show a more positive trend. Nevertheless, to reach a doubling total by 2030, the global renewable energy share needs to increase by roughly 1 percentage point per year; a six fold growth from the level observed in recent years.

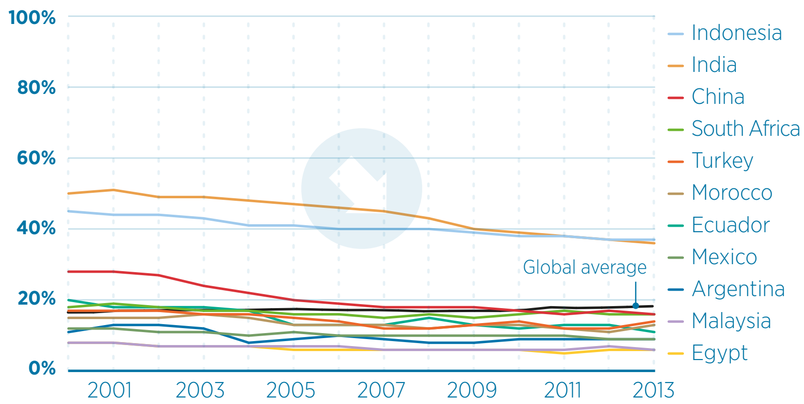
The renewable energy share must increase by 1 percentage point annually up to 2030 as a worldwide average. Growth by country will vary according to local conditions. The current growth rate is just 0.17 percentage points per year, meaning a six-fold increase is necessary to realise a doubling.

Despite the growth in renewable energy use in most countries, there was little change in the global average over the past decade. This is largely because of the even faster-growing demand for non-renewable energy, particularly in the form of modern fuels to substitute for traditional bioenergy sources, such as firewood.

Constant renewable energy share
in TFEC (incl. traditional use of bioenergy)



Decreasing renewable energy share
in TFEC (incl. traditional use of bioenergy)



Note: The order of the countries in the legend correspond to the share of renewable energy in 2013. They are presented in this order to make it clearer which country matches which line.

IRENA analysis based on IEA Energy Balances (IEA, 2015a)

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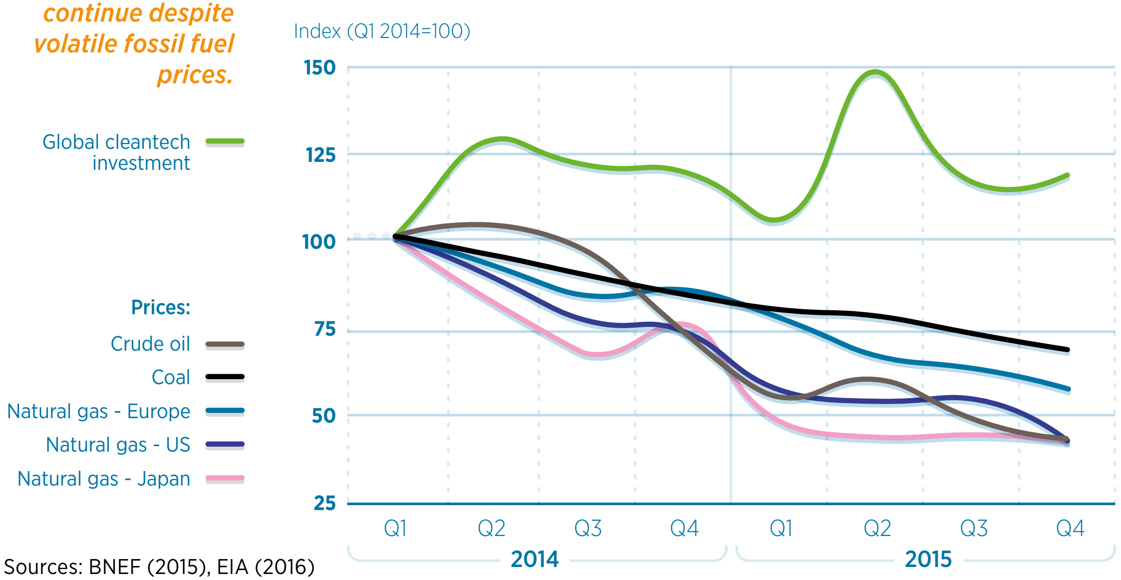
MORE CLARITY ON 2030 GAINED IN THE PAST TWO YEARS

Preliminary data available from industry organizations at the beginning of 2016 indicate that 2015 was a record year for renewables. A total of 150 gigawatts (GW) of new renewable capacity was installed. Moreover, country plans are considering the changing trends in renewable energy in power generation. All these positive developments were despite the volatility in fossil fuel prices which have fallen to unexpected lows in the past year.

Investments in renewables continue despite volatile fossil fuel prices.

Figure 4: Investments in global cleantech and fossil fuel prices



Sources: BNEF (2015), EIA (2016)

Impact of volatile fossil fuel prices on investment decision making

Different energy applications typically use different types of fossil fuels. Nearly all transport activities rely on oil-based products, whereas for buildings and in industry, depending on the country and sector, a mix of oil, gas and coal is used. For power generation oil does not play a significant role. There, a mix of gas and coal dominates.

In late 2015, oil prices were around USD 50/barrel, down from more than USD 100/barrel at the end of 2013. At the beginning of 2016 prices fell further to USD 30/barrel. In the power sector, oil makes up less than 5% of supply worldwide, which illustrates how there is limited competition between renewable energy and oil for power. Natural gas, on the other hand, is used to generate roughly a fifth of global electricity – and is the main fossil fuel source for heat. This is a more significant competitor for renewables. Gas prices vary significantly by region. The United States had some of the lowest gas prices worldwide in 2015 at around USD 2 to USD 3 per GJ. In contrast, Japan imports liquefied natural gas (LNG) at about USD 9/GJ for natural gas (down from USD 14/GJ at the end of 2014). International gas prices are affected by a number of factors including regional supply and demand trends, the availability of gas by pipelines and the global market for LNG, which has led to wide regional differences in gas prices. Oil markets are among the multiple factors determining gas prices. Gas prices in some regions have fallen sharply during 2014/15 due largely to changes in the supply/demand balance.

Despite falling prices of fossil fuels, in investments in renewable energy continue to increase: 2015 was a record year for solar photovoltaic and wind power installations.

The link between oil and coal prices is weak. Crude oil costs are a factor for coal miners but the commodity has its own supply and demand factors that are the main contributor to pricing. Coal prices are currently at historically low levels because of diverse and ample supplies as well as slowing growth in demand, particularly in China. Prices have fallen by more than 30% since 2013. In contrast to oil, coal does play a large role in the power sector. Today about 40% of global electricity production is based on coal. However, one can expect lower coal prices to pose little threat to the uptake of renewables in the power sector. Coal is not being replaced based on economics but because of its detrimental effects in terms of air pollution and carbon emissions. If coal prices remain at low enough levels though, this could slow the rate of renewable energy use for electricity and endanger the Paris Agreement.

Nonetheless, global investment in renewable energy has remained strong (Figure 4). Preliminary data available at the beginning of 2016 indicate that 2015 was a record year for wind and solar. Wind investments grew from USD 80 billion per year in 2011 to more than USD 100 billion per year in 2015. For solar photovoltaic (PV), despite decreasing capital costs, investments remained between USD 100 and USD 150 billion annually from 2011 to 2015 and total installed capacity has gone up (BNEF, 2015).

While all fossil fuel prices have fallen at varying levels, costs of renewables have also, and analysis shows that low oil prices do not seem to have affected solar and wind in the power sector. Despite falling fossil fuel prices, new non-renewable energy technologies could be more costly. For example, costs of coal and gas fired power generation might increase if retrofitted with carbon capture and storage (CCS).

Progress in renewable energy deployment has continued also in heating and transport, with countries including Chile and India increasingly implementing solar process heat. Solar water heaters are now widely used in many countries in the Caribbean and Mediterranean. Scandinavian countries are using modern and sustainable bioenergy for heat and power generation, and China is now in its fifth decade of developing anaerobic digesters, with the resulting biogas now benefiting 100 million rural people (Xia Zuzhang, 2014). In transport, Norway and the United States state of California lead in electric vehicle (EV) use. In Norway, every fifth car sold is battery-powered (Jolly, 2015). California now accounts for about 10% of the total global plug-in hybrid vehicle sales (Fulton, 2015).

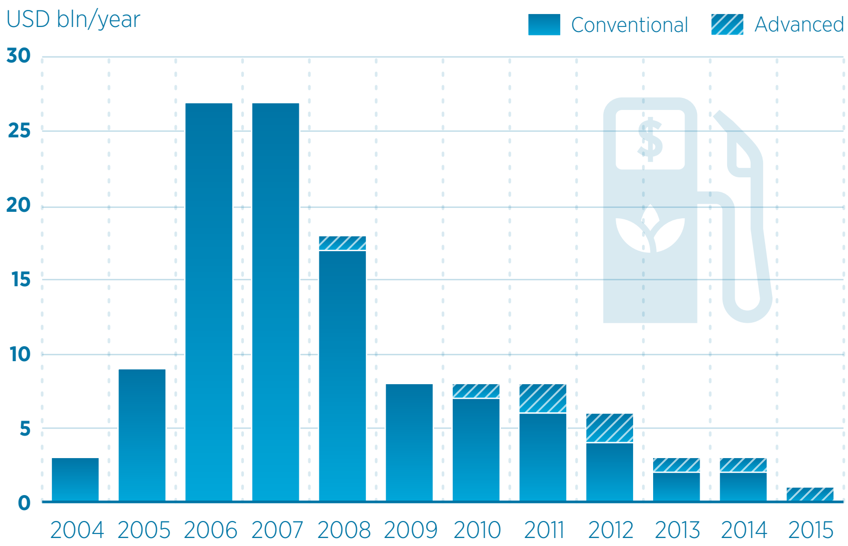
Despite the positive progress in a number of technologies, low fossil fuel prices are impacting bioenergy more directly, however. This is because bioenergy is commonly used as a source of heat and for motor fuels which otherwise typically relies on oil products. As a result, the recent drop in oil prices may affect economics of bioenergy and discourage future investments. Cost-competitiveness of bioenergy and other renewables is in particular important because direct uses of energy for heating and transport account for up to 80% of the total final energy use worldwide.

Investment levels for advanced liquid biofuels plummeted in 2009, years before the recent drop in fossil fuel prices, as a result of decreasing deployment support (Figure 5). In the short term, however, the use of biofuels could remain stable since countries need to fulfil blending mandates – an example of how other factors such as policy can play an important role beyond energy prices only.

No matter the short-term movements in commodity prices, investments in the energy sector generally span at least 20 years, and over the next few decades the trend for renewables is clear: the price of most renewable energy technologies will continue to drop. For natural gas, on the other hand, the general expectation is price increases.

Figure 5: Global investments in liquid biofuels, by technology

Liquid biofuel investments have dried up in recent years.



IRENA analysis based on BNEF (2015)

The International Energy Agency's World Energy Outlook (WEO) 2015 expects prices in the United States to more than double by 2030 from today and increase by more than 50% in Europe and Japan (IEA, 2015b).

One exception to the rule of falling prices for renewable energy would be for bioenergy, where stricter regulations on particle emissions, security issues, certification schemes, and other areas could make new equipment more expensive. Furthermore as markets are created, bioenergy prices could rise. But in general, renewables are already cost-competitive in many applications and regions today, and this trend will continue as technologies improve. Investors facing the inherent risk of price fluctuations for fossil fuels and an increasing market acceptance of clean technologies and higher environmental standards will continue to favour renewable solutions.

Country plans are considering the changing trends in renewable power

The new Reference Case for 2016 contains important improvements over the 2014 edition of REmap (IRENA, 2014a). Countries are taking into account in their plans the recent developments in renewable power generation technologies, partly as a result of their cooperation with the REmap programme.

The difference in total renewable energy capacity between the two editions is about 500 GW for the year 2030. The most notable change is for solar PV (dominated by developments in India and China). The projected capacity in 2030 is about 340 GW higher; at 780 GW compared with 440 GW in 2014. This is an increase of more than 70%, mainly explained by the improved economics of solar PV, which indicate that it is now a mainstream technology considered by all countries in their national plans.

Solar PV is followed by wind and bioenergy. The increased targets for bioenergy in power may be explained by countries utilising all options to realise their ambitious power generation goals, and seeing the benefits of bioenergy when combined to produce heat and power in the same facility. Depending on the type of feedstock, this might crowd out the use of energy crops for liquid biofuel production, which is less cost-competitive and for which sustainability is debateable.

With all of these changes built in to the new Reference Case, the renewable energy share in power generation in 2030 is estimated slightly higher, from 28% in 2014 to 30% in 2016. Although the increase might seem limited, this is still important progress, when one considers that the power generation growth projections of countries to 2030 have increased.

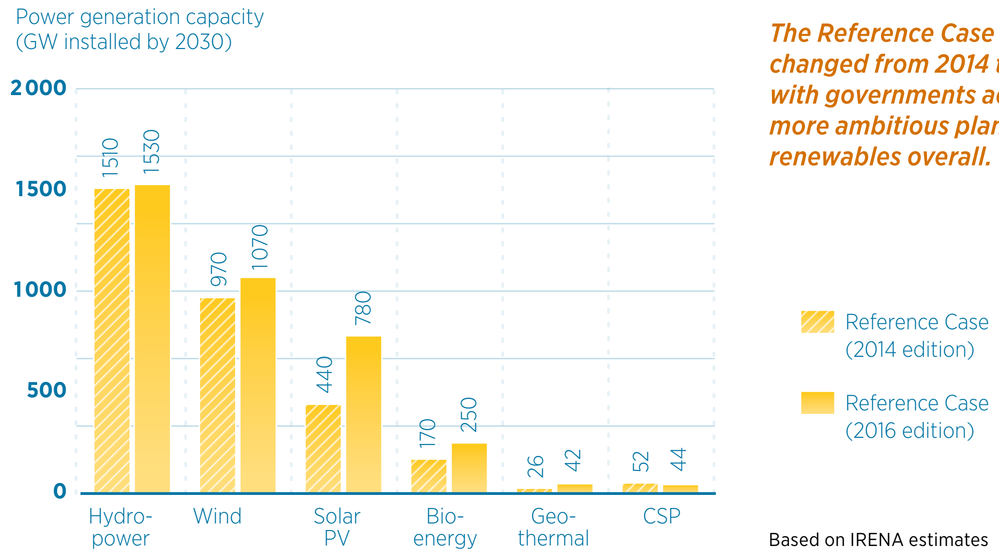
When the renewable energy share in TFEC is considered, the analysis finds no change: both 2014 and 2016 estimates point to 21% by 2030 in the Reference Case. However, total renewable energy use according to the new estimates are compared to a higher TFEC, which factors in larger anticipated energy demand growth in government plans. If the amount of renewable energy use was compared to the TFEC in 2030 from the prior assessment, the share of renewables would be 1 percentage point higher, at 22%.

Some recent achievements in policy-making

Past years have seen a number of important energy and climate policy changes. Intended Nationally Determined Contributions (INDCs) were submitted (now called Nationally Determined Contributions (NDCs)) at the COP21 (UNFCCC, 2015), and several countries have prepared their new short- to long-term energy strategies. Important renewable energy investment decisions were made, where in many cases REmap programme recommendations were influential.

At COP21, in a joint statement, the Africa Renewable Energy Initiative pledged 300 GW of renewable energy capacity in Africa by 2030 in line with REmap Africa recommendations. Moreover, 8 country reports covering 60% of global renewable energy use have

Figure 6: Reference Case changes between 2014 and 2016 editions of REmap



The Reference Case itself changed from 2014 to 2016, with governments adopting more ambitious plans for renewables overall.

Based on IRENA estimates

proven to be a valuable vehicle for national dialogue and action. For example REmap (IRENA, 2015a) was one of the sources that was used for the preparation of the United States' INDC. REmap's China report (IRENA, 2014b) has informed the discussions around the challenges that need to be addressed in China's 13th Five-Year Plan. Several international policy efforts such as the Group of Twenty (G20) now include renewable energy in their agenda. In the toolkit of options for advanced renewable energy deployment prepared by the G20, REmap is one of the five options (IRENA, 2015b).

Improvements in IRENA's REmap approach

In addition to these changes in the Reference Case, a number of methodological improvements were made to make the REmap analysis more robust.

One of them is in the area of traditional uses of bioenergy for cooking and heating. Based on data available from various literature and through country consultation, IRENA has made a first attempt to improve on available reporting from the IEA on solid bioenergy use in residential buildings for China and India. According to the IEA definition of traditional use of bioenergy, these two countries account for about one-third of the total global today, representing around 11 exajoules (EJ) of TFEC. There was previously no modern bioenergy consumption in India, and only 3 EJ in China (IEA, 2015a). However REmap 2016 data show that traditional uses of bioenergy in China and India could be lower, at around 7.5 EJ, and that there is some modern bioenergy use, representing around 2 EJ. Several other improvements in methodology were made to the data from other countries as well, typically based on modern cookstove sales information.

The external cost accounting methodology has also been significantly improved over the previous system. The revised methodology results in higher external costs and hence overall savings from the doubling of renewables, because of better accounting for the 2010-2030 gross domestic product (GDP) growth by country, the inclusion of more emission sources, and better specification and assessments of costs across countries (IRENA, 2016f). One example is the external costs of transport on human health, which have separated into urban and rural. In urban areas, impacts are significantly higher, the data show. These new methods point to significantly higher costs relating to air pollution over the earlier assessment.

The bioenergy demand and supply potential has also been revised in the 2016 edition compared to the 2014 edition, in particular for the power generation sector and transport. Total primary bioenergy demand with all REmap Options implemented has fallen from 108 EJ to 93 EJ. Lower demand implies that there will be lower environmental and resource burdens in view of the limited bioenergy feedstock availability, but this also highlights the need for non-bioenergy renewable energy technologies to realise a doubling by 2030. Total bioenergy supply potential has been estimated to be at least 10 EJ lower at a range of 75 to 140 EJ in 2030.

2015: A YEAR OF FOSSIL-FUEL DIVESTMENT

If the atmospheric concentration of greenhouse gases (GHG) exceeds 100 gigatonnes of CO_2 equivalent (Gt CO_2-eq), it is unlikely that the global average temperature rise will be limited to 2 °C, representing a level above 500 parts per million (ppm) of GHG concentration in the atmosphere. This level can be twice as high as if the carbon stored in all proven fossil fuel reserves are emitted. An estimated 88% of global coal reserves will have to stay in the ground to prevent a global warming beyond 2 °C (McGlade and Ekis, 2015). Over the past decade, the climate change debate has focused on energy demand, with the main policy instruments being carbon pricing and emissions trading. Increasingly, however, there are signs of a greater focus on supply as the focus turns towards divestment – leaving carbon in the ground. CCS technology which is typically discussed as the key option to put carbon back into the ground has failed to materialise, making the case for divestment even stronger. In addition to climate concerns, coal facilities will need to be retired early if the renewable energy share is to double quickly enough. Simply put, coal facilities in particular must make space for renewable energy to grow (Henn and Dubois, 2015) (McGlade and Ekins, 2015).

The divestment movement gained significant momentum in 2015. The amount of divestments pledged in 2014 stood at USD 0.05 trillion, but that number skyrocketed to USD 2.6 trillion before COP21 – and USD 3.4 trillion during the Conference (Henn and Dubois, 2015). Pension funds from the Netherlands to Norway and California are abandoning the fossil-fuel sector, as are private-sector investment funds. As a result, the value of coal assets is falling worldwide, with some company share prices falling as much as 90% over the course of 2015.

Partly because of new emission regulations and partly because of market signals, numerous countries and regions worldwide have closed or plan to close coal facilities. Ontario, Canada, was coal-free in 2015 for the first time in modern history. Austria, Finland, France, Portugal, and the United Kingdom (UK) could all complete a coal phase-out within the next decade. Germany has resolved to shrink its giant Garzweiler II opencast lignite mine by a third, moving the closure date up to the late 2030s. The United States has 200 coal plants scheduled for closure, and coal consumption is peaking in China – where the government also aims to set up the largest emissions trading platform worldwide by 2017.

The list of state and non-state actors currently involved in divestment is even longer. An estimated 20 000 organisations are now members of the Climate Initiatives Platform. The Lima to Paris Action Agenda (LPAA) and the NAZCA database list 10 800 climate mitigation commitments from 2 200 cities and regions, along with 2 000 companies and 500 investors from more than 100 countries (NAZCA, 2016). Collectively, they represent USD 75 trillion.

01

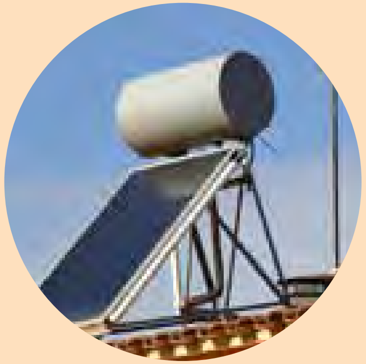
COUNTRY AND REGION EXAMPLES

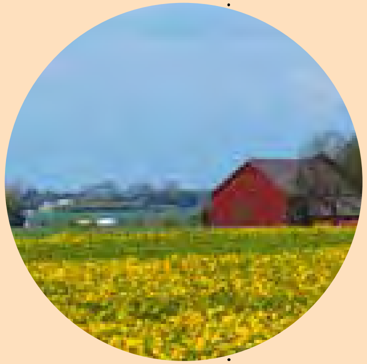
RENEWABLE HEAT

- **Cyprus** has the highest penetration of solar water heaters per capita thanks to a requirement that solar thermal systems be installed in all new buildings and as a part of all major retrofits. In 2016 **Germany** also adopted similar legislation, and **Denmark** has likewise banned oil-fired heating systems for over 90% of households – a successful strategy towards preventing a resurgence of fossil fuels for heat during periods of low oil prices, such as at the time of this report.

RENEWABLE HEAT

- Roughly 66% of all **Danish** households are connected to district heating networks, which are vital for renewable heat. Renewable district heat is supplied from wood, waste and straw, but also biogas, solar thermal and geothermal.
- Roughly half of **Swedish** households also have district heating connections, and Sweden is currently the biggest investor in R&D for district heating in Europe. The Swedes increasingly use biogas as a transport fuel.
- The pulp and paper industry in **Finland** is an important bioenergy producer and is moving towards integrated biorefineries.
- **Germany** has around 9 000 biogas electricity and combined heat and power units running on renewable waste, energy crops from local farms, or both.





HIGH PENETRATION LEVELS OF RENEWABLES

- Renewable electricity's share of the national system in **Germany** reached 80% of the supply total in 2015 for several hours. Consumption of power from wind in **Denmark** averaged 42% in the same year.
- **Spain** generated more electricity from wind power than any other source in 2013, just ahead of nuclear power.
- Onshore wind is gaining traction in **Latin America** and **Africa**, making the new wind power sector a truly global market.
- **Uruguay** already has around 80% renewable electricity.
- **Kenya** has established a centre of excellence for geothermal power, a source which can now cover more than half of supply in the country.
- In 2014 total installed battery-storage capacity reached more than 800 megawatts (MW) worldwide. **China, Germany, Japan** and the **United States** lead in R&D, while **India, Italy**, and **Republic of Korea** lead in implementation.
- The inauguration of the 160 MW CSP plant in Ouarzazete, **Morocco**, in February 2016, which included three hours of molten salt storage, strengthened the case for this technology in regions with high insolation and where energy storage is urgent for grid stability.

ELECTRIFICATION

- More than 6 million **solar home systems** are in operation worldwide, half of them in **Bangladesh**.
- 50 to 250 GW of diesel generators in micro-grids could be hybridised with renewables, 12 GW of which is located on islands.
- Total global **small hydropower** (SHP) capacity (< 10 MW in IRENA statistics) amounted to 133 GW in 2014, complemented by 0.7 GW of **small wind turbines**. **China** has led the development in recent decades.

RENEWABLE ENERGY PLANS

- **Africa** has witnessed the rapid adoption of renewable energy targets over the past decade, with 41 countries having introduced at least one type of technology or sector-specific target, as well as dedicated off-grid policies.
- In October 2015, the government of **Argentina** passed a new law to raise the share of renewables to 20% by 2025, and includes a number of new measures to realise this target.
- In October 2015, the **Association of Southeast Asian Nations** (ASEAN) set a 23% renewable energy target for primary energy to be reached by 2025.
- **China**'s solar PV target for 2015 increased from 17.8 to 23.1 GW, which includes projects that began construction in 2015 and will be commissioned by end of June 2016. This increase suggests the 2020 target could be revised upward from 100 to 150 GW for solar PV and from 200 to 250 GW for wind, with strong interest and engagement from provinces.
- In early 2015, the **Economic Community of West African States** (ECOWAS) released its region-specific renewable electricity target of 75.6 terawatt-hours (TWh), which would be 31% of total generation in 2030.
- **France**'s energy-transition law was passed in August 2015; it aims for drastic changes in the outlook for the country's energy sector.
- In December 2014, the **Turkish** government approved its National Renewable Energy Action Plan, targeting a 30% renewable energy share in power generation and 10% in transport by 2023.
- **Ukraine**'s national renewable energy action plan was adopted by the Cabinet of Ministers on 1 October 2014 and includes an 11% renewable energy target for the total energy mix by 2020.
- In the **United States**, the government proposed a Clean Power Plan with tougher pollution standards for new and retrofitted power plants.
- A landmark deal between the **United States** and **China** committed the United States to cut emissions 17% from their 2005 levels by 2020.

01

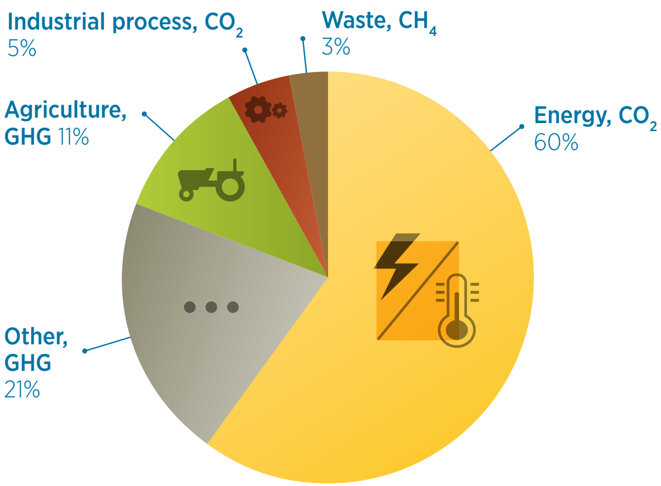
RENEWABLES HELP TO DECARBONISE GLOBAL ENERGY SUPPLY

Global anthropogenic GHG emissions amounted to 50 Gt CO_2-eq in 2010 (PBL, 2015), which stand as the most recent figure available. About 60% of total GHG emissions worldwide can be traced back to energy consumption (29.8 Gt) (Figure 7). The remaining 40% is non-energy related, such as CO_2 emissions from industrial processes and non-CO_2 GHG, notably from agriculture.

A closer look at energy-related CO_2 emissions shows that power generation is responsible for the bulk, followed by industry and transport. Of all CO_2 emissions from fossil energy, 44% come from coal, 36% from oil and 20% from natural gas.

Figure 7: Breakdown of global greenhouse-gas emissions, 2010

60% of total GHG emissions come from energy consumption.



Source: PBL (2015)

In 2015, the CO_2 concentration in the atmosphere reached 400 ppm (Dlugokencky and Tans, 2016). The IPCC estimates that a CO_2 concentration of 450 ppm would result in a global temperature rise of 2 °C above pre-industrial levels. The energy-related cumulative CO_2 emissions budget for 2 °C is about 900 - 1 900 Gt of CO_2 (Friedlingstein *et al.,* 2014). The 450 ppm CO_2 peak leaves 650 Gt of energy-related CO_2 emissions between now and 2050, with around 25 Gt per year in 2030. This number, however, is really an upper limit and assumes a continued strong emissions decline after 2030, with no or even negative emissions after 2050, necessitating the widespread application of technologies such as bioenergy with carbon capture and storage (BECCS), or some form of geo-engineering.

At COP20, in Peru in December 2014, governments agreed that countries should submit their INDCs by 1 October 2015. These INDCs contain pledges that will contribute to achieving the objective set forth in Article 2 of the UNFCCC. The sum of contributions will become the foundation of climate change efforts after 2020. The UNFCCC Secretariat was requested to quantify how well the sum of contributions corresponds to the ambition of avoiding 2 °C of global warming. Based on IRENA analysis, aggregating the ambition level of all submitted INDCs still yields a gap to the 2 °C target.

The CO_2 emission levels if all the INDCs are aggregated (UNFCCC, 2015) yield a reduction potential of about 7-8 Gt compared to the level of emissions that would otherwise be reached according to the Reference Case in 2030, at 42 Gt (Figure 8). About two-thirds of this saving potential (4.5-5 Gt) is related to energy efficiency and non-renewable low-carbon options, with the remainder (2-2.5 Gt) from renewables. The potential reduction from renewables according

Depending on the degree to which the renewable energy share increases, up to 12 gigatonnes of energy-related carbon dioxide emissions can be eliminated beyond the Reference Case. This is higher by a factor five than the emission reductions that would be achieved when the Intended Nationally Determined Contributions of all countries are aggregated.

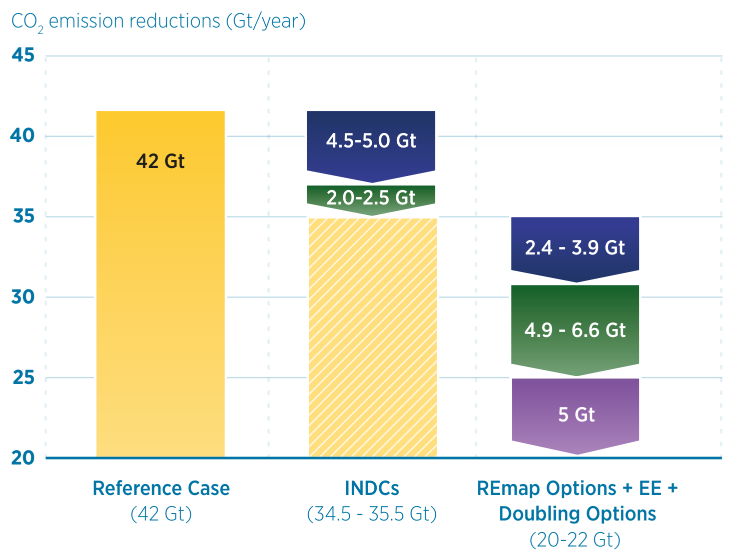
to the INDCs is included in the REmap Options. However, it is also important to consider that INDCs are a static representation of governments' views to 2030 as they are now. With technological learning, cost reductions and innovation, the potential of renewable energy is much higher than what is envisioned according to the INDCs.

Clearly, energy and climate discussions are merging. But while the Paris Agreement has increased the focus on lowering emissions, many INDCs do not detail the role renewables in meeting their commitments, though some three quarters of them specifically mention renewables. Whereas some countries have little or no specific focus on renewables, others listed quantified renewable energy targets, and some even aim for it to account for all of power generation. Many also include a focus on smart grids, industrial efficiency, clean vehicles, and efficiency, which all will play very important roles in abating emissions. However, some countries are banking on land use, land-use change, and forestry (LULUCF) rather than renewables for GHG emissions abatement.

Figure 8 shows CO_2 emission reduction potential from INDCs in the year 2030 and what could still be done in addition according to the REmap Options by 2030 compared to the Reference Case. REmap Options include the potential of INDCs and offers more. According to the REmap Options there is more than twice as much potential from renewables alone compared to what is envisioned by the INDCs, along with additional efficiency gains. With Doubling Options, the potential of renewables is by a factor five higher. While the INDCs send an important signal, REmap builds on that ambition and shows what additional technologies are available.

When the national plans of all 40 REmap countries are aggregated, global CO_2 emissions from the combustion of fuels for energy would reach 42 Gt by 2030 in the Reference Case, much higher than the

Figure 8: Breakdown of energy-related CO_2 emission reductions: INDCs, REmap Options and Doubling Options



Renewables can do five times more to mitigate climate change than what is envisioned according to the INDCs.

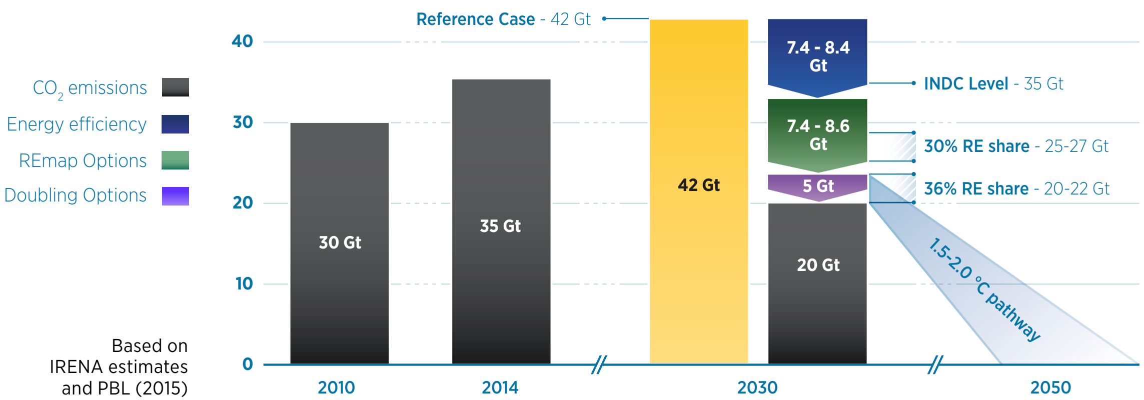
Based on IRENA estimates

Global leaders can limit global temperature increases to 2 degrees Celsius, but reaching the ideal target of 1.5 degrees Celsius requires more than a doubling of the renewable energy share. While this report identifies the need for significant effort to reduce energy-related carbon dioxide emissions, a similar effort will be required to reduce emissions of other greenhouse gases.

25-27 Gt aimed for that year. Savings that can be achieved from energy efficiency can limit this growth to as low as 33-34 Gt (19% reduction). With the REmap Options that were identified based on the bottom-up analysis of 40 REmap countries, accelerated uptake of renewables can reduce emissions further to 25-27 Gt (this includes the 2-2.5 Gt reductions related to renewable energy identified by INDCs, for a 41% reduction). The lower end of this range is sufficient to keep the world on a 2 °C pathway, but the replacement of fossil fuels needs to start now and efforts should continue beyond 2030 to ensure long-term climate change mitigation goals are achieved. These efforts to reduce energy-related CO_2 emissions need to be complemented with similarly ambitious efforts and implementation of measures to reduced other greenhouse gases as well.

Figure 9: Global energy-related CO_2 emissions, 2010-2050

Renewables can put the world on the 2 °C path.



Based on IRENA estimates and PBL (2015)

Doubling the share of renewable energy in TFEC to 36% does not necessarily mean a reduction at the similar magnitude in fossil fuels used in the total primary energy supply (TPES). Supply-side efficiency to reduce losses from fossil fuel use in the transformation of primary energy to electricity will also be critically important to mitigate climate change. This potential is covered under the energy-efficiency measures. With the additional technology and strategies to enable a doubling, that include renewable energy, energy efficiency and modern modern energy access, CO_2 emissions can be at 20-22 Gt by 2030 – half the total emissions in the Reference Case. This translates to 12-14 Gt of energy-related CO_2 emission reductions from renewables. This reduction potential is as high as the total amount of emissions that would be emitted (12 Gt) in 2030 from existing coal plants that are expected to still be in operation by 2030, and from new plants that are currently being planned for (planned capacity estimated at 1 428 GW from about 2 440 plants) (van Breevoor *et al.,* n.d.).

Technology deployment in all energy applications is necessary for a doubling, and to set the world on a trajectory below the 2 °C climate target agreed on at COP21. The gap can only be closed with a concerted effort by all countries in all sectors.

RENEWABLES FOR IMPROVING ENERGY SECURITY

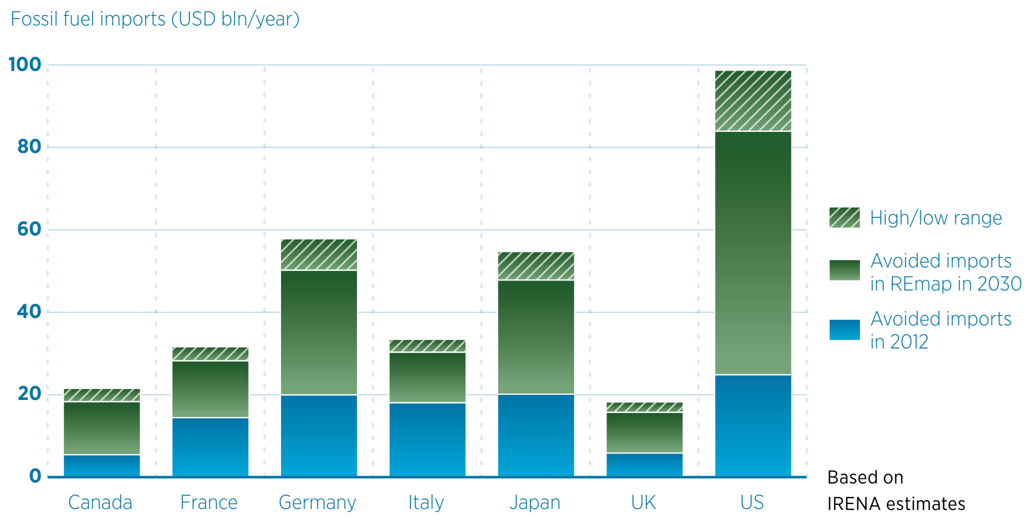
Energy is needed for almost all types of economic activity. History has shown that the disruption of energy supplies comes with negative economic and social impacts. Maintaining secure and reliable supplies of energy is critical to economic growth, human welfare, and social goals.

In 1973, oil met 46% of global energy requirements, although today its share has fallen to 31% (IEA, 2015a). Despite this, the world's economy remains vulnerable to oil supply disruptions (as has happened in the past on numerous occasions), and markets react nervously to news about political or economic unrest in major exporters. Oil's share has fallen at the expense of natural gas demand, which has grown from 16% of TPES in 1973 to over 21% currently. In many respects, this has increased supply vulnerability, as consumer countries have become increasingly reliant on imports via pipelines and LNG shipping routes, and now gas security is a major concern for many countries. For example, the European Union depends on 66% natural gas imports for its total supply. With concerns about natural gas supplies, electricity security and the security of gas supplies for heating and industry has become a growing concern for both developed and emerging economies. At the same time, the power sector is undergoing one of its most profound transformations as the contribution of renewables grow.

With the increasing diversity of the global energy mix, and of the energy mix of the Group of Seven (G7) countries, energy security policies are evolving worldwide to reduce dependence on imports. IRENA assessed the role that renewables can play for G7 countries in improving their energy security and found that REmap would reduce imports of fossil fuels by USD 275-315 billion per year by 2030 in the G7 countries. This estimate includes all avoided imports from the current contribution of renewables, as well as those in 2030 with the implementation of REmap Options. Renewable energy can therefore play an important role in helping to improve the robustness of the energy system to external energy security shocks by exploiting economic, domestic renewable energy sources for electricity and to meet energy demand in the transport, industry and residential and commercial sectors.

Over 275 billion of additional fossil-fuel imports can be avoided by 2030 with more renewables.

Figure 10: Energy-security benefits of renewables in G7 countries, 2012-2030



Based on IRENA estimates

NUMEROUS OTHER BENEFITS

Renewables do much more than reduce GHG emissions. The socio-economic effects can be grouped into four categories: macro-economic effects; distributional effects; energy system-related effects and additional effects (see Figure 11).

A recent study by IRENA focused on the macro-economic effects of a doubling of the global renewable energy share (IRENA, 2016a). This first-of-its-kind study has shown that a doubling of renewable energy can create new employment opportunities, enhance human welfare, and fuel economic growth.

To start, doubling the share of renewables in the global energy mix by 2030 would increase global GDP by 2030 by 0.6% or around USD 700 billion, compared to the Reference Case. Most of these positive impacts on GDP would be driven by the increased investment in renewable energy deployment, which triggers ripple effects throughout economies. If a doubling of the renewable energy share is achieved through a higher rate of electrification of final energy uses, the increase in global GDP is even higher, at about 1.1%, or USD 1.3 trillion globally (IRENA, 2016a).

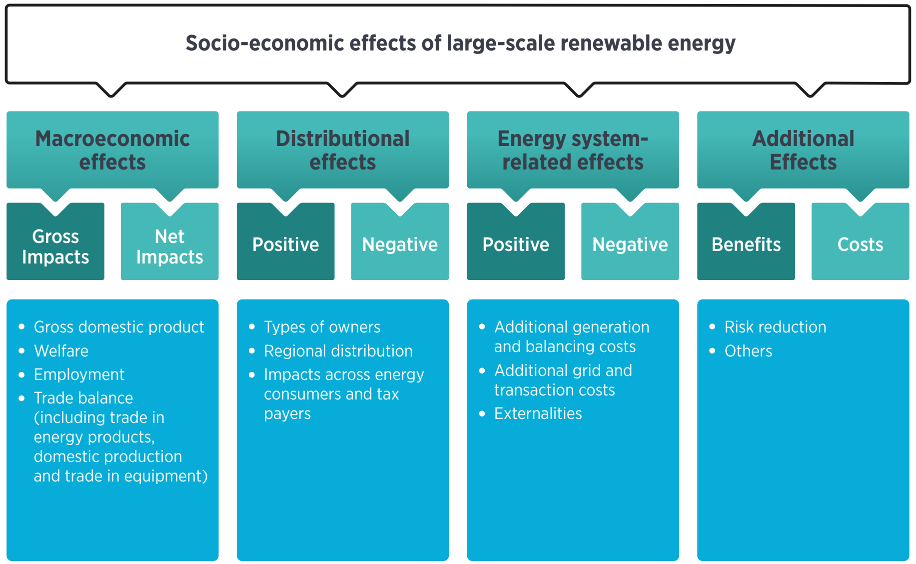
With the Doubling Options implemented, the total number of jobs (direct and indirect) related to renewable energy from 9.2 million in 2014 (IRENA, 2015c) to 24.4 million in 2030. That is almost 11 million more renewable energy jobs than in the Reference Case. Jobs will be lost in other sectors as non-renewable energy is replaced, but there will be a net increase of 6 million in the process. These jobs are located throughout the supply chain, from R&D to design, installation, and on-site maintenance. Workers ranging from highly-skilled to general labourers will be needed, so many of these jobs will be well-paid ones and are more likely to be spread across regions, including rural areas.

Renewable energy deployment increases demand for energy-related equipment and services as well as of fossil fuels. Trade in renewable energy equipment and other goods and services will increase as a result of the scaled-up deployment in the power sector and in buildings, industry and transport. This will also result in a decrease in trade of other energy sources, notably fossil fuels.

The increase in the share of renewable energy in the global energy system will impact both fuel importers and exporters. For fossil-fuel importers, the switch to a greater share of renewables has potentially favourable trade implications stemming from the ripple effects on their economies, as well as improved energy security from a greater reliance on indigenous sources. Fossil-fuel exporters appear vulnerable to changes in trade patterns. Given the high contribution of fossil fuels to their GDP, the dependency on export revenues can have significant effects on their economies. This is not a foregone conclusion, however.

Figure 11: Analysing the socio-economic effects of large-scale renewable energy deployment

Renewable energy deployment has various socio-economic effects.



IRENA (2016a)

Early renewable energy deployment in fossil-fuel exporting countries could be seen as an opportunity for economic diversification, thereby positioning them in the new markets that will be created.

There are also important environmental and other socio-economic benefits. Replacement of traditional uses of bioenergy with modern renewables reduces the need for users to spend time foraging, which may come with myriad social benefits. On the other hand, there are also barriers to this shift stemming from financial limitations. Other important socio-economic benefits are related to meeting the local needs of communities such as improvement of infrastructure, addressing poverty, providing support for local organisations, environmental projects etc. These benefits will be more prominent as distributed generation gains further share in the market.

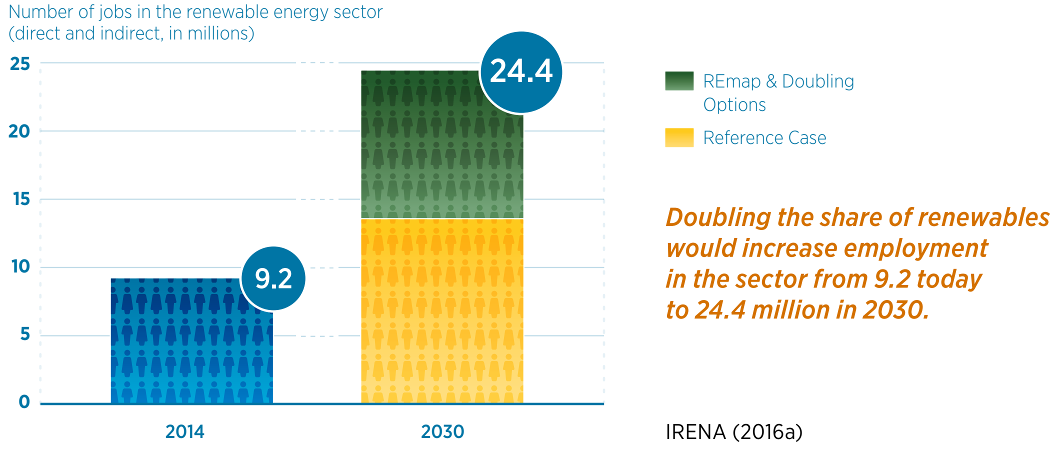
A greater share of modern renewables in our energy system results in a better local environment with less air pollution. Health related costs associated with outdoor air pollution are the largest source of external costs associated with fossil-fuel combustion. However on a per capita basis, the impact of indoor air pollution is especially large for households because traditional uses of bioenergy harm welfare and result in a large number of deaths.

Environmental damage from GHG emissions come with a tremendous price tag as well. In Africa alone they are estimated to reach USD 50 billion per year by 2050, according to the United Nations Environmental Program (UNEP, 2015a).

According to REmap findings, reduced externalities related to air pollution and climate change resulting from higher shares of renewables will result in savings up to USD 4.2 trillion annually in 2030. This is 15 times higher than the additional costs of a doubling

Another important environmental benefit is the nexus between energy and water. Nearly 15% of global freshwater withdrawals annually are used in energy supply. A transition to renewable energy could cut this consumption almost in half in the United Kingdom and by more than a quarter in the United States, Germany, and Australia.

Figure 12: Employment in the renewable energy sector, 2014-2030



IRENA (2016a)

Coal power requires up to 200 times more water than solar arrays and wind farms for the same amount of electricity. According to the findings of a recent study about China's power sector, a combination of renewables and better plant cooling can reduce the water-intensity of China's power generation by up to 42% (IRENA and China Water Risk, 2016). Bioenergy can require substantial water input depending on the feedstock (IRENA, 2015d).

Doubling of the renewable share in global energy use by 2030, compared with today's levels, would result in significant savings to society. By reducing externalities related to air pollution and climate change, it would set the world on a course towards limiting temperature rise to no more than 2 degrees Celsius. It would also boost gross domestic product growth and employment.

IDENTIFYING THE GAP TO DOUBLING

This chapter focuses on the core component of REmap: identifying the gap between government plans (the Reference Case) and the additional technology options to further increase the share of renewable energy by 2030 (REmap Options and Doubling Options). Stark differences exist between countries, such as their starting points, policy frameworks and resource availability, but all countries will have a role to play in this process.

Amongst all sectors of our energy system evaluated in this roadmap, the greatest potential for renewables beyond the Reference Case was found for the power sector. A majority of countries can achieve a 40% share for renewables in power by 2030 if all REmap Options are to be implemented, and many have already put policies in place. However, this will not be sufficient to put the world on a doubling in its total energy mix since power consumption accounts for 20% of the total energy mix. The other 80% is direct uses of fuels in buildings, industry and transport for cooking, cooling, heating and transport. Efforts are needed here as well.

In this roadmap, besides sectors, opportunities across countries were also identified, but one area in which governments have been less ambitious in facilitating renewable energy is industry, as only modest growth is anticipated in the Reference Case. For buildings, both residential and commercial, there is great potential for renewables. Transport has the least renewable energy share today, and this will remain to be the case in the Reference Case in 2030 as well. However, if all REmap Options are to be implemented, the modern renewable energy share would significantly increase to 30% by 2030 compared to today's level of about 9%.

To achieve a doubling of the renewable energy share by 2030 governments need to go beyond REmap Options and, in combination with increased energy efficiency and modern energy access, consider implementing the Doubling Options. These additional measures include electrification in buildings, industry and transport, sector coupling (*i.e.*, connection of the power sector with heating, cooling and transport to ensure use of surplus renewable electricity in an economic manner) and strategies such as early retirement of energy-intense facilities burning fossil fuels. Most of these technologies come at a higher cost.

Nevertheless, the cost of the REmap Options and Doubling Options are offset by significantly higher reduced externalities, due to lower levels of air pollution and CO_2 emissions. This is the case in every country, although policy frameworks often do not fully reflect these externalities.

This chapter provides more detailed findings from IRENA's REmap analysis by paying particular attention to the potential and costs at country, sector and technology levels according to the Reference Case and if the world is to realise a doubling of its global renewable energy share by 2030.

02

KEY POINTS

- REmap shows how a **DOUBLING OF THE RENEWABLE ENERGY SHARE** between 2010 and 2030 can be reached. If all options are implemented the share for modern renewable energy, which excludes traditional uses of bioenergy, would quadruple.
- A doubling of the renewable energy share by 2030 would set the world on a path to **RENEWABLES PROVIDING A MAJORITY OF ENERGY** by 2050; this is required to cap global warming to 1.5 - 2 degrees Celsius by the end of this century.
- The **REMAP OPTIONS**, identified with country experts, would lead to a 30% renewable share in total final energy consumption when energy efficiency and modern energy access efforts are added; this compares to just 21% in the Reference Case based on national energy plans.
- To reach a **DOUBLING OF THE RENEWABLE ENERGY SHARE** to 36% by 2030, IRENA assessed "Doubling Options", which include, inter alia, higher electrification rates, early retirements, and industry relocation. While these come at a higher price, avoided external cost greatly offset their cost.
- The **POWER SECTOR** leads the way in terms of growing the share of modern renewable energy; with the REmap Options many countries could attain a renewable share in power generation exceeding 40%.
- **INDUSTRY** is the most overlooked sector for renewable energy integration; the Reference Case increases the share only marginally to 15% by 2030. The REmap Options identify a range of technology options to further grow this to 26% in the same year.
- **BUILDINGS** present the greatest potential for increasing the use of renewable energy as a result of the expansion of modern bioenergy use and more electricity use, which is increasingly supplied with power generated from renewables.
- **TRANSPORT** is the sector with the smallest share of renewables; this could grow five-fold however if opportunities in biofuels and electric mobility are captured.
- The **REMAP OPTIONS** take the renewable share to 30% and require investment support of USD 230 billion per year in 2030; with the Doubling Options this would be 36% and USD 415 billion. This compares with USD 493 billion in support to fossil fuels in 2014.
- Including **REDUCED EXTERNALITIES** in the analysis clearly makes the case for both the REmap and Doubling Options: total savings are estimated to range from USD 1 trillion up to 4.2 trillion annually in 2030 as a result of reduced air pollution and greenhouse gas emissions.
- More than half of the REmap Options are **COST-EFFECTIVE** without considering externalities; the remainder is competitive when including reduced externalities. However, national policies heavily distort markets; policy adjustments are needed to reach fair pricing of renewables.

RENEWABLES USE TODAY AND IN 2030: PRESENT PATHWAY

The Reference Case features strong growth in renewable power, whereas the traditional use of bioenergy for heating and cooking is declining. In the Reference Case, given energy demand across all sectors is rising, the renewable energy share in 2030 would not imply a great jump from current levels.

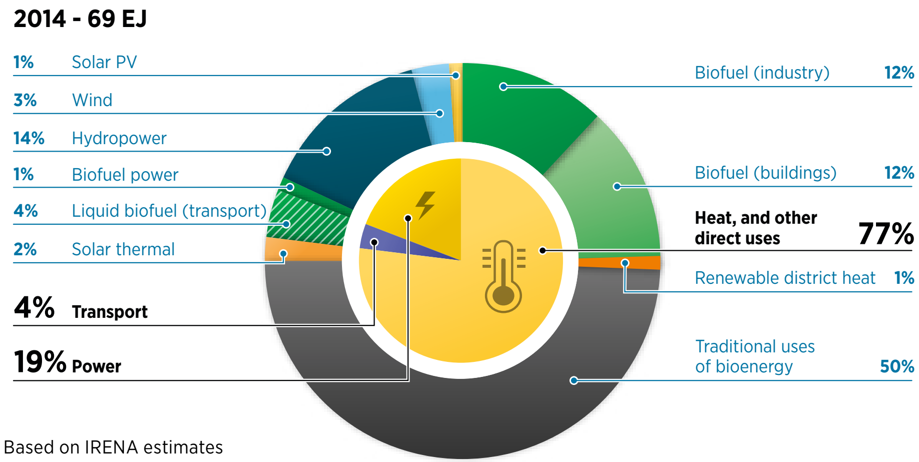
Since the 2014 edition of REmap, more countries have set targets and included renewables in national plans. Most other countries have revised renewable targets. These changes have been accounted for in the Reference Case now.

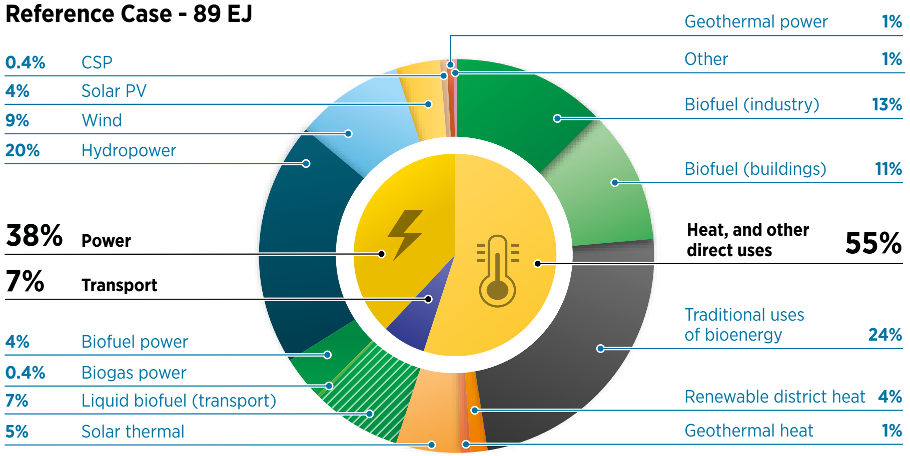
The updated estimate shows that renewable energy share in the global energy mix will reach 21% by 2030 if all existing plans and policies are implemented, which is similar to what was estimated according to REmap in 2014. Though renewables deployment is increasing along with ambitions to do more, the growth in overall demand also continues, mainly due to an increase in energy-access efforts in developing countries. Renewable energy growth is therefore only barely outstripping energy demand growth.

The required progress in energy efficiency is still not being made. The full potential of efficiency measures have been highlighted in various studies (*e.g.,* see IEA and the World Bank, 2015) and is not reflected in national energy plans. The result is an approximately 30% increase in TFEC by 2030 compared to today's level, as opposed to approximately 20% if efficiency measures were fully pursued. There is also limited policy focus in many countries on the important role of

Total final renewable energy use can increase by a quarter in the Reference Case.

Figure 13: Renewable energy use in 2014 and 2030 (Reference Case)





Based on IRENA estimates

bioenergy, and addressing the availability of sustainable supply is an area that needs more attention. Whilst policy approaches differ by country, collectively there is currently a focus on the power sector. More attention should be paid to industry, buildings, and transport. These types of policy evolutions would make doubling the renewable energy share in the global energy mix by 2030 an easier task.

Bioenergy poses major challenges, as neither the use of, nor the share represented by, traditional use of bioenergy is falling, although this is required to meet long-term targets. When considered in the context of the overall rise in demand for cooking and water heating that can be seen in global statistics, a static use of bioenergy can be considered positive. Traditional use of bioenergy is not growing because people are moving to cities and gaining access to other types of fuels. Ideally the replacement fuel would be sourced from renewables, but in many cases modern petroleum products such as LPG and kerosene are used instead. Modern bioenergy options – briquettes, biogas, ethanol gels, and others – could receive policy support so they can play a greater role in substituting traditional use of bioenergy.

As of the end of 2014 renewable energy accounted for 18.4% of global TFEC, half of which was modern renewables and half traditional uses of bioenergy, which by definition is hard to quantify as most consumption is not measured. In developing countries, traditional use of bioenergy can represent more than half of the TFEC. Amongst modern forms, hydropower and modern bioenergy were most common. Other modern renewables contributed less than 1% of TFEC, including wind, solar and geothermal.

The 21% share for renewables in the Reference Case by 2030 is equivalent to growth of about 0.17 percentage points per year – in other words, a continuation of the current trends. The pace of renewable energy uptake is not sufficient to significantly increase the renewable energy share in the global energy mix. In the Reference Case, modern renewable energy would comprise only 14%, which indicates an annual growth rate of 0.35 percentage points of its share between now and 2030.

Renewable energy uptake by sector varies, however. The Reference Case sees strong growth in renewable power, such as hydropower and wind. Since the last edition of REmap in 2014, the amount of solar PV in the Reference Case has doubled. Wind and solar (PV and thermal) each represent 9% of projected renewable energy use in the Reference Case in 2030, and hydropower 20%. Bioenergy would account for 60% of the total, down from 80% in 2014. Despite a decline in its overall share, traditional use of bioenergy would continue to account for a large share of total renewable energy use in 2030.

The share for power consumed in total renewable energy use would double from 19% in 2014 to 38% in the Reference Case. Direct uses of renewable energy for buildings, industry and transport would shrink from 81% to 62%.

PRIMARY VERSUS FINAL ENERGY

Throughout this report, renewable energy shares are estimated relative to TFEC, consistent with SE4All's Global Tracking Framework report (IEA and the World Bank, 2015). However, accounting methods vary by country.

European Union countries and several others estimate their renewable energy shares based on gross final consumption (GFC), for example, whereas Indonesia and the United States use TPES. Both offer advantages and disadvantages. Primary energy is, for instance, crude oil and lumps of coal before conversion into the gasoline and electricity – the "final energy" – that reaches consumers. As useful as this distinction is in revealing system losses for energy sources with fuel (fossil, nuclear and bioenergy), it is problematic when comparing these sources to wind, hydropower, and solar, for which there are no losses when they are converted from primary energy to a final form for consumption.

When calculating the consumption of finite resources, a focus on primary energy makes sense; as what counts is the amount of resources extracted. To arrive at primary energy equivalents for renewables and nuclear, different accounting measures can be used: the Physical Energy Content method (used by the IEA and the Statistical Office of the European Union – EUROSTAT), the Direct Equivalent method (used by the Intergovernmental Panel on Climate Change (IPCC) and UN Statistics) or the Substitution Method (used by the United States Energy Information Administration). Totals differ depending on the method, as does the renewable energy share. The Physical Energy Content Method, which is the one used in this report, generally provided lower shares than the Substitution method, for example.

To avoid these pitfalls, IRENA prefers to consider final energy rather than primary in making its calculations. However, it is also important to recognize the methodological drawbacks of using final energy as a metric, because it undervalues renewable electricity, which is often utilised at near 100% efficiency (for heating in building and industry and transport). Fuels used in buildings, industry and transport are valued based on their energy content, but not the useful service they provide; and conversion losses for useful services are not counted. Losses occur, for instance, when gasoline is combusted in an engine or when coal, natural gas or bioenergy is used for heating.

02

REMAP OPTIONS TO 2030: GREATER GROWTH POTENTIAL THAN GOVERNMENT PLANS RECOGNISE

Implementing all REmap Options would triple the use of modern renewable energy by 2030. The largest potential for growth beyond the Reference Case remains in industry, buildings and transport.

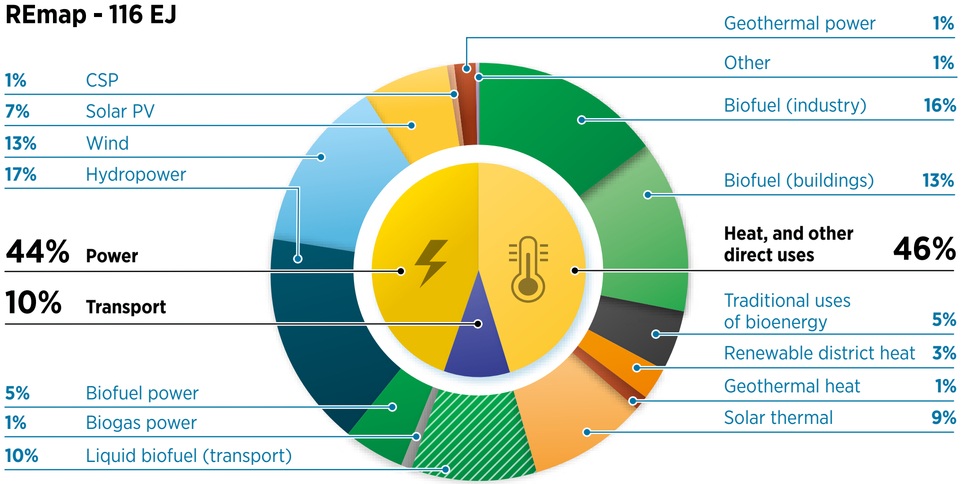
According to the Reference Case total final renewable energy use would grow from 69 EJ in 2014 to 89 EJ in 2030. With REmap Options the figure would reach 116 EJ (Figure 14). Half of total final renewable energy use in 2014 was accounted for by traditional uses of bioenergy. So modern renewable energy was about 35 EJ. Focusing just on modern renewables, the implementation of all REmap Options would result in total use of 116 EJ.

With the REmap Options, the share of renewable power consumption in total renewable energy use increases to 44% compared to 38% according to the Reference Case, and 19% in 2014. However, the largest potential for additional deployment remains in buildings, industry, and transport.

Overall, with the REmap Options, the share of modern renewables would climb to almost 25% of TFEC in 2030, and with modern energy access and energy efficiency, the share would reach 30%. There remains a 6-percentage-point gap to realise a doubling.

With REmap Options, renewables use in buildings, industry and transport as well as renewables-based district heating, would account for nearly 60% of modern renewable energy use in 2030.

Figure 14: Renewable energy use in 2030 with REmap Options, including modern energy access with renewables



Based on IRENA estimates

Changes in technology mix with the REmap Options

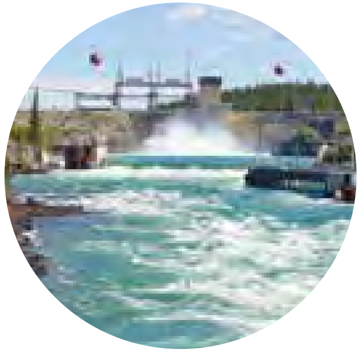
The change in the technology mix of renewables with implementation of REmap Options is significant. At 9% of global TFEC, traditional use of bioenergy makes up half of total global renewable energy use. In the Reference Case some of this bioenergy is already projected to be substituted with modern energy (both fossil fuels and renewables). This means efficiency for water heating and cooking in much of developing Africa and Asia will significantly improve. With the REmap Options, remaining traditional uses of bioenergy from the Reference Case are substituted with modern forms of renewables. Much of this happens in Africa, where this finding is broadly in line with IRENA's REmap Africa roadmap (IRENA, 2015e). This is, however, a very ambitious goal, and presents significant challenges, but also is in line with the goals of SE4All and the seventh UN Sustainable Development Goal (SDG7). Furthermore, power capacity to supply about 100 TWh per year electricity is implemented through electrification in rural areas – providing electricity to communities that previously had no or limited access to electricity. This rural electrification represents around ten percent of the total increase in electricity generation from the REmap Options. The significant challenges and potential solutions to realising these potentials are discussed in Chapter 3 of this roadmap.

Direct uses of renewable energy for transport, heating and cooling would account for less of the total final renewable energy use in 2030, falling from a share of 81% today to 56%, because of their more-efficient use and the growing share of renewable electricity. The way heat is produced would also change. Solar water heaters would play an expanding role with the REmap Options; with their share in total global renewable energy use quadrupling to 9%. In many developed markets the use of heat pumps would increase significantly, replacing fuels used on-site for heat generation by electricity (technology is covered under consumption of power from renewables along with other electrification options). The use of bioenergy by industry to create process heat would also grow, mainly in combined heat and power plants (CHP), although at a slower pace.

In transport, which has the lowest current renewable energy share among all sectors, liquid biofuels' share in total renewable energy use would expand from 4% in 2014 to 10% with REmap Options. In absolute terms the growth is four-fold, from 128 billion litres to approximately 500 billion litres per year. Around a quarter of this total use in 2030 would come from advanced liquid biofuels, which can be sourced from processes that have lower GHG emissions since they use more sustainable feedstocks. But, in general, bioenergy in transport will require a careful approach because most production will still require feedstocks that compete with crops for food production.

In addition to liquid biofuels, about 160 million four-wheel EVs would be used worldwide with REmap Options. Achieving this scale would imply that 10% of total vehicle stock in 2030 to be battery-electric or plug-in hybrids. Yearly sales would need to average 10 million cars – a 20-fold increase over the current level of about 500 000 (IRENA, 2015f). Realizing a 10% share in total vehicle stock by 2030 is an ambitious target, but it is still lower than what is envisioned by the United Nations Urban Electric Mobility Initiative (UN, 2014a). The contribution of electrification to the renewable energy use in transport is small because, to begin with, these vehicles are much more efficient, so small capacity additions go a long way. As well only a certain portion of this electricity would come from renewables, and passenger vehicles account for only half of total transport energy use.

In the power sector the share of PV and wind in total power generation is seen rising nearly fivefold with the REmap Options, from 4% in 2014 to 21% by 2030. In turn, renewables based power



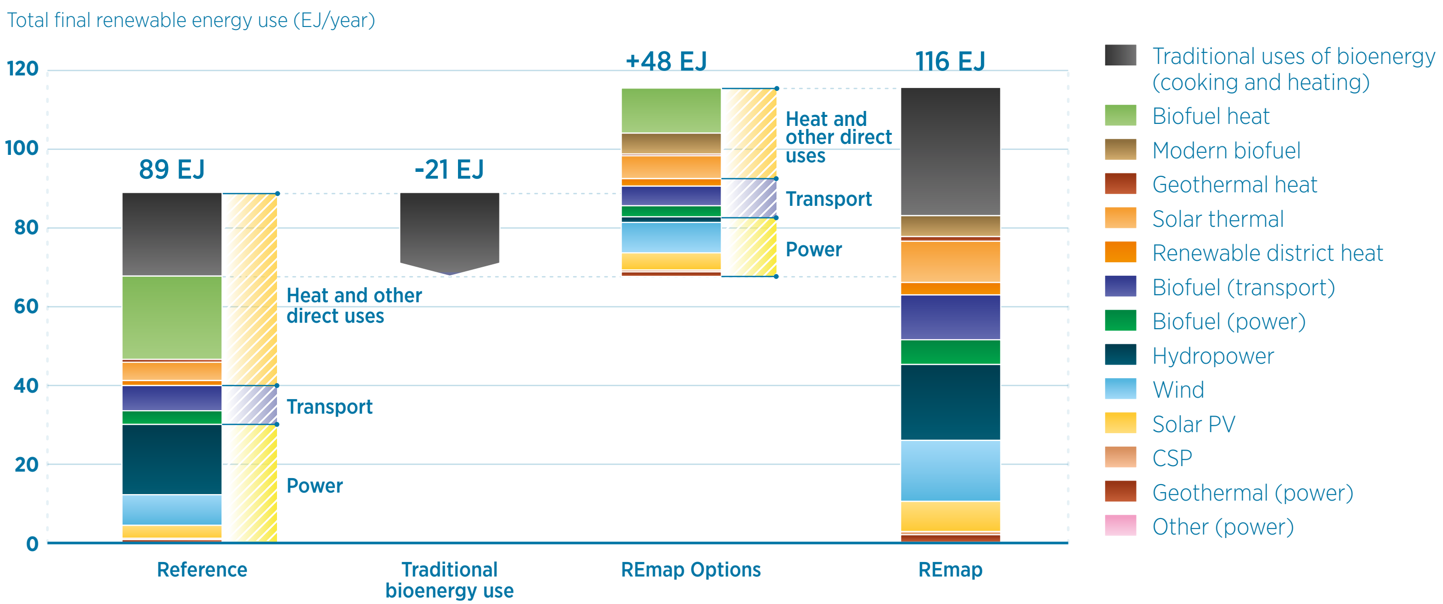
02

generation would double from 23% in 2014 to 45% by 2030. Hydropower continues to account for a large share of total electricity generation, estimated at 17% with all REmap Options. About 10% of this total is small hydropower (plants with capacity less than 10 MW following IRENA classification). The REmap Options produce an improved energy supply in the following respects:

- By ensuring universal access to modern energy through renewables for all, increasing resource sustainability and minimising welfare risks and the environmental impacts of unsustainable uses of bioenergy. Projections for modern bioenergy are cautious, however, because of food-security and water-supply concerns. It should also be recognized that bioenergy can be used for all energy applications (heat, power and transport fuels), so its usefulness is widespread.
- By providing more-realistic measures of potential for solar PV and wind, which continues to be underestimated.
- For large-scale hydropower the findings show limited additional potential beyond the Reference Case, unlike for other renewable power technologies. However, the opportunities in small-scale hydropower, the potential of which is often overlooked and a technology that can provide benefits to local communities, is highlighted.
- By addressing the global potential of solar water heaters, not only for space heating in buildings but also for process heat in industry, which is generally overlooked.

Figure 15: REmap Options by technology, assuming extension of modern energy access

The REmap Options add another 48 EJ of modern renewable energy – roughly twice the final energy demand of India today – beyond the Reference Case.



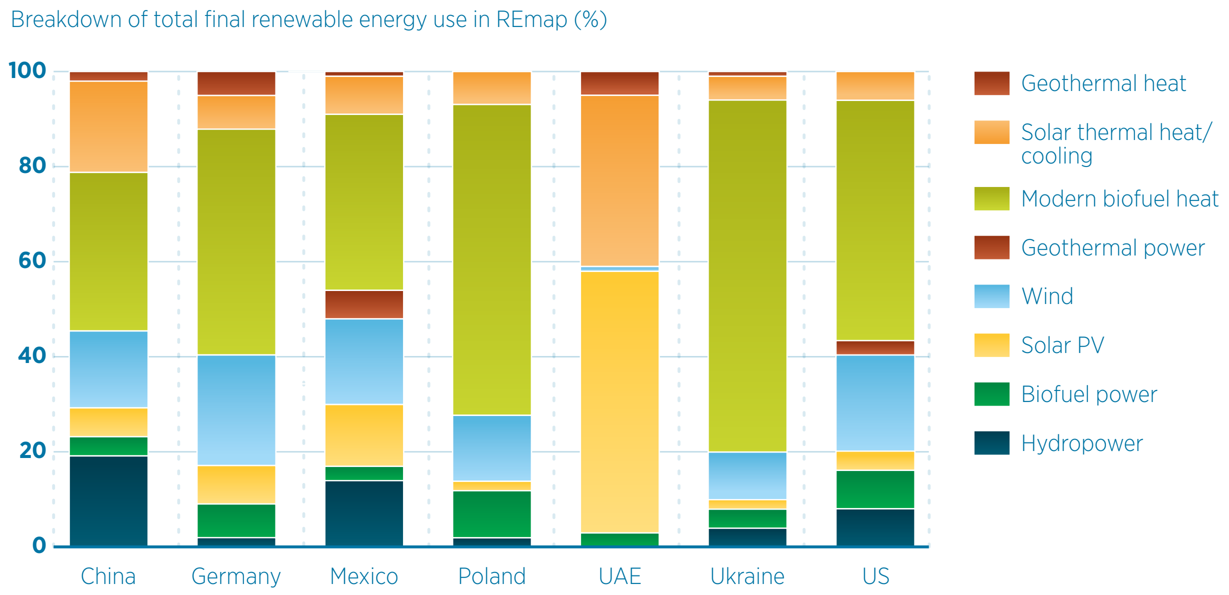
Based on IRENA estimates

The REmap Options, identified with country experts, would lead to a 30% renewable share in total final energy consumption when energy efficiency and modern energy access efforts are added; this compares to just 21% in the Reference Case which is based on national energy plans.

- By identifying technology options that are affordable today but in specific volumes in specific countries. They include mainstream renewable energy technologies such as solar and wind, but also new options such as biomethane for transport or electrification for industry, buildings and transport. These were, where possible, identified in cooperation with country experts.

When factoring in the drop in traditional use of bioenergy of 21 EJ compared to the Reference Case) and with the REmap Options total modern renewable energy use in 2030 would reach 116 EJ, an increase of nearly 50 EJ from the level in the Reference Case of roughly 68 EJ. This is one of the biggest differences in total renewable energy use between the Reference Case and REmap. A closer look at the

Figure 16: Breakdown of renewable energy use in REmap in seven countries



Based on IRENA estimates

Note: The first seven countries for which IRENA has produced REmap country reports

Solar accounts for the largest share in the United Arab Emirates compared to bioenergy in most countries. The specific mix is different everywhere and there is no single recipe.

discrepancies between the two is useful for policymakers, because they highlight where additional renewable energy technology policy focus would be most needed.

Overall, with the REmap Options modern renewable energy use is 70% higher than in the Reference Case. Solar thermal heat, transport biofuels and wind additions double in total use. Additions of bioenergy for heat and power generation are lower in relative terms. Solar PV additions double compared to the Reference Case.

In both cases, roughly half of the total final renewable energy use is for heating and cooking. A further 40% is for consumption of power from renewables, and 10% for transport. The main difference between the two cases is the technology mix, mainly for industry where little progress was made in the Reference Case, whereas there is considerable potential with REmap Options. Likewise, while the use of renewable energy fuels in transport roughly doubles in the Reference Case, it grows three to four-fold with the REmap Options, including electrification.

Specific renewable energy mix differs from country to country

Renewable energy mix differs by country, with some relying heavily on solar and others on bioenergy. These differences depend on resource availability, technology cost, policy frameworks and other factors. The technology options for almost all applications in the United Arab Emirates are solar, for example (IRENA and Masdar Institute, 2015). China today is by far the leading country for solar thermal use in space and water heating applications (IRENA, 2014b). Ukraine and Poland rely on bioenergy, given their large heating and limited availability of other sources (IRENA, 2015g; IRENA, 2015h). The United States and Mexico have a diverse selection of technology options (IRENA, 2015a; IRENA and SENER, 2015). In most countries, TFEC in buildings, industry and transport accounts for more than half of total modern renewable energy use, a finding that is similar to the global expectation.

DOUBLING OPTIONS TO 2030: TECHNOLOGIES AND STRATEGIES TO BOOST RENEWABLES TO 36%

Doubling the renewable energy share in the global energy mix to 36% can be achieved through greater electrification in heating and transport, coupled with higher shares of renewables for electricity generation.

In the REmap process, countries were asked to identify the realistic potential to increase renewables uptake significantly, with the results collected and incorporated into the REmap Options. These technologies mainly employ existing renewable energy technologies.

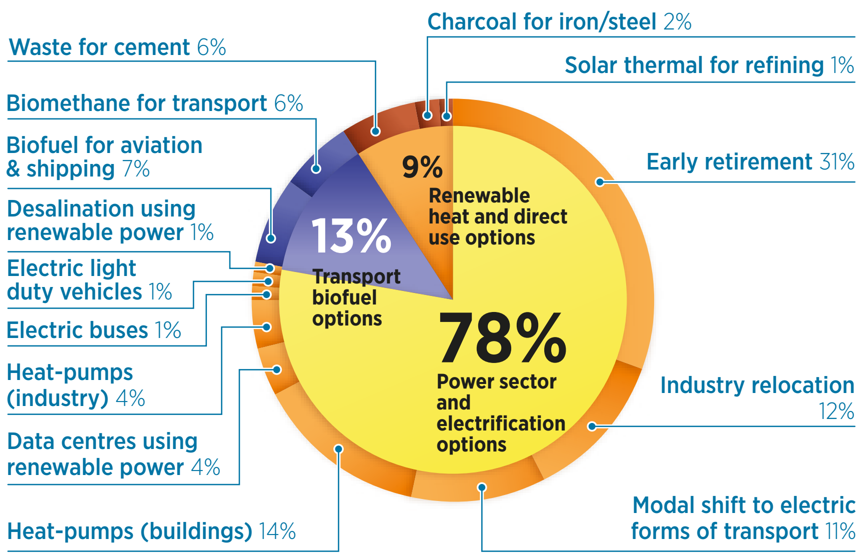
IRENA has undertaken its own exploratory assessment to identify technology options to realise a doubling of the global renewable energy share (defined as "Doubling Options"), and whilst this has not been based on a collaborative process with countries, it has provided important insights into the types of actions and technologies that may be needed to increase the renewable energy share beyond 30% when the REmap Options, energy efficiency, and modern energy access were considered only. As the Doubling Options result in even lower energy-related CO_2 emissions, they can put the world on a pathway to limiting the global temperature rise to a figure below 2 °C.

To reach a doubling of the renewable share to 36% by 2030, IRENA assessed "Doubling Options", which include, inter alia, higher electrification rates, early retirements, and industry relocation. While these come at a higher price, avoided external costs greatly offset their cost.

The chart shows which sectors and technologies would be used to realize a 36% renewable energy share by 2030 from the level of 30% when only REmap Options were implemented. In absolute terms, this represents a growth in total final renewable energy use of approximately 19 EJ, from 116 EJ to 135 EJ. The results show that more than three-quarters of the Doubling Options are in the power sector, in combination with electrification of heating and transport. The balance is split between the additional use of advanced liquid biofuels for aviation and shipping, biomethane for transport, and renewables-based (including renewable waste) heating in buildings

Electrification and power sector technologies make up over three-quarters of the technologies and strategies that enable a doubling.

Figure 17: Breakdown of Doubling Options by technology and sector



Based on IRENA estimates

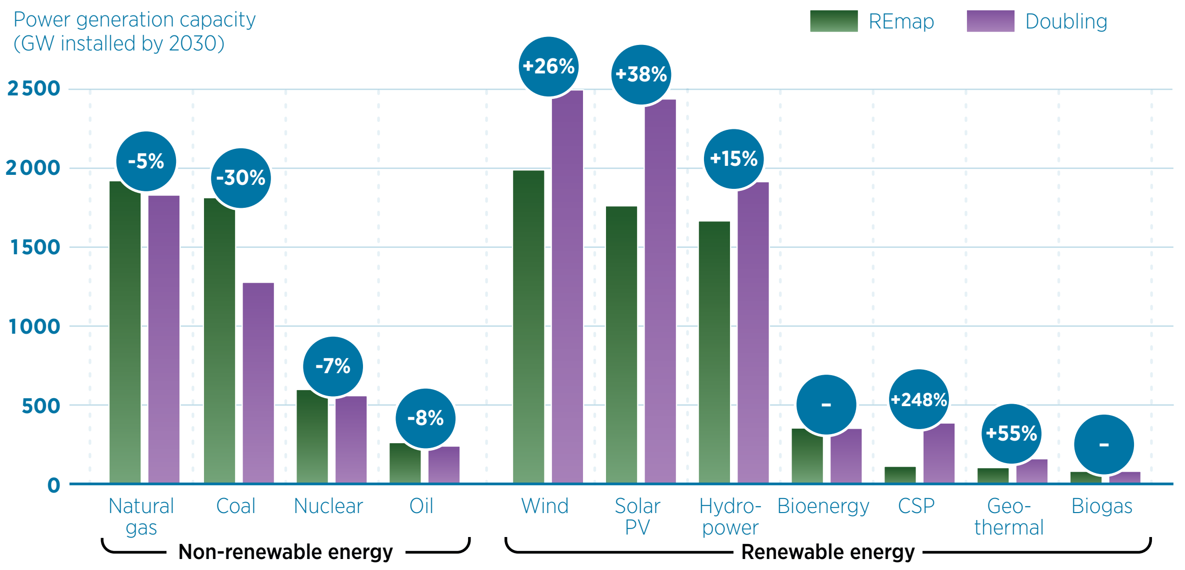
and industry. Sector coupling will play a greater role, in which surplus electricity can be used for heating buildings, industry and transport and synergies created for accommodating higher shares of variable renewables in the power system.

In transport, technologies include biomethane and hydrogen, especially in trucks. Some countries are considering different options to use excess renewable electricity in production processes, such as in power-to-gas to produce hydrogen. In turn, this hydrogen can be stored, and subsequently used in fuel-cell vehicles where a number of automobile manufacturers have been looking into such opportunities. Liquid biofuels would be adopted in aviation and shipping, and modal shifts would be required in which electrified public transport options substitute the use of passenger cars to some extent. These technologies increase the total renewable energy share by about 1.6 percentage points from 30%.

Another 2 percentage points of the global energy mix can be met by renewable energy use in industry. Technologies include heat pumps for process heat, locating new industrial plants in areas where cheap sources of renewable power are available, meeting the growing demand of electricity for desalination through novel renewable energy sources, and locating new data centres and server farms where renewable resources are in abundance, to save on the cooling

Figure 18: Global power capacity in 2030 with REmap Options and Doubling Options

Electrification and early plant retirement can reduce coal-fired capacity; allowing greater gains for CSP and geothermal power in particular, but also for solar PV and wind.



Based on IRENA estimates

costs needed for computing hardware. Most of these processes are already underway, though some will become commercially viable within the next decade. They are, however, costly compared to non-renewable technologies.

In addition, applications in chemical plants, which are often integrated into oil refineries and use process heat at medium temperatures, are considered. New technologies in development to supply heat in such plants include solar-powered industrial process-heating technology, which has been proven to generate steam at costs competitive with natural gas-based generation used for enhanced oil-recovery techniques across the Middle East. Therefore, some additional deployment of solar thermal process heat is assumed with the Doubling Options. For industries that require high-temperature heat, the increased utilisation of renewable waste can be an option in some settings. Vehicle tires are a type of renewable waste, as natural rubber is a main input. By 2030, a significant tire volume will be scrapped annually, and could be utilised in this way. Other types of waste including kitchen, demolition, textile also have high energy content and could be recovered for combustion in cement kilns. This could be an inexpensive way to increase the share of alternative fuels for high-temperature process heat applications.

In terms of industry relocation, the aluminium sector has begun building new facilities where inexpensive renewable electricity is available in abundance, such as in Iceland. Data centres are also increasingly eyeing such locations for future facilities and are a high-growth area of the economy. Whereas industry was once sited near fossil fuels to save on transporting them, increasingly what is valued is proximity to renewable power generation.

Thus, the Doubling Options in transport and industry applications would raise the renewable energy share from 30% to 33.6%. The remainder 2.4% would come from a mix of strategies that include early retirement of non-renewable power plants, new power market design to enable more variable renewable energy (VRE) deployment, further sector coupling that enables linking of power and heat supply (which is already occurring in places like Germany and California, but will need to spread to more regions), more interconnection capacity for great regional resource utilisation, and storage for heat and cooling to ease VRE integration.

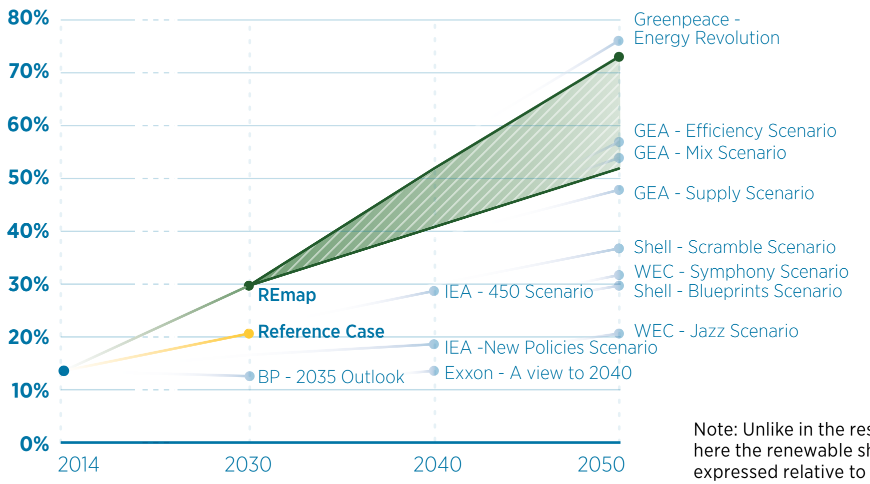
The power sector is particularly important because changes here would make a bigger difference in meeting global goals than those in other energy sectors. In the power sector, by 2030 coal-fired generation capacity will be around 1 800 GW if all REmap Options are implemented. About one-fifth of this total capacity will be more than 30 years old; and replacing them with renewable energy technologies before the end of their useful lives would further the overall goal of boosting the renewable energy share. The challenge in early retirement is therefore not technological, but financial and political. Reimbursement and financing mechanisms could therefore be used as incentives. New policy measures such as carbon pricing would work toward the game goal.

Early retirement could push solar PV and wind capacity increases above 2 400 GW each, and drop coal-powered generation to approximately 1 300 GW. The renewable energy share in power generation would exceed 50% as a result. The share of VRE would rise to 25% worldwide, pointing to the importance of flexibility measures needed to ensure the steady power at system levels, demand-side management (DSM), storage systems and back-up capacity.

RENEWABLE ENERGY USE IN 2050: PATHS TO HIGH PENETRATION

REmap focuses on a timeframe to 2030, but a general perspective to 2050 is needed to take sufficient action against climate change. The role of renewables in 2050 differs significantly depending on the outlook. An important factor is the level of energy efficiency that can be achieved by 2050. Technology development is another crucial factor.

Figure 19: Renewable energy share in total primary energy supply based on REmap and various energy scenarios, 2013-2050



Note: Unlike in the rest of this report, here the renewable share has is expressed relative to TPES. The purpose is to include data from more studies, many of which also express their findings based on this metric.

Based on IRENA estimates and BP (2016); Exxon Mobil (2016); IEA (2015b); GEA (2012); Greenpeace (2015); Shell (2008); WEC (2013)

The range in projections shows a large uncertainty in how much renewables could grow between now and 2050, but also highlight the opportunities for deployment in the timeframe.

Multiple long-term projections exist with varying degrees of ambition for the penetration of renewables and growth in total energy demand. Projections vary based on the underlying assumptions and the methodological differences across the different scenario analyses. Figure 19 shows, in contrast with the rest of this report, the renewable energy share based on TPES. This metric was chosen to allow for the inclusion of as many projections as possible since only few studies provide data available to make a comparison based on the TFEC metric. IRENA's Reference Case is in line with a set of projections (from Exxon, BP, IEA NPS, and the WEC) that project a future of continued reliance on non-renewable energy (and a renewable energy share of 20-40% by 2050), or that focus more on complementing renewable energy with nuclear and CCS to achieve climate goals. On the other end of the spectrum are outlooks such as those by the Solutions Project (The Solutions Project, n.d.) and Greenpeace Energy [R]evolution (Greenpeace, 2015), as well as the roadmap presented in this report, which project a highly ambitious deployment path of renewable energy towards a share of TPES beyond 50%.

Optimistic projections often anticipate rapid growth through renewable power capacity coupled with electrification in heating and transport. Greenpeace projects a 95% share for renewable energy in power by 2050 and assumes a significant growth in the share of electricity use in total final energy demand from about 20% today to 46% by 2050. The Solutions Project assumes 100% electrification of our energy system, and zero fossil fuel use in energy by 2050. Some projections emphasise energy efficiency (such as the GEA Efficiency Scenario) in achieving higher renewable energy shares, especially focusing on the potential in buildings and industry. Others expect a continued increase in energy demand. The resulting range in TPES is from 433 EJ to 1 050 EJ by 2050, compared with 568 EJ in 2013. Projections also vary widely for the role bioenergy can play, which today accounts for about 10% of TPES. Shell's "Scramble Scenario" for 2050 anticipates nearly 30% liquid biofuels in transport, and Greenpeace estimates a 25% bioenergy share within industrial energy demand. Estimates for renewable power capacity different greatly due to these different paths chosen. The IEA projects 2 400 GW of combined wind and solar PV by 2040; whereas the WEC Symphony Scenario puts this estimate twice as high at 4 800 GW.

IRENA has also evaluated what the technology mix could look like in 2050 – and its implications on renewable energy share and global CO_2 emissions. Potential for renewable energy deployment varies depending on how demand for primary energy changes over the timeframe. Based on trends from the national plans of several countries where such information is available, the REmap analysis results in a range of 475 EJ to 700 EJ of global TPES in 2050. Two possible renewable energy development pathways are explored: one in which the relative share of renewable energy for buildings and industry and renewable power remains equal; and one in which significantly higher levels of electrification of the end-sectors is achieved, resulting also in more renewable power capacity.

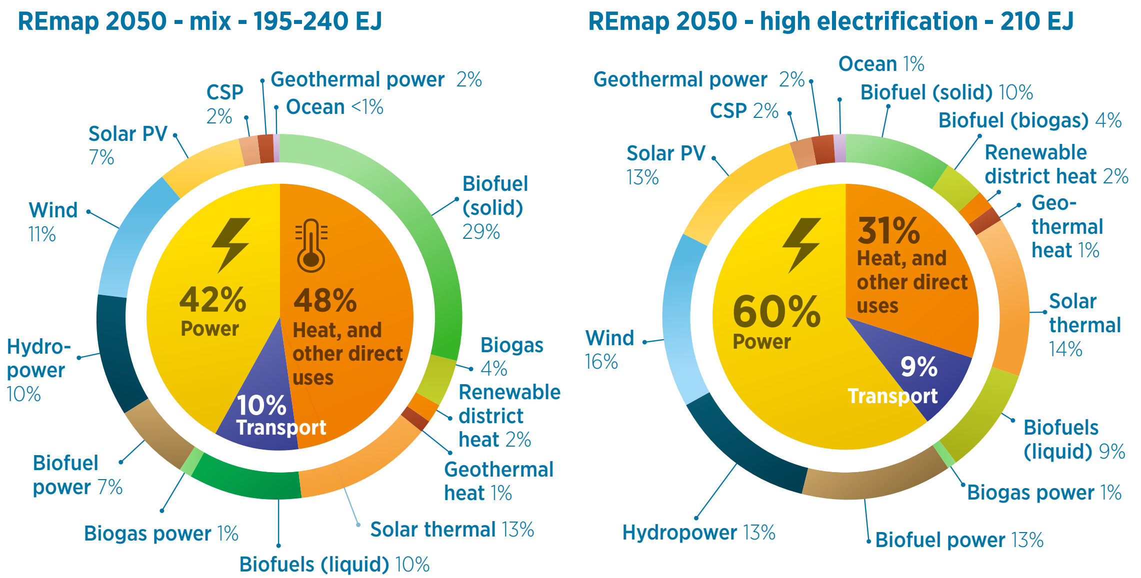
In Figure 20, the results of the two pathways on the total final renewable energy use in 2050 are presented. In the path where renewable energy deployment follows the ambition of a doubling by 2030, the renewable energy share in TPES increases from 30% to between 52-60% by 2050, thanks to the availability of more bioenergy feedstocks for heating and transport but also through a moderate increase in electrification coupled with renewable power generation. The range in renewable energy use is mainly a result of changes in energy efficiency (which itself is also in part driven by increased electrification).

If energy-efficiency improvements are significant, only 195 EJ of final renewable energy would be consumed, and a primary energy supply of 500 EJ would be needed, sufficient to maintain supply at today's levels. CO_2 emissions would be lower than 2030 levels, at around 10 Gt. With lower deployment of energy efficiency measures, total final renewable energy use would be 240 EJ in an energy system supplied with 700 EJ of total primary energy. The resulting CO_2 emissions are around 20 Gt – higher than what is needed for a 2 °C pathway.

With significant electrification in transport and buildings, the share of electricity in TFEC would rise to 45%, up from around 20% today. The result is a decline in both non-renewable fuels and bioenergy used in buildings, industry, and transport, and significantly higher power generation provided primarily by more solar PV, wind, geothermal, and ocean energy. TPES would drop further to 475 EJ, and the renewable energy share would increase to 73% overall and 80% in power generation. CO_2 emissions would fall to 5 Gt, making possible a cap in the global temperature rise of 2 °C or less.

Depending on the level of energy efficiency improvement and deployment of electrification technologies, the make-up of energy use could differ significantly in 2050. The power sector could see the biggest increase, comprising as much as 60% of total final renewable energy use.

Figure 20: Total final renewable energy use worldwide in 2050



Based on IRENA estimates

RENEWABLE ENERGY USE IN 2030 BY COUNTRY: CONTRIBUTIONS BY EACH AND ALL

The REmap Options identify potential for additional renewable energy in all countries, with great differences between countries in starting points, local capabilities, and realistic deployment potential by 2030.

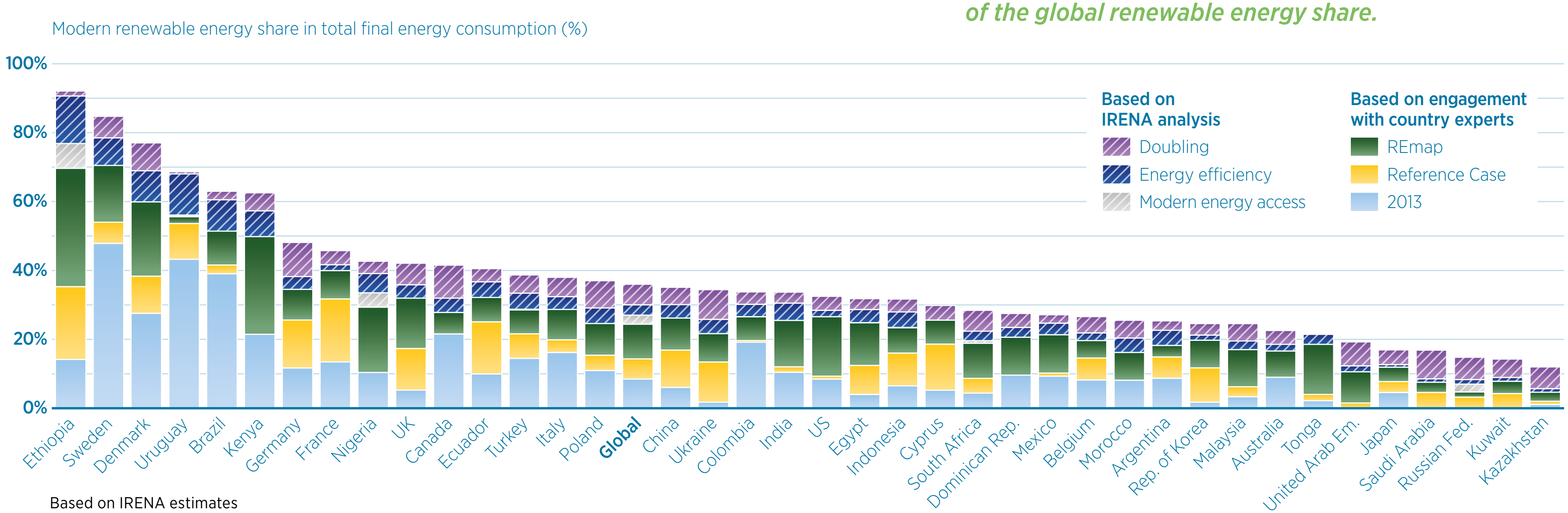
Country engagement through the REmap programme has highlighted stark regional differences: in starting points, renewable resources, access to financing, policy framework, and many other factors. All of them explain why some countries can achieve a tripling or even a quadrupling of their renewable energy shares, while others are less likely to achieve significant growth.

Figure 21 provides, on a country level, the implications of the global objective of reaching a doubling in the share of renewables to 36% in the global energy mix by 2030. The starting point is the share represented by modern renewable energy in 2013, shaded blue. While the global average modern renewable energy share was at 9%, countries including Egypt, Japan, and Malaysia are below 5%. On the other end of a rather wide range are countries starting at much higher levels, above 30%. Brazil, Sweden, and Uruguay are examples.

In most countries, the Reference Case (shaded yellow) foresees modest increases in renewable energy shares, as long-term country

Figure 21: Share of modern renewables in energy use of REmap countries, 2013-2030

Each country will contribute to a doubling of the global renewable energy share.

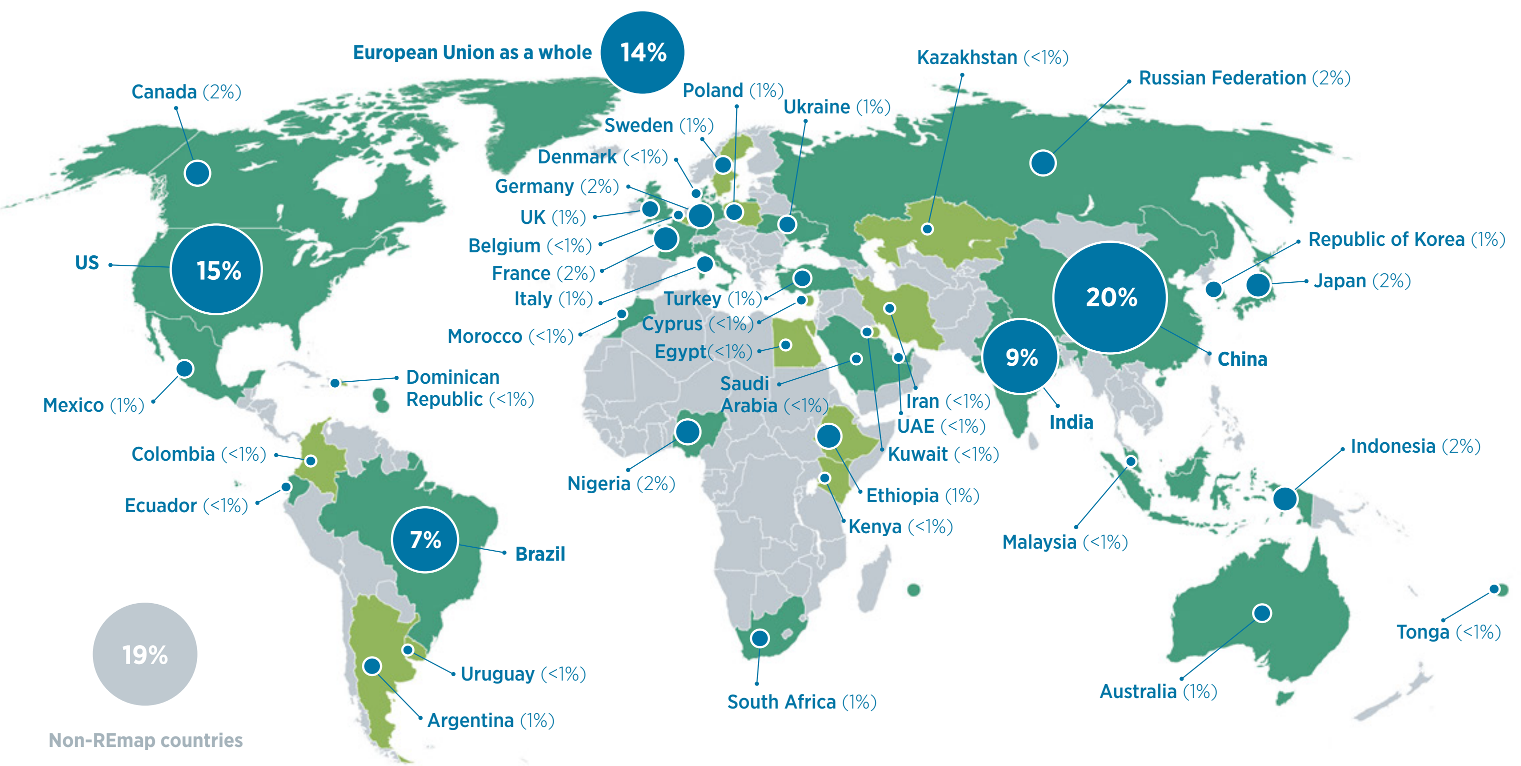


Based on IRENA estimates

plans often still need to evolve. However, several countries are notable exceptions, mainly in the European Union (EU), but also Argentina, Indonesia, Japan, and Republic of Korea. The European Union countries all have renewable energy targets for 2020 as defined by their national renewable energy action plans, while the overall European Union target for renewable energy is set at 27% by 2030. In addition, several member states (such as Belgium and Germany) have their own targets, which are reflected in the Reference Case.

With REmap, additional potential for renewable energy technologies is identified in all countries (the green bars). For some countries, the starting point (*e.g.*, Uruguay) or the Reference Case (*e.g.*, France) show high renewable energy shares, and the potential with REmap Options is more limited. These countries demonstrate good levels of ambition in their energy planning. However, for many others government plans are not nearly ambitious enough and REmap shows significant extra potential (large green bars in graph). For example, countries including

Figure 22: Share of modern renewables in energy use of REmap countries, 2013-2030



The top five countries make up more than half of renewable energy use; the next five bring this to nearly two-thirds.

Note: Percentages indicate how much renewable energy each country consumes in 2030 if a doubling of the renewable energy share is achieved.

Based on IRENA estimates

the United States, India, Canada, and the United Arab Emirates have high levels of renewable resources which remain untapped; today and in existing plans until 2030.

For some countries, the renewable energy potential is likely to exist beyond what was identified in REmap, but more work is needed by policymakers and other stakeholders to identify options, especially in countries where fossil fuels play a large role in the economy. The transition for these countries in adopting renewables might take more time.

Countries where traditional use of bioenergy plays a large role show different dynamics. In sub-Saharan Africa (Ethiopia, Kenya and Nigeria are examples) and in countries such as Brazil and India, the share of renewables is actually expected to decrease in the Reference Case. Technology options in these countries mainly identify potential to substitute the remaining volumes of traditional use of bioenergy in the Reference Case with modern renewables. In Nigeria, for example, large volumes of bioenergy (including solid biofuels in industry), are used today, and the country expects its renewable energy share to shrink dramatically as industry switches to natural gas, according to the Reference Case. REmap Options include more modern bioenergy.

Additional modern energy access (light blue shading), which generally leads to electrification, are also important to achieve higher renewable energy shares.

To achieve a global doubling of the renewable energy share, energy efficiency (dark blue shading) plays a crucial role. Like with renewables, government plans vary in their ambitions. For most however, more can realistically be achieved by 2030. Finally, the "Doubling Options" were assessed at a country level (purple shading), to achieve the global doubling in the renewable energy share to 36% by 2030.

While each country has potential for additional renewables beyond their Reference Case, the top five countries in terms of total renewable energy use – China, the United States, India Brazil, and the Russian Federation – account for over half of the total global renewable energy use in 2030 with all REmap Options implemented. That means decisions in a few countries are critical for success of global renewable energy acceleration. Regions will also play an important role. The European Union for example as a whole can contribute to 14% of the total final renewable energy use in 2030 when all REmap Options implemented, as high as the contribution of the United States. The African continent as a whole would represent approximately 10% of the total, half of which are accounted for by the six countries that participate in REmap already (IRENA, 2015e).

REmap country reports have been published or are in preparation for six of the top 10 largest renewable energy using countries in 2030. As a platform for the sharing of ideas, REmap brings together country experts to help governments see their goals in context and fully appreciate their national potential.

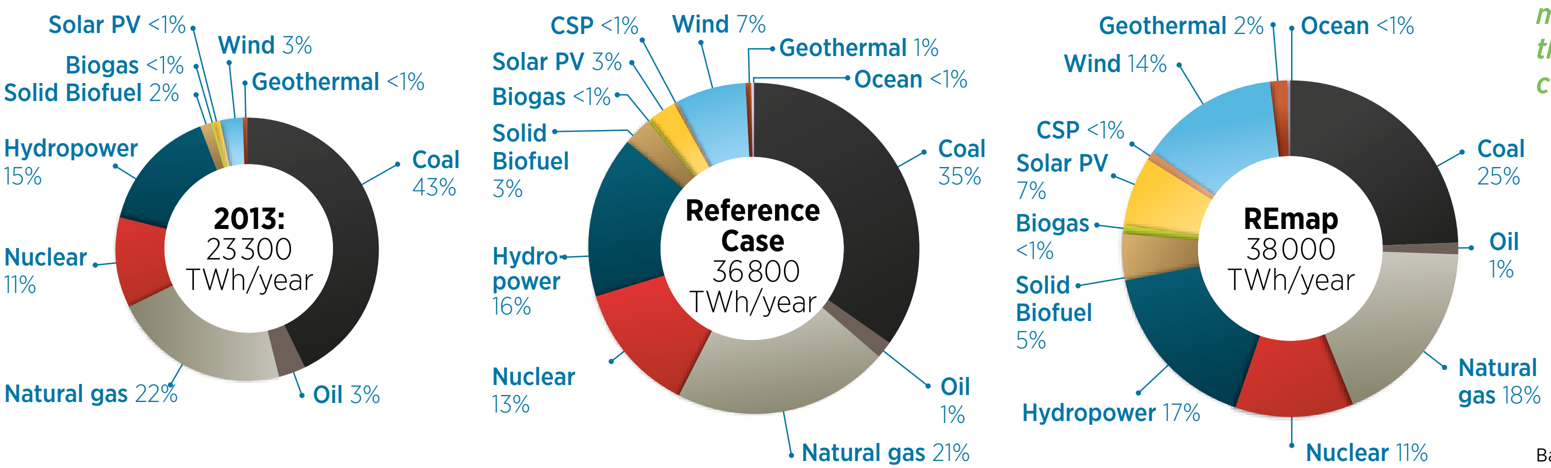
POWER GENERATION: WHERE RENEWABLES CAN GROW THE MOST

With the REmap Options, total installed renewable energy capacity could overtake non-renewable capacityand renewables would make up 45% of total power generation.

In the Reference Case, power generation globally would increase by about 60%, from 23 300 TWh in 2013 to nearly 37 000 TWh in 2030 (see Figure 23). The total renewable energy share in power generation sector worldwide is seen reaching 30% according to the Reference Case in 2030, up from 23% in 2014. Wind as a share of the total would jump from 3% to 7%), with solar PV expected to remain below 3%. The share of natural gas would remain the same and coal use be reduced, but combined these two inputs would still account for a majority of power generation by 2030 in the Reference Case.

With the REmap Options, additional electrification would further increase by about 1 100 TWh, growing generation of power to approximately 38 000 TWh, with generation based on renewables reaching 45% of the total worldwide. Wind power would be most prominent, going from 3% in 2014 to 14% in 2030. Solar PV with the REmap Options jumps from less than 1% in 2014 to almost 7% in 2030. The share of hydropower would grow more slowly because it already has significant market share as it starts from a higher base but would still account for the largest share of renewable power generated, at 17%. With REmap Options, coal's market share would plunge from 43% to 25% between 2014 and 2030, and whilst natural gas use would increase in absolute terms, its share in total generation would also shrink, from 22% to 18%.

Figure 23: Global power generation in 2013 and in 2030 (Reference Case and with REmap Options)

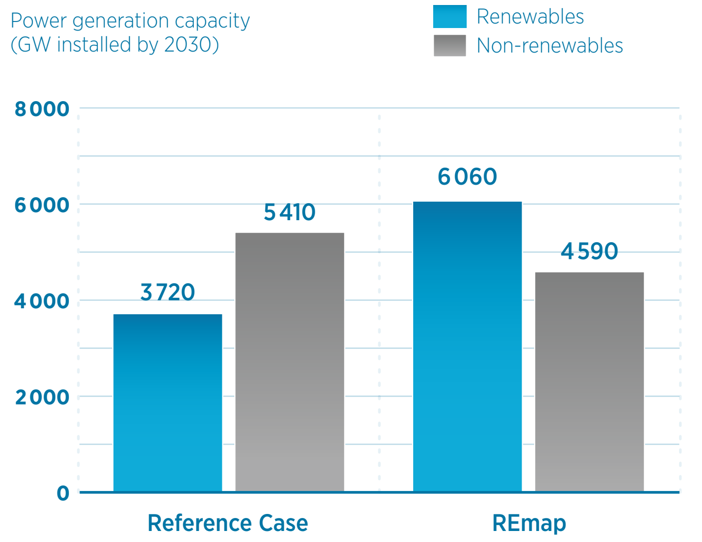


The share of coal in the total power generation mix shrinks to 25% with the REmap Options, compared to 43% today.

Based on IRENA estimates for Reference Case and REmap; 2013 based on IEA (2015a)

Total installed renewable power capacity overtakes non-renewable capacity with the REmap Options.

Figure 24: Renewable and non-renewable power generation capacity in 2030: Reference Case and with REmap Options



Based on IRENA estimates

While Figure 24 highlights that renewable power generation capacity overtakes fossil fuel and nuclear capacity, Figure 25 shows the projected installation per technology. With the REmap Options, installed wind power capacity would reach nearly 2 000 GW by 2030, making it the largest source. At 1 760 GW, solar PV would overtake hydropower in terms of installed capacity (although the higher capacity factor for hydropower explains its much larger share in terms of generation).

An important opportunity highlighted in the figure is that non-renewable capacity could be reduced by 820 GW with the REmap Options relative to the Reference Case by 2030. Coal could fall by about 570 GW; and natural gas by 150 GW. At present coal plants with a total capacity of more than 1 400 GW is currently planned or under consideration worldwide, so renewables would reduce the need for more than 40% of this new capacity. Decreases for new nuclear and oil capacity would be smaller.

Countries considering such new builds should asses the likelihood of these facilities becoming stranded assets. Coal plants in particular can remain in operation for decades. Any new plants built today are very likely to become liabilities by mid-century, considering their expected long service lives. One reason is that as more renewable capacity is built after 2030, the need for non-renewable capacity will continue to shrink, and where it is needed flexibility to raise or lower electricity production fast will be prized. As open-cycle gas turbines are more flexible than nuclear and coal, and CO_2 emissions from power generation are also much less (than coal), they may emerge as a preferred option.

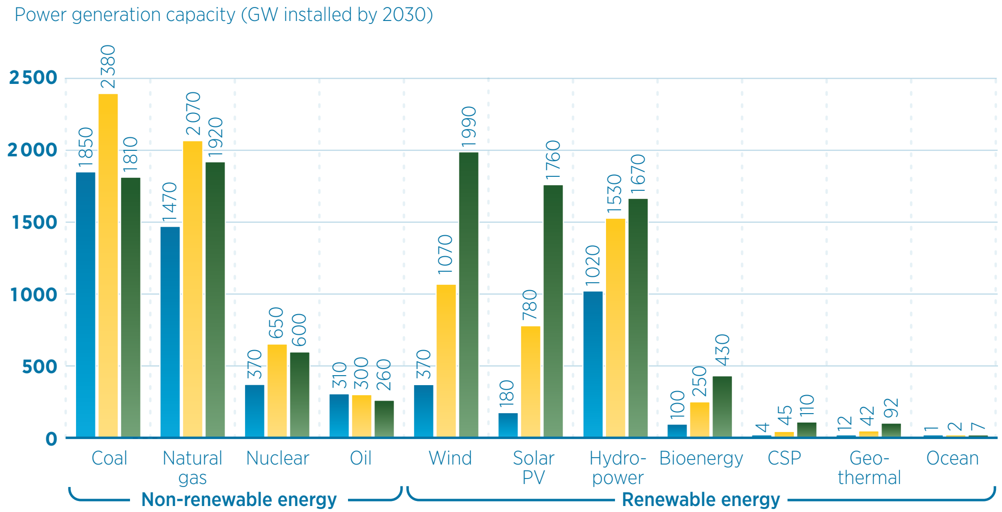
Annual installations rates with REmap Options

Though country plans are addressing the changing trends in renewable power generation, there could still be better recognition of the market trends on the way to closing the gap that remains with the REmap Options (Figure 26).

For wind power, about 63.7 GW was added in 2015 (WWEA, 2016), while the latest market report of the IEA projects about 46 GW/year of installations until 2020 (IEA, 2015c). The Reference Case estimates 44 GW/year until 2030, while the REmap Options highlight the need to roughly double to just over 100 GW/year.

For solar PV, the annual solar PV projection of 38 GW until 2030 according to the Reference Case is an underestimation of the market trends according to today's level of installations and what the IEA has been projecting at an average of 42 GW/year to 2020. With the

Figure 25: Installed capacity for renewable power generation, by technology, 2014-2030



Wind would be the largest source of power capacity with the REmap Options, just ahead of natural gas, followed by coal.

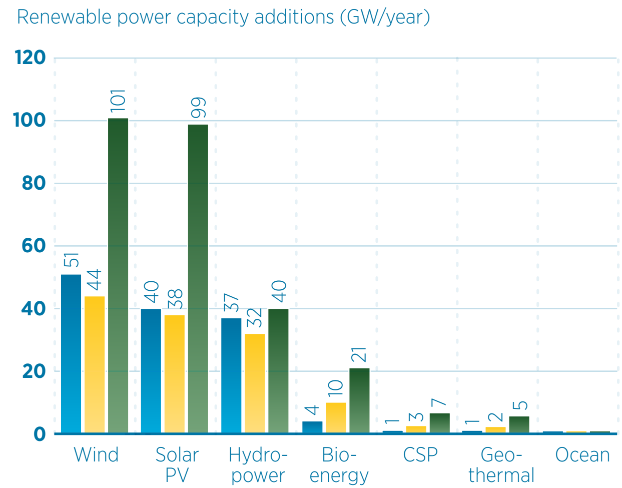
Based on IRENA estimates

REmap Options, a close to 100 GW/year level would be attained. This is double what has been installed in 2015 of 51 GW (PV Market Alliance, 2016).

For hydropower, the REmap Options require only a slight increase from historical levels to about 40 GW/year up to 2030. However, compared to the Reference Case (32 GW/year), as well as the IEA projections until 2020 (just 24 GW/year), this represents significant additional effort. In 2015, it was estimated that 33 GW of hydropower was installed (IHA, 2016).

For technologies such as ocean, concentrating solar power (CSP) and geothermal, the Reference Case for 2030 projects much faster deployment compared to historical developments. However, clearly more needs to be done to entice the market to invest in these

Figure 26: Renewable power capacity additions annually, 2014-2030



With the REmap Options, the annual wind and solar installations rates to 2030 can double compared to historical levels.

Based on IRENA estimates

technologies. CSP with storage, for example, could mitigate the challenges presented by VRE by reducing the need for backup capacity. With the REmap Options, these technologies with lower capacity today, require a jump in installation rates that is at least five-fold.

Total annual installation rates with the REmap Options are clearly higher than what has been achieved today. However, considering the historical trend in annual installation rates is likely that they will be closer to reality than what is estimated per the Reference Case. Governments thus need to update their national energy plans to reflect the increasing potential of renewables in their projections. While wind and solar PV markets are growing, capacity additions would need to at least double in comparison to recent years.

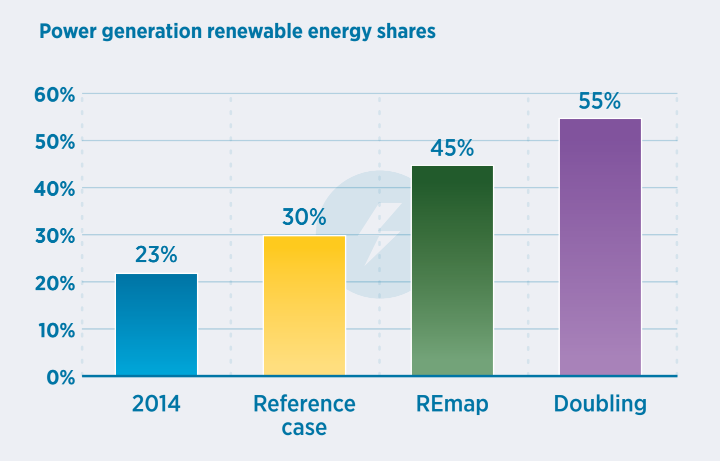
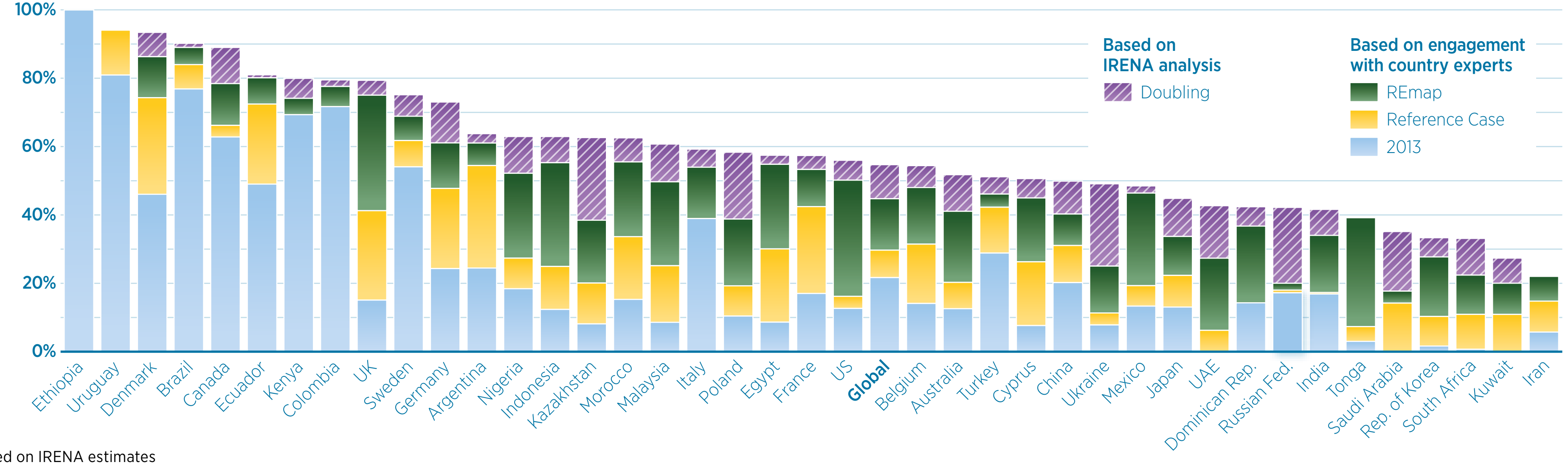


Figure 27: Renewable energy share in power generation for REmap countries, 2013-2030

Renewables can exceed 40% of total power generation in a large number of countries.



Based on IRENA estimates

Although several countries already operate power systems almost entirely free of fossil-fuels, the global average renewable energy share in the power sector was around 23% in 2014. With REmap Options, most countries would reach renewable energy shares above 40%. Doubling Options would push that level above 50%.

Brazil, Ethiopia, and Uruguay already have more than 75% renewable electricity and are close to their full potential in the Reference Case. Thanks to considerable geothermal resources, Kenya also has a large share of renewables in its power supply at present, although current government plans would see that share falling slightly as a result of fast-growing electricity demand. Several countries have ambitious government plans already, and the Reference Case is therefore considerably higher than the level in 2013 in Denmark, Ecuador, Egypt, Germany and Republic of Korea. Several others contribute only small growth to the Reference Case, such as Iran and Mexico. This is not necessarily because the countries are not considering renewables in their plans: in many cases total demand for electricity is growing as fast as the total growth in renewable power.

Nonetheless in all countries there is additional potential. In no country is the outcome with REmap Options lower than the Reference Case.

The power sector leads the way in terms of growing the share of modern renewable energy; with the REmap Options many countries could attain a renewable share in power generation exceeding 40%.

With the REmap Options, the renewable energy share increases in a number of countries significantly. For example, the United States has a conservative Reference Case despite diverse and abundant renewable energy resources and market developments that clearly outpace official projections. The REmap Options therefore assume that these resources can be tapped. Belgium, Egypt and Germany also have ambitious renewable energy scenarios that have not yet been adopted as official national plans; however, the potential of these scenarios reflected with the REmap Options are added to their already ambitious Reference Cases.

Where the REmap Options indicate only modest increases beyond the Reference Case, the reason is not necessarily a lack of potential for renewable energy. Instead, often more work is needed to identify options. This is typically the case in countries where modern renewable energy has played an insignificant role in the energy mix.

In contrast, the United Arab Emirates has similar resource availability, and the country's increasing focus on renewables and sustainability issues has led to higher expectations for renewable energy deployment beyond the Reference Case. In countries where the Reference Case already takes the renewable energy share to high levels, such as Brazil and Sweden, the additional renewable energy potential is rather limited.

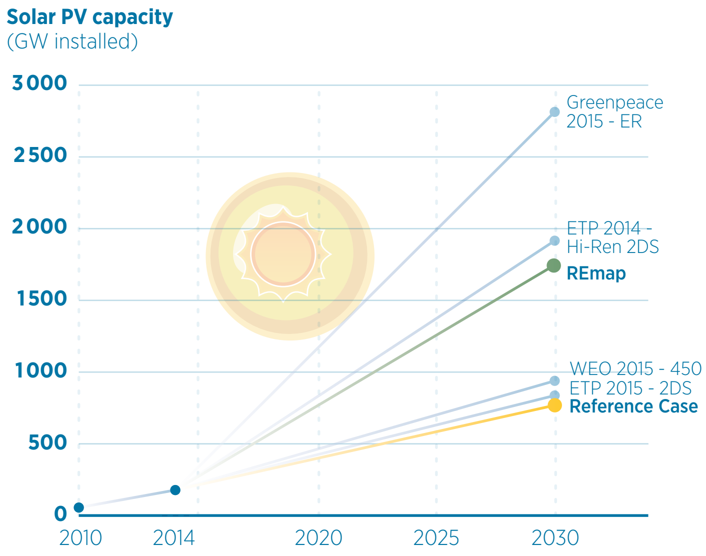
POWER GENERATION: A WIDE RANGE OF CAPACITY PROJECTIONS COULD SHAPE RENEWABLE ENERGY POLICY-MAKING

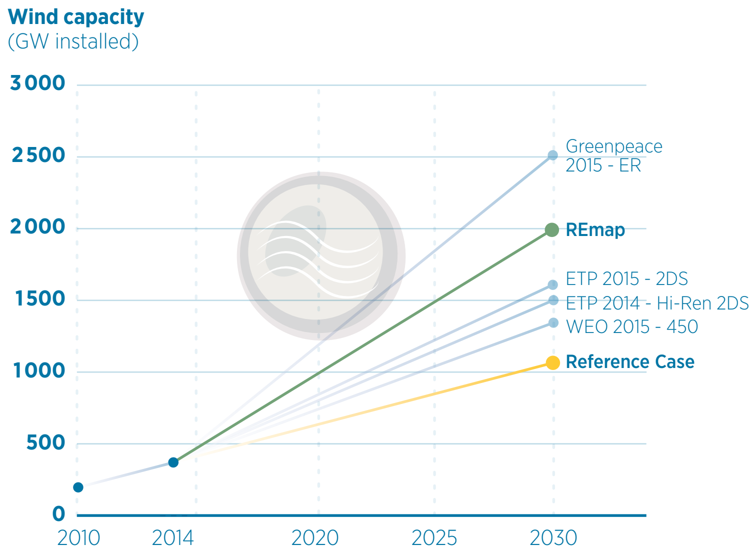
IRENA's REmap adds an important data point to projections available from other studies allowing for renewable energy policy-making based on a real-world outlook building on country level expertise.

Global energy scenarios, and roadmaps vary depending on the outlooks as well as the methodology and assumptions of the organisations that publish them. For renewables, some of the most referenced ones come from the IEA, in its World Energy Outlook (IEA, 2015d, 2014) and Energy Technology Perspectives (ETP) (IEA, 2015d). Greenpeace's Energy [R]evolution (Greenpeace, 2015) is another popular source. As in REmap, detailed projections of installed renewable energy capacity for 2030 are available from these reports. Typically, there is a business-as-usual scenario, like the Reference Case here, and one or more other scenarios based on varied assumptions. Figure 28 compares the Reference Case and REmap estimates for solar PV and wind power capacity with the ambitious climate and low-carbon technology scenario projections from these reports.

Figure 28: Solar and wind capacity projections according to different scenario analyses, 2010-2030

REmap solar potential estimates exceed the IEA WEO estimates by a factor two and by 30% for wind.



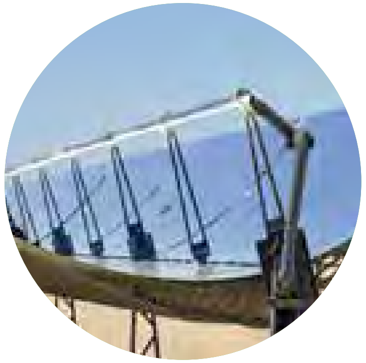


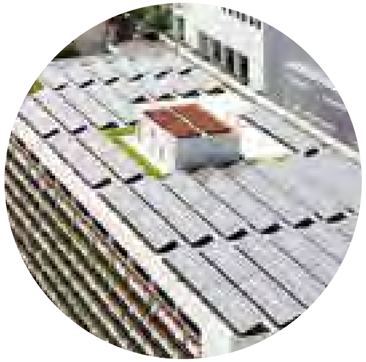
Based on IRENA estimates and IEA (2015b, 2015d, 2014) Greenpeace (2015)

For solar PV, a wide range of outcomes for 2030 are observed. Greenpeace shows the requirement for a continuation of exponential growth rates to achieve its 100% share of renewables in power by 2050 (Greenpeace, 2015), while the IEA (in ETP 2DS and WEO) expects a more linear increase (IEA, 2015b; IEA, 2015d). Implementing all REmap Options and following IEA's ETP Hi-Ren 2DS scenario, in comparison, results in expectations somewhere in the middle (IEA, 2014). While Greenpeace specifically aims for 100% renewable power by 2050 and therefore a very sharp increase in installations, the REmap Options estimate place a higher value on what IRENA considers to be realistic annual installation rates in countries, and does so by collaborating with country experts. The projections from the IEA WEO seem conservative in comparison, displaying a view of the world more in line with current government plans as reflected in the Reference Case. For wind power the story is similar, however, the maturity of the technology explains why the estimated deployment figures by 2030 are less spread out than for solar PV. Greenpeace assumes the highest level of wind power, at about 2 500 GW, whereas with REmap Options this figure would be closer to 2 000 GW. The IEA WEO and ETP projections are around 1 500 GW, while the Reference Case in this report is significantly lower at 1 000 GW by 2030.

As many scenarios for renewables (in particular for solar PV) have historically underestimated their potential, a wide range and better renewable energy projections are needed to improve policy-making and business planning. Low scenarios might become self-fulfilling prophecies: if growth of a certain technology is projected to be low then fewer businesses and banks are willing to invest and policy makers are less likely to include the technology in the development of energy plans.

The REmap findings add to projections presented in this section in several important ways. To begin with, REmap is a transparent assessment built on collaboration with country experts. The result is an analysis that includes real-world factors hard for computer models to capture. By doing so, REmap adds an important data point to the range of projections used for renewable energy policy-making.





INDUSTRY: THE MOST OVERLOOKED SECTOR

Few countries fully recognise their renewable energy potential in national plans.

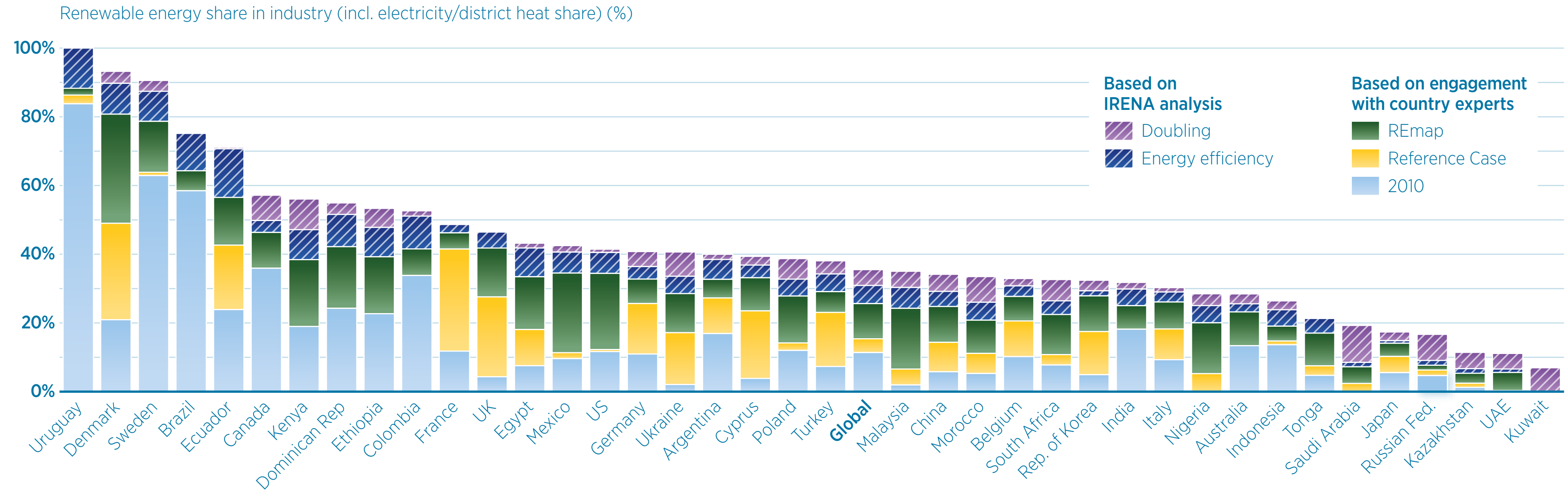
Few countries take into account for the potential of renewables in industry. While bioenergy is the main alternative to fossil fuels for process-heat generation, renewables sourced on-site and grid electricity consumption will be equally important to raise the sector's renewable energy use.

In the Reference Case, renewables will make only small progress in industry, rising from a share of 11% in 2010 to 15% in 2030. With the REmap Options it would increase to 26%, including process heat from direct uses of renewable energy and consumption of electricity from renewables (both on-site generation and purchases from grids).

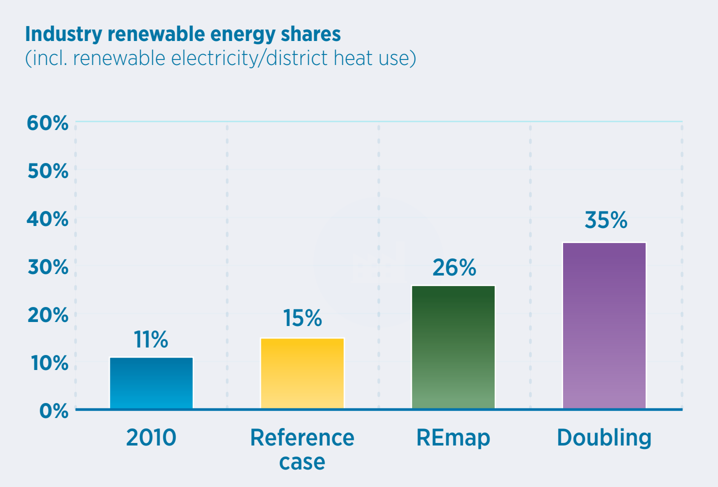
The Doubling Options add more electrification (mainly through heat pumps), relocating industry to renewables-rich areas, and more optimal use of bioenergy. These additional moves would increase the share of renewable energy in industry to 35%.

While renewables on average are only modestly used in this sector, there are exceptions. In countries like Brazil and Uruguay bagasse and black liquor are by-products of industrial processes put to use effectively. In most of sub-Saharan Africa, industrial sites have bioenergy inputs (tea, coffee, cocoa, textiles, etc), partly from renewable waste streams and partly from wood fuel, although

Figure 29: Renewable energy share in industrial energy use in REmap countries, 2010-2030



Based on IRENA estimates



Industry is the most overlooked sector for renewable energy integration; the Reference Case increases the share only marginally to 15% by 2030. The REmap Options identify a range of technology options to further grow this to 26% in the same year.

bioenergy is often used inefficiently and not sourced sustainably (though this report assumes all such consumption as modern).

Businesses tend to price a combination of low cost and secure supply in sourcing energy with the aim of maintaining their competitiveness in markets. Diversifying supply to include more renewables can help to meet both of these aims. Incentives are also playing a role. In regions such as Latin America, "green certifications" allow companies to access premium markets where their products can be sold at higher prices (IRENA, 2016b forthcoming).

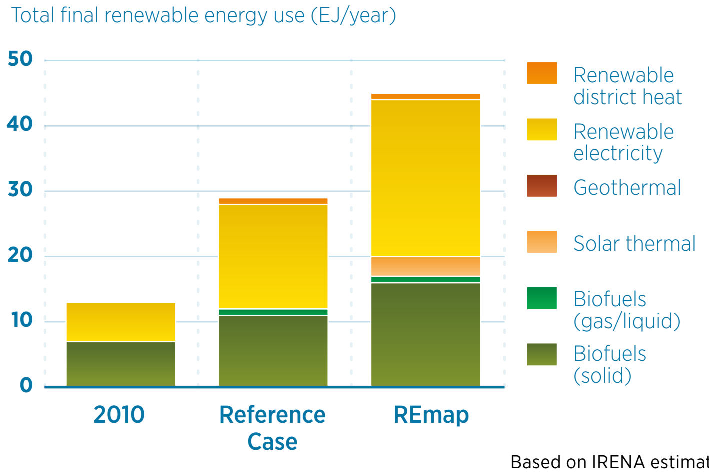
However despite significant potential and a commercial argument in favour of them, the Reference Case considers renewables deployment only to a limited extent. In some situations, use is expected to fall in the Reference Case. Modern bioenergy uses, however, will remain important to increase the share of renewable energy in industry given its potential to supply heat for heat varying levels of process heat temperature.

Renewables can be used to generate process heat in a number of ways. Estimates of total potential show that up to one-third of the sector's total energy demand can be realistically sourced from renewables (IRENA, 2014c). The technologies suitable for renewable energy integration in production plants depend on the temperature needed for process heat.

Energy-intensive sectors such as iron and steel, aluminium, non-metallic minerals and some chemicals production require high-temperature process heat. The energy demand in these processes represents about half of total industrial energy use. Bioenergy presents the primary solution here. There are other renewable energy options such as hydrogen, biocoke, and others for processes that need high-temperature heat. However, due to their limited commercialisation, more R&D is required in these areas.

In industry, renewable electricity is as important as renewable heat.

Figure 30: Total final renewable energy use in industry, 2010-2030



Based on IRENA estimates

The remainder of demand comes from low- and medium-temperature process heat (below 400 °C) in less energy-intensive sectors, such as food production. Bioenergy can be used, but before that other renewable energy technologies, such as solar thermal solutions can be employed (including concentrated solar thermal for rocess heat temperatures up to 250 °C). Low-temperature heat can also be provided by geothermal and heat pumps. While the geothermal market in the power sector is expected to grow at about 1 GW of new capacity annually to more than 5 GW per year by 2030, the role of geothermal in the heat sector should not be overlooked: low-enthalpy resources are quite relevant for heating in the built environment (buildings, industry, district heat (DH) and greenhouses).

In line with its versatility in application, bioenergy is already today the main source of renewable energy for process heat (Figure 30). With the REmap Options its use would nearly double, mainly through increased CHP capacity on-site at industrial plants. More significant is the growth estimated for solar thermal and geothermal heat, which are only used marginally today.

In total, with REmap Options, renewables use would reach 20 EJ for process heat generation. In addition, electrification and district heating in industry are increasing, as are shares of renewable energy for power and district heat generation. This adds another 25 EJ of renewable energy energy in industry. Total final renewables use is thus estimated at 45 EJ, representing 26% of the sector's TFEC in 2030.

BUILDINGS: WHERE THE POTENTIAL IS THE GREATEST

Buildings, including both residential and commercial, can reach significantly higher renewable energy shares with the REmap Options in 2030 compared to industry and transport.

Today, buildings account for one third of global TFEC. Within that share, about 33% is used for heating spaces, 30% for cooking and 20% for heating water. Demand for cooling is small at only 2%, but this share is expected to at least triple to 6% by 2030.

Renewables already make up a large share of energy demand in buildings, at about 35% in 2010. Renewable energy demand today is met by traditional uses of bioenergy for cooking and heating, which account for about 60% of the renewables share. Traditional bioenergy is used for cooking and partly for water heating in Africa and parts of Latin America and Asia. However, significant hazards stem from this practice, such as indoor air pollution, which is hugely detrimental to human health. When its uses are excluded, modern renewable energy share in buildings is much lower, at 13%.

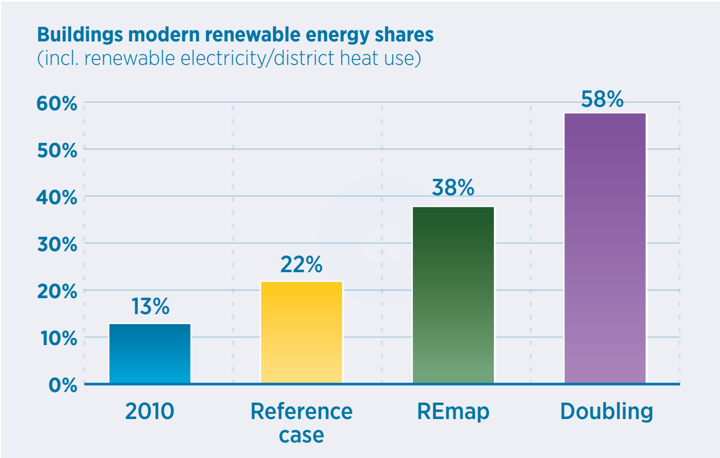
In the Reference Case, some traditional use of bioenergy declines, and the share of modern renewables increases from 13% in 2010 to 22% by 2030. The total renewable energy share is then estimated as 36% when including the remaining volumes of traditional use of bioenergy. This is similar to the level in 2010, but the technology mix is different. With the REmap Options, traditional uses of bioenergy for cooking are substituted with modern renewable energy forms and further uptake of modern renewables in other applications result in a 38% for renewables in the sector's total energy use, higher than in either industry or transport.

In both the Reference Case and with the REmap Options, the share of renewable energy in buildings across countries is expected in a wide range (Figure 31). The share of modern renewables in buildings will range from less than 10% to more than 90% if all REmap Options were to be implemented.

Most countries already plan for a substantial uptake in renewable energy use in buildings. In Germany, for example, the Reference Case alone would increase the renewable energy share nearly threefold. Nonetheless, REmap findings show potential for an additional increase of 10 percentage points in Germany. Likewise, Denmark would reach more than 80% renewables with the REmap Options, more than double that of the Reference Case. In buildings, countries from varied regions are estimated to have high renewable energy shares, such as 80% in Kenya and 51% in France – a considerable increase compared to the limited use of modern renewable energy in 2010.

In other countries however, the historic share and identified potential are limited, and for some countries, the Reference Case actually estimates a drop in the total renewable energy share by 2030, due to the reduced use of traditional bioenergy. However most industrialised countries are projecting modest increases in the share of renewables in buildings, and the REmap Options show that potential exists for a doubling of renewable energy share of this type of energy use by 2030. However this can only be achieved if policies and building codes change to enable this level of renewable energy uptake.

The world had 40 EJ of renewable use in 2010 in buildings: 25 EJ from solid biofuels (wood fuel) used in traditional ways for cooking and heating and 15 EJ from modern renewables. The total amount



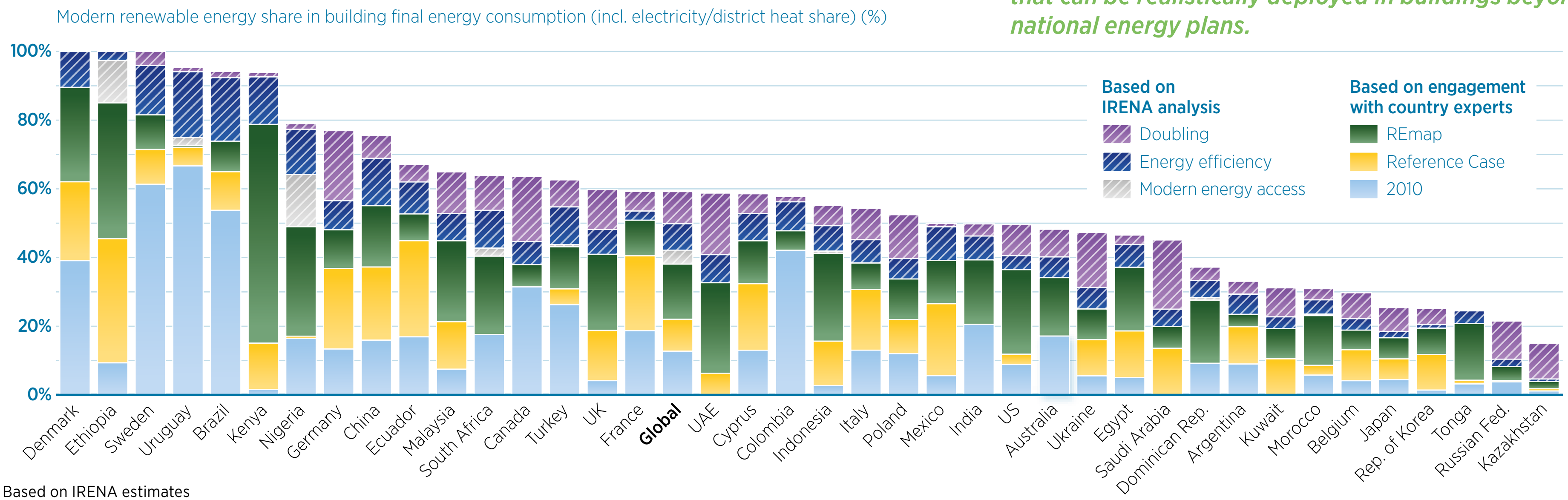
of modern renewables use will grow more than threefold to exceed 50 EJ by 2030 with the REmap Options. In total, renewables would represent 38% of total buildings, TFEC of 132 EJ in 2030.

With REmap Options, bioenergy will remain the main source of renewables in the sector. Total bioenergy demand will be split into 18 EJ of solid biofuels and 3 EJ of biogas and liquid biofuels. The shares of biogas and liquid biofuels (such as ethanol gel for cooking) can reach much higher levels for cooking. Solar thermal would grow more than fivefold between 2010 and 2030 to reach 7 EJ.

Energy policies are more often focused on electricity, whereas heat receives limited attention from policy makers (IRENAm, 2015; REN21, 2015): only about 50 countries have renewable-heat policies

Figure 31: Share of modern renewable energy in building energy use in REmap countries, 2013-2030

There is a significant potential of renewables that can be realistically deployed in buildings beyond national energy plans.



Based on IRENA estimates

in place, whereas more than 120 have established them for electricity, and these address capital grants, rebates feed-in tariffs, tax reductions and exemptions, soft loans, guarantees and carbon taxes.

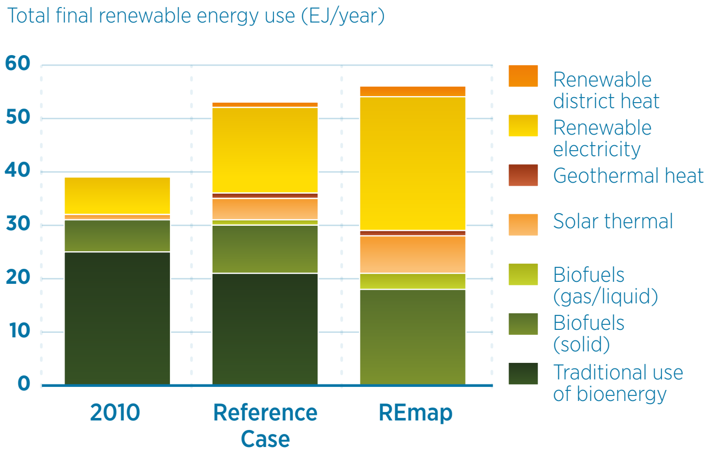
Various types of renewables and electricity-based heating-and-cooling technologies can meet demand in buildings. The opportunities and costs for producing renewable heat are location-specific and depend on the quantity and quality of the resource. Options such as bioenergy and solar heating can be cost-competitive with other energy sources under the right conditions.

There are also considerable differences across building types and urban versus rural settings. These differences impact the potential for renewables uptake. In Germany, for example, a new building requires about 10% of the total energy demand of an old building that has not been renovated. Renovating to improve energy efficiency is typically the first choice in the sector. In countries where energy demand is growing slowly renovation rates are also slower, which limits the opportunity to implement efficiency measures and renewable energy technologies. In developing countries the opportunity is larger because of the need for new buildings, which can be designed to be more efficient. Urbanisation rates are also increasing in developing countries, such as in countries of Africa. From 2010 to 2030 the world's urban population is expected to increase from about 3.5 billion to 5 billion (UN, n.d.). Although it is less prominent compared to decentralised heating/cooling systems in buildings, renewables based district heating/cooling offers an important opportunity, and therefore must be at the core of urban planning.

Buildings present the greatest potential for increasing the use of renewable energy as a result of the expansion of modern biomass use and more electricity use, which is increasingly supplied with power generated from renewables.

The district heating sector and decentralised heating in buildings offer also an important potential to accommodate higher shares of VRE for power generation. For example, district heating provides large-scale thermal storage, which is cheaper and more effective than building-level storage. District heating networks are needed for large CHP units, which can be an important source of balancing power in the electricity grid. Bioenergy can be used for the combined generation of district heating and power.

Figure 32: Global renewable energy share in buildings (including renewable electricity and district heat)



Renewable energy use in the building sector will increase almost 50% in REmap.

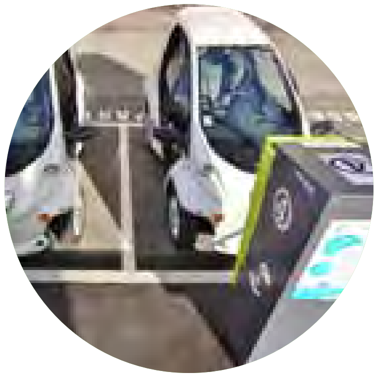
Based on IRENA estimates

TRANSPORT: A SMALL SHARE NOW, BUT SIZABLE POTENTIAL FOR RENEWABLE SOLUTIONS

Transport could see five-fold growth through an increased uptake of liquid biofuels and rapid growth in electricity-based mobility.

Renewables represented about 3% of TFEC in transport in 2010. About 2.8% came from liquid biofuels and 0.2% from renewable energy through electric mobility. In the Reference Case, that total would rise to 5%, and with the REmap Options to 11%. 10% would come from liquid biofuels (conventional and advanced liquid biofuels, biogas and renewables-based hydrogen) and 1% from EVs.

The renewable energy breakdown in 2030 shows considerable differences across countries. In countries where electrified railways and public transportation are common, such as in some European countries, electric mobility accounts for the largest share of renewables. In the United States, Brazil and in some European countries conventional biogasoline* (incl. ethanol) dominates the mix. With the REmap Options, Sweden, Ethiopia, and Brazil would have the highest share of renewables overall, at more than 30%, with Denmark, Germany, and France and Indonesia all between 20% and 25%.



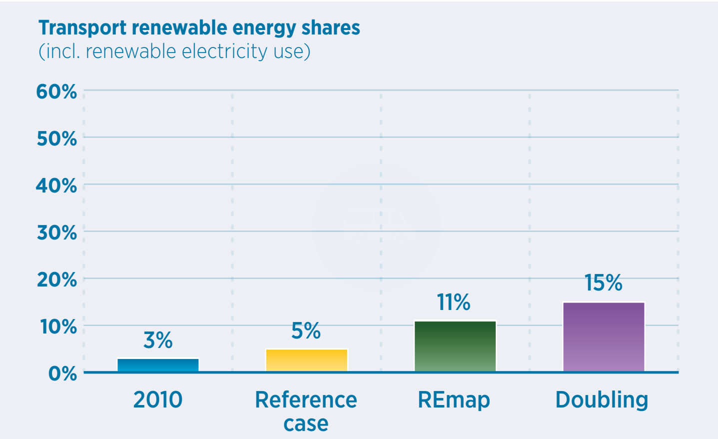
Liquid biofuels must continue to play an important role, particularly as other low-carbon options are limited in their ability to meet demand for long-haul and heavy transport, aviation and shipping. Liquid biofuels are also a way to diversify energy sources for importers. Brazil is expected to continue to focus on liquid biofuels and further develop deployment potential. Both Denmark and Sweden have great potential for advanced liquid biofuels and biodiesel (including freight) beyond their Reference Cases. In addition to this potential, a large deployment of EVs is expected. All countries have a significant deployment potential simply because the base level is very low.

In the Reference Case, global transport energy demand would reaches 130 EJ in 2030, compared with 92 EJ in 2010, an increase of about 40%. Total demand for electricity in transport would reach 3 EJ in the Reference Case, just under a doubling over today's level.

With the REmap Options the sector could significantly increase its share of electricity use to about 5.4 EJ, more than 40% of which would be generated by renewables. Additionally, liquid biofuel use (in energy terms) would more than quadruple, to about 12 EJ (about 500 billion litres). Biomethane demand would grow by about 10 times to 50 PJ (or 1.3 billion m^3). Total liquid biofuel demand would reach roughly four times the level in 2014 (128 billion litres). Based on an assumption that the average liquid biofuel plant produces around 200 million litres per year, there is a need to build 40 advanced liquid biofuel plants in the next 15 years and more than 75 for conventional liquid biofuels. Conventional liquid biofuels continue to account for a larger share of total production because of the relatively higher production costs of advanced liquid biofuels, and their limited deployment to date.

*) Biogasoline refers to liquid biofuels used in internal combustion engines.

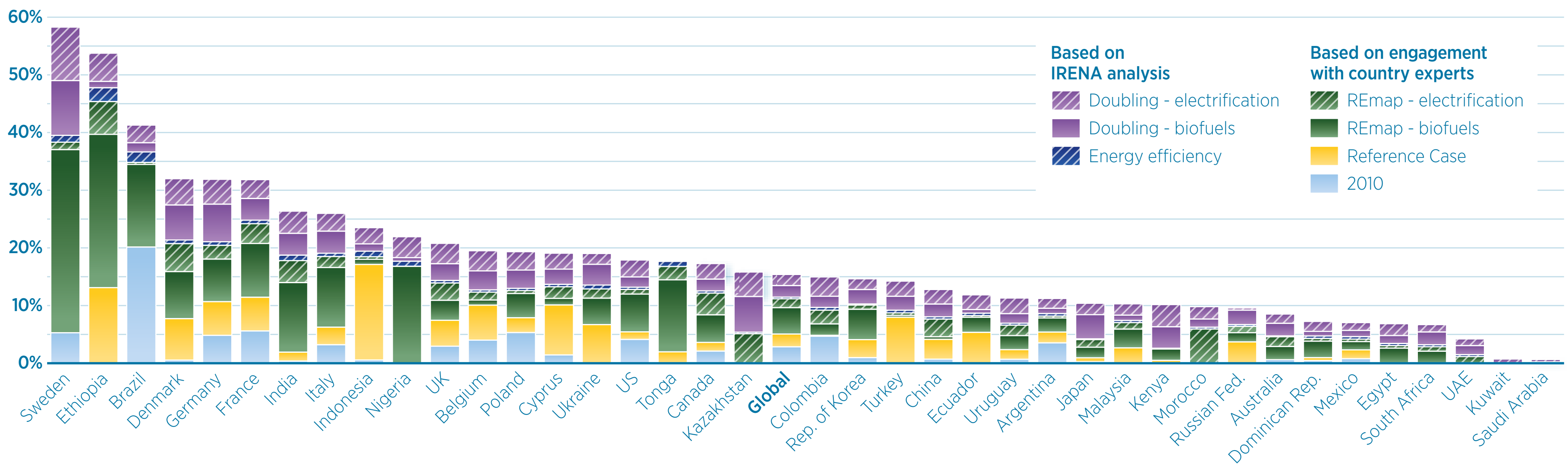
Transport is the sector with the smallest share of renewables; this could grow five-fold however if opportunities in biofuels and electric mobility are captured.



Progress with renewables has been mixed in recent years for transport. Liquid biofuels such as biogasoline, biodiesel, and bio jet kerosene offer a readily available alternative to conventional gasoline and diesel, and their production reached approximately 128 billion litres per year in 2014. About 75% of this total comes from biogasoline, which is equivalent to about 4.5% of total demand for all types of liquid transport fuels (3.5% in terms of energy content). Advanced liquid biofuels from lignocellulosic bioenergy, agricultural residues and waste still have low production volumes, at about 1 billion litres in 2014, or less than 1% of total liquid biofuel production (IRENA, 2016c forthcoming). Projections of planned capacities foresee a tripling of production; however the investment flow has slowed recently.

Figure 33: Share of renewable energy in transport energy use in REmap countries, 2010-2030

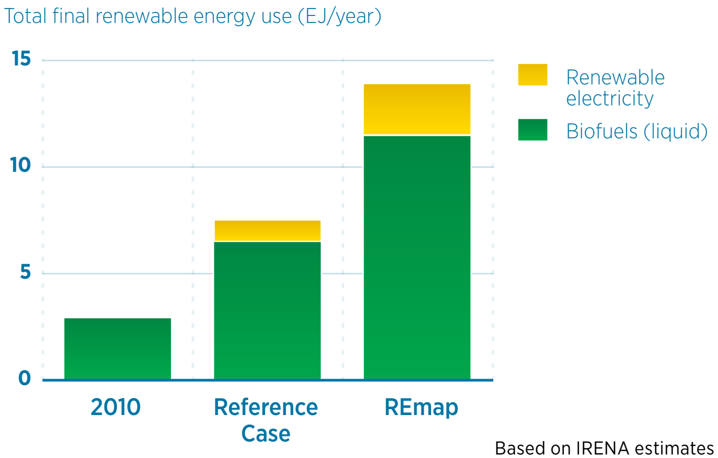
More than half of all REmap countries can raise the renewable energy share in transport to above 10%.



Based on IRENA estimates

Liquid biofuels account for 85% of the renewable energy use in transport, which represents a fourfold increase in their use by 2030 from 2014.

Figure 34: Total final renewable energy use in transport, 2010-2030



Based on IRENA estimates

In China, the government offers various incentives for the deployment of alternative-energy vehicles and has set a target of 5 million alternative energy vehicles by 2020. France, Germany, Norway, the Netherlands and the United States also have electric mobility targets, but overall the growth in EVs has been slow. According to the REmap findings, up to 10% of the total global vehicle fleet will be either EVs or plug-in hybrids by 2030 if all REmap Options identified in the 40 countries are implemented. This would constitute 160 million vehicles in the total vehicle stock in 2030. Realizing this potential would require yearly sales to reach 10 million, up from just around 0.5 million last year (IRENA, 2015f). In addition, electric two and three wheelers, used largely in Asia, would number 900 million, up from 500 million expected in the Reference Case.

BIOENERGY FOR POWER, HEAT, COOKING AND TRANSPORT

Bioenergy will continue to be the largest source of renewable energy in 2030 with all REmap Options and Doubling Options implemented, accounting for half of the total global renewable energy use. Technology and policy challenges to realising this potential are significant.

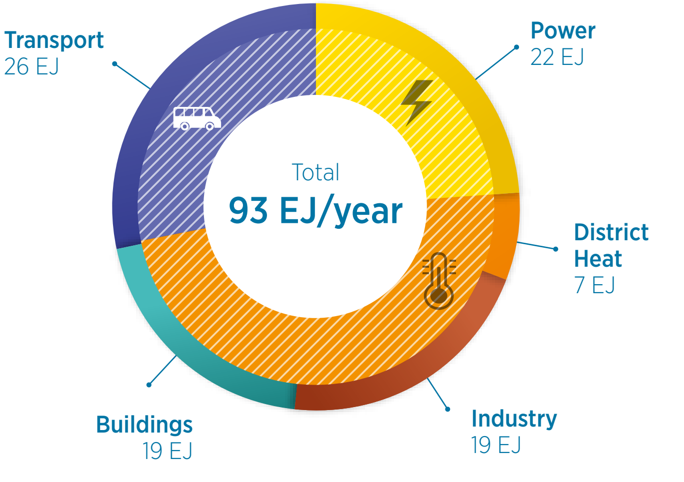
Bioenergy will clearly play a key role in realising the potential identified with the REmap Options and in keeping to a 2 °C global temperature-rise pathway. By 2030, with the implementation of all REmap Options, bioenergy can amount to about half of total global renewable energy use. Bioenergy is a versatile resource that can be converted into final energy for heat, power and transport fuels. It can also can be stored in the form of solid, liquid or gaseous fuels.

With the REmap Options, total primary bioenergy demand would increase to 93 EJ in 2030. Current demand in primary energy terms is about 53 EJ. Total supply thus needs to increase by approximately 70% in the next 15 years. Demand comes from all sectors and for all energy forms. This is an important value added created by bioenergy compared to other renewable energy sources. About half of the total is for heating in buildings and industry, while the remainder is split between transport and power generation.

Different types of bioenergy feedstocks will be required for various applications. In transport, a total of 500 billion litres liquid biofuel will be required annually. Given the recent investment trends, meeting this demand will be a challenge, in particular scaling up of cellulosic biogasoline production to commercial levels, which is today limited.

The challenge in the power sector is similar and also significant, requiring 21 GW of new capacity annually to meet total renewable energy generation with the REmap Options. Current market trends show this would require a significant increase, as additions are

Figure 35: Primary bioenergy supply needed globally with the Doubling Options, by sector and application, 2030



Each sector accounts for approximately a quarter of total primary bioenergy use.

Note: transport final consumption has been converted to primary energy with a 50% conversion efficiency.

Based on IRENA estimates

expected to increase only modestly from below 5 GW/year until the end of this decade (IEA, 2015c). About 40% of the total bioenergy use for power generation is assumed to be coupled with industrial process heat generation in CHP.

Challenges are not limited to demand only, but it also has a supply and trade side, in view of the competing uses of this limited resource across different countries and sectors. A detailed discussion of supply, trade, cost and sustainability aspects related to bioenergy is provided in Chapter 3.

Table 1: Global bioenergy market growth, 2014-2030

	2014	2030	Annual growth	
	(EJ/year)	(EJ/year)	(%/year)	(EJ/year)
Buildings, traditional	27	0	0	-1.7
Buildings, modern	8	19	5.6	0.7
Industry	8	19	5.6	0.7
Transport	5	26	10.9	1.3
Power and district heating	5	29	11.6	1.5
Total	**53**	**93**	**3.6**	**2.6**

Based on IRENA estimates



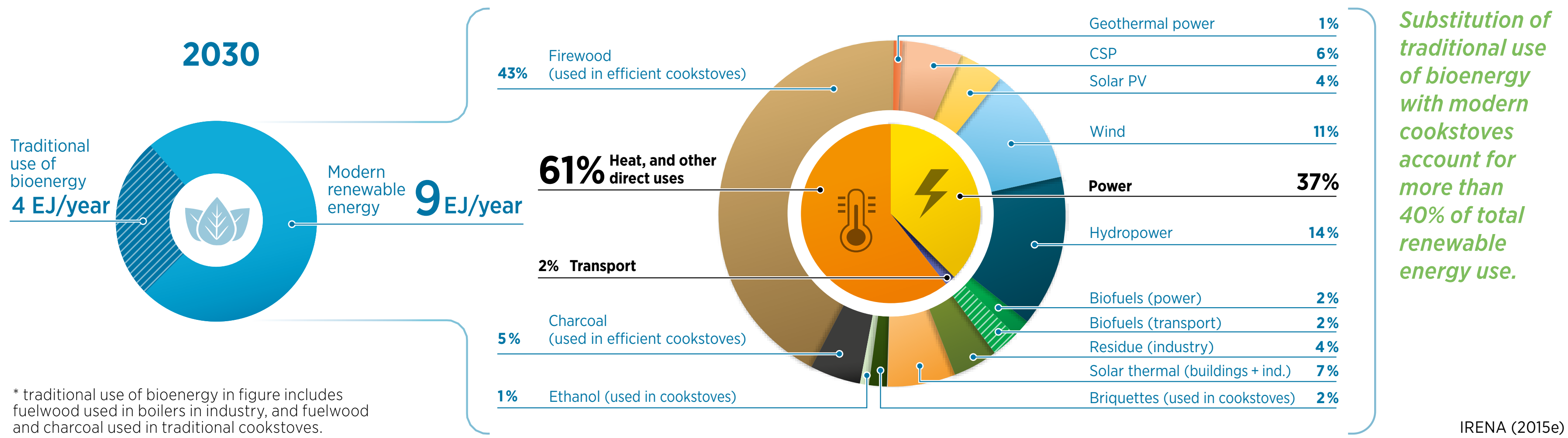
REGIONAL ROADMAPS: EXPANDING COVERAGE BEYOND COUNTRY REPORTS

As part of the global REmap exercise IRENA is producing region-specific roadmaps to complement the core country-level work undertaken within REmap. The most recent of these regional roadmaps is "Africa 2030" (IRENA 2015e) which was released at the South Africa International Renewable Energy Conference (SAIREC) in October 2015.

Africa 2030 illuminates a viable path to prosperity through renewable energy development. It is built on a country-by-country assessment of supply, demand, renewable energy potential and technology prospects. It highlights possible roles for various renewable energy technologies across the five regions of Africa until 2030. The analysis identified modern renewable technology options that would meet 22% of Africa's TFEC by 2030, a more than four-fold increase from 5% in 2013.

Four key modern renewable energy technologies with highest deployment potential for Africa are modern bioenergy for cooking, hydropower, wind, and solar power. The power sector represents a significant opportunity for transformation, as the share of renewables in the generation mix could grow to 50% by 2030 in REmap. This transformation will require on average USD 70 billion per year of investment between 2015 and 2030. Within that total, about USD 45 billion would be for generation capacity. The balance of USD 25 billion would be for transmission and distribution infrastructure.

Figure 36: Modern renewable energy use in Africa with the REmap Options, 2030



IRENA (2015e)

SECTOR-LEVEL COSTS FOR DOUBLING THE RENEWABLE ENERGY SHARE BY 2030

The overall cost of increasing the renewable energy share to 30% in the global energy mix is just USD 1 cent per kilowatt-hour. Achieving this level with low costs requires focus on how they differ based on technology, sector and country.

Costs of substituting non-renewable energy technologies with the REmap Options

For the 40 participating countries a total of around 600 REmap Options have been identified. When the substitution cost of each option is aggregated, the average weighted cost viewed from the government perspective is estimated at USD 2.2 per GJ of final renewable energy, or equivalent to around USD 1 cent per kWh. This translates to a total system cost in 2030 of USD 105 billion per year, equivalent to around 0.1% of global GDP. However, when viewed from the business perspective, the substitution cost is even lower, at USD 1 per GJ. The difference can be explained largely by how fuels are taxed.

Despite significant technology learning that has and will continue to result in lower capital costs, some of the renewable energy technologies will still be more expensive than their non-renewable counterparts by 2030. Measures to incentivise businesses to invest in these technologies will be required. The REmap Options would require investment support of USD 230 billion per year by 2030. Subsidies for renewable energy in 2014 amounted to USD 135 billion per year (IEA, 2015b). The value estimated in this report for 2030 depends on the technology cost, performance, discount rate and energy price assumptions of this report. However, a comparison with fossil-fuel subsidies provides perspective; the investment support is less than half of the estimated USD 493 billion spent on fossil-fuel subsidies in 2014 (IEA, 2015b). Investment support needs are higher than the total system costs because latter is a sum of the costs of all technologies that are both more expensive and save money compared to fossil fuels. In comparison, investment support refers to only those technologies that are more expensive.

Costs differ by sector due to technology choice and the substituted fossil fuel

Average substitution costs vary by sector, depending on the mix of renewable energy technologies and non-renewables substituted. Understanding the attractiveness of renewables from a sector perspective reveals where REmap Options are particularly competitive.

Table 2 shows the weighted substitution cost of renewable energy technologies in each sector, aggregated on a global level. Generally, industry has the lowest level of taxation on fossil fuels (or purchases at a subsidised rate). That means the substitution cost is higher from the business perspective than the government perspective. Buildings represent the most competitive application, largely due to the substitution of traditional use of bioenergy, but also because solar thermal heating is affordable.

There are technologies with negative and positive substitution costs in transport. Costs associated with substitution in transport are almost entirely driven by oil and biofuel prices. The recent price drops for crude oil has lowered the projected oil price in the REmap analysis in 2030, from USD 120 to 105 USD per barrel (IEA, 2015b), for example. The production costs of biofuels are also expected to decrease. From the business perspective, policy support for liquid biofuels has made them cost-competitive with petrol and diesel.

Table 2: Global substitution costs of REmap Options by sector, 2030

	Government perspective (USD/GJ)	Business perspective (USD/GJ)
Industry	3.3	3.9
Buildings	-3.0	-3.5
Transport	7.4	-1.3
Power	1.2	2.1
District heating	5.8	6.1
Average of all sectors	**2.2**	**1.0**

Note: 1 megawatt-hour (MWh) equals 3.6 GJ

Based on IRENA estimates

Costs are expected to decline significantly for electric mobility by 2030, with the majority of technology options identified resulting in savings when the total cost of ownership is considered from the business perspective, even despite slightly higher vehicle costs compared to non-renewable alternatives. This is mainly because electric motors are much more efficient: 1 GJ of electricity moves a car the same distance as 2-4 GJ of gasoline (however if expressed in primary energy terms, efficiencies of both systems may be very similar to each other depending on the power generation fuel mix). However, the negative substitution cost of electric mobility has a lower overall effect on transport's average substitution cost, because of its lower anticipated renewable share in energy use compared with biofuels.

The REmap Options take the renewable share to 30% and require investment support of USD 230 billion per year in 2030; with the Doubling Options this would be 36% and USD 415 billion. This compares with USD 493 billion in support to fossil fuels in 2014.

The substitution costs in the district heating sector are high, due largely to the use of more expensive biofuel feedstocks.

In the power generation sector, technologies are close to cost-competitiveness. The substitution cost is USD 1.2/GJ and USD 2.1/GJ from the perspectives of government and business, respectively. In countries where coal is cheap, the costs of substitution are higher than these global averages. Estimates between countries also vary considerably based on resource availability and quality. Generally, solar PV, onshore wind and hydropower result in savings, while bioenergy generally leads to additional costs.

Storage needs associated with solar PV and wind will rise. Productivity from wind does not necessarily peak at any consistent time of day or night, and higher levels of it can be integrated without the need for storage. On the other hand, solar irradiance is more predictable than wind, but solar PV is generated for fewer than half of the day, and half of daily production comes around midday, depending on local conditions. A strategic combination of the two can help minimise storage needs. For countries with large demand for cooling, which peaks at the same time as solar irradiance, higher

shares of solar PV may be appropriate. CSP in particular offers added value to the system as it can continue to supply electricity in the night. As a rough estimate, IRENA calculates that grid integration costs could increase total energy system costs by between USD 30 billion and USD 130 billion.

There are important conclusions for technology and innovation policy from these cost estimates. The REmap Options identified for the buildings, which have to date received limited attention from policymakers, have a lower cost of substitution compared to the power sector. This finding depends on whether the investment decision is made for renovation in which case cost of substitution is much higher and is also influenced by the landlord/tenant problem or for new capacity. In the REmap Options, the choice was made to assess the cost for investments in new capacity which result in lower costs of substitution. Nevertheless, this suggests that to accelerate renewable energy uptake and innovation there is a need to utilise the cost-effective potential in buildings and extend policy support to industry, where large potential has been identified that could reduce costs.

Costs for reaching a doubling are higher

The REmap Options take the global renewable energy share to 30% by 2030 at a total cost of USD 105 billion per year, based on a substitution cost of USD 2.2/GJ. Deployment of the Doubling Options result in significantly higher costs than REmap Options. System costs increase from USD 105 billion per year in REmap to USD 290 billion with the Doubling Options. This is explained by the significantly higher substitution costs of the Doubling Options of USD 10/GJ. On average, the cost of all technology options implemented beyond the Reference Case is estimated at USD 4/GJ.

The substitution costs are highest for the early retirement of polluting power plants, aviation and shipping biofuels, modal shifts in transport and industry relocation. Heat pumps are generally affordable, however, in comparison with other Doubling Options. Implementing the Doubling Options would require investment support of USD 415 billion per year in 2030. This money should largely be spent on technological learning and to correct market distortions. However it is relevant to note that there is currently a similar volume of support for fossil fuels, and if policy frameworks are adjusted then support for renewables to make them cost-competitive would be smaller or wholly unnecessary. Although they are much more expensive, several countries, including Denmark and Germany, have already started implementing some of the changes included with the Doubling Options, for example through an increasing focus on sector coupling.

EXTERNALITIES REDUCED THROUGH IMPROVED ENVIRONMENT AND CLIMATE CHANGE MITIGATION

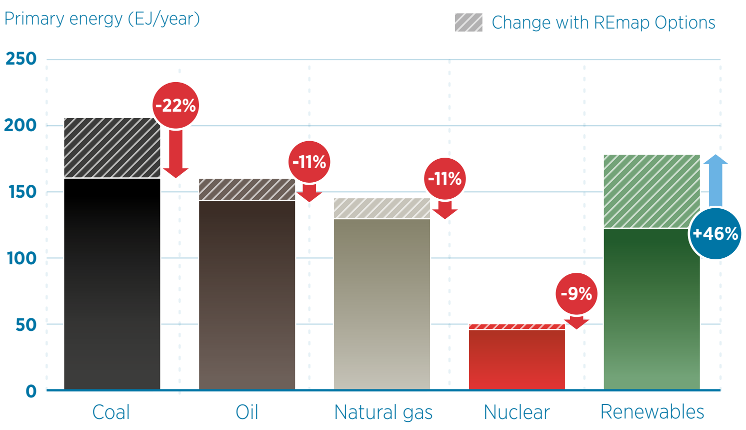
The REmap Options could result in USD 1.0 to 3.1 trillion in annual savings in 2030 from reducing externalities assessed in this analysis. If the savings related to the Doubling Options are included, the total increases to USD 1.2 to 4.2 trillion per year. Policymakers should design markets so that these external costs are priced into energy prices. This can further incentivise the transition to renewables.

Reduction in fossil fuel consumption

Global fossil fuel use will grow nearly 40% between 2010 and 2030 according to the Reference Case. In comparison, with the implementation of all REmap Options, that growth rate would fall to 18%. Coal and oil use would grow by only 9% and 12%, respectively, whereas natural gas by 43% in the period.

The total reduction in fossil fuels and nuclear with REmap Options is 83 EJ worldwide in 2030 when compared with the Reference Case. Total renewable energy use (as primary energy) will increase by about 46% in REmap. Compared to the consumption of different non-renewable energy forms, which range between 45 EJ and 160 EJ per year, renewables use will grow to about 180 EJ per year, making them the largest single source of primary energy when grouped together. The use of coal would drop by 22%, reducing one of the main sources of CO_2 emissions and reducing externalities from lower air pollution. Reductions in traditional uses of bioenergy would reduce emissions and other externalities as well.

Figure 37: Global change in primary energy use with REmap Options, 2030



Based on IRENA estimates

Renewables would mainly replace coal to become the largest source of primary energy.

Note: Renewables in this figure are calculated using the IEA's physical energy content method. However there are different methodologies for calculating primary energy equivalents for some forms of renewable electricity and heat. Depending on the method, the renewables share can change.

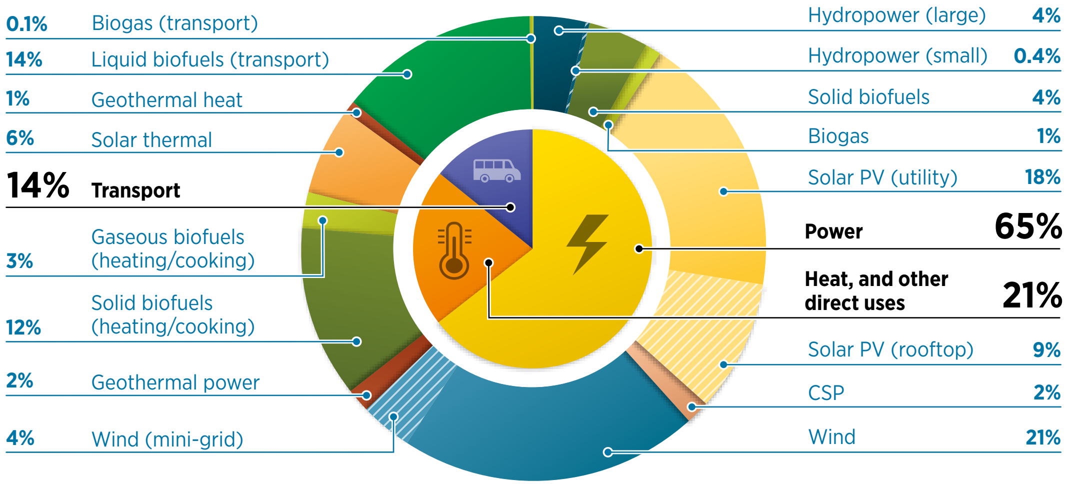
A doubling of the renewable energy share by 2030 would set the world on a path to renewables providing a majority of energy by 2050; this is required to cap global warming to 1.5 - 2 degrees Celsius by the end of this century.

Technology and sector contribution to CO_2 emission reductions

All renewables can help to reduce global CO_2 emissions. The magnitude of their potential contribution depends on what fuel they substitute and the CO_2 emissions from the renewables supply chain. Reduction potential in the power sector compared to the Reference Case accounts for two-thirds of the total potential in 2030: between 4.8 Gt and 5.6 Gt out of the total range, which would be 7.4 Gt to 8.6 Gt in 2030. The largest reduction potential is from wind followed by solar PV. Distributed generation (including off-grid systems) can cut CO_2 emissions between 0.4 Gt and 0.5 Gt per year (TEC, 2015). Buildings, industry, transport and district heating account for the remaining 2.6 Gt to 3.0 Gt in the total reduction potential.

Wind and solar PV can account for nearly half of the total CO_2 emissions avoided by the REmap Options.

Figure 38: Avoided CO_2 emissions by sector and technology with REmap Options, 2030



Based on IRENA estimates

Reduced externalities relating to lower air pollution and CO_2 are significant

The substitution costs presented in the previous section do not capture the total picture however, because most countries have not included the external costs of air pollution and CO_2 in their national policies. Air pollution, for example, is detrimental to human health and agricultural crops. CO_2 is the main GHG driving climate change. Many recent studies (such as the IPCC assessments) have revealed significant costs to society, specifically for less developed countries and vulnerable populations (IPCC, 2014).

Assessments make clear that external costs are driven by air pollution resulting from the combustion of fuels (both fossil and bioenergy), but there is a very large range in estimating total external costs depending on how each emission is valued across countries.: in 2010 they amounted to between 4.8% and 16.8% of global GDP (or between USD 3 trillion and USD 10.5 trillion). The large range is a result of significant variances for costs associated with air pollution, as well as in the assessment of carbon price (ranging from USD 17 to USD 80 per tonne CO_2 in 2030); (IRENA, 2016f; US Government, 2013).

By 2030, in the Reference Case, the share of these costs as a percentage of GDP will decrease to between 2.8% and 10% of global GDP (see Figure 39). Growth in global GDP therefore outpaces the growth in external costs (which still occurs), but the relative share of external costs as a percentage of global GDP decreases due to the high deployment of renewables, cleaner combustion of fossil fuels, and the reduced use of traditional bioenergy. However in absolute terms these costs still increase, both for costs relating to air pollution and CO_2, to between USD 3.6 and 13.2 trillion per year in the Reference Case. On a global level, the largest cost is from outdoor air pollution, followed by CO_2 and indoor air pollution caused by the traditional uses bioenergy. The REmap Options further lower the external costs with 0.7% to 2.4% of GDP.

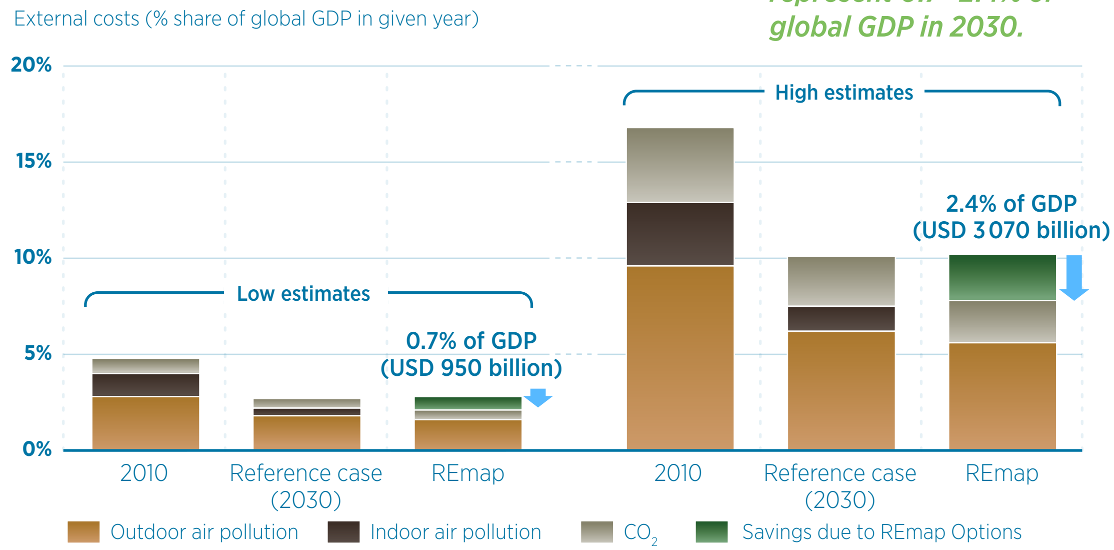
Comparing costs and reduced externalities shows the scale of the savings from renewables: the REmap Options would result in system costs of USD 105 billion per year worldwide, or USD 290 billion when the Doubling Options are considered. But they would also provide additional reductions in externalities. When these reduced externalities are considered, total savings would be 4 to 15 times greater than the system costs of realising a doubling. In absolute terms, realising a doubling would result in savings from reduced externalities of up to USD 4.2 trillion annually by 2030. Indoor air pollution is a major externality, and it accounts for from about half to two-thirds of this total. CO_2 savings are also important, but their relative importance depends on the price of carbon.

One of the most significant changes in this updated REmap report is an improved methodology for estimating the impacts of energy use on human health and agricultural crops – the analysis has found that these impacts have roughly tripled. However, persistent uncertainties in the process have prevented the calculation of a reliable and precise estimate of the cost of externalities. Hence while developing policies to internalise external costs, it will also be important to enhance the understanding of these very uncertain external costs. The analysis in this report also merely refers to the impact of renewable energy technologies (pathways with more efficient non-renewable energy uses, for example, have not been considered).

Including reduced externalities in the analysis clearly makes the case for both the REmap and Doubling Options: total savings are estimated to range from USD 1 trillion up to 4.2 trillion annually in 2030 as a result of reduced air pollution and greenhouse gas emissions.

Figure 39: External costs as a share of GDP and reduced externalities with REmap Options, 2010-2030

With the REmap Options, reduced externalities represent 0.7-2.4% of global GDP in 2030.



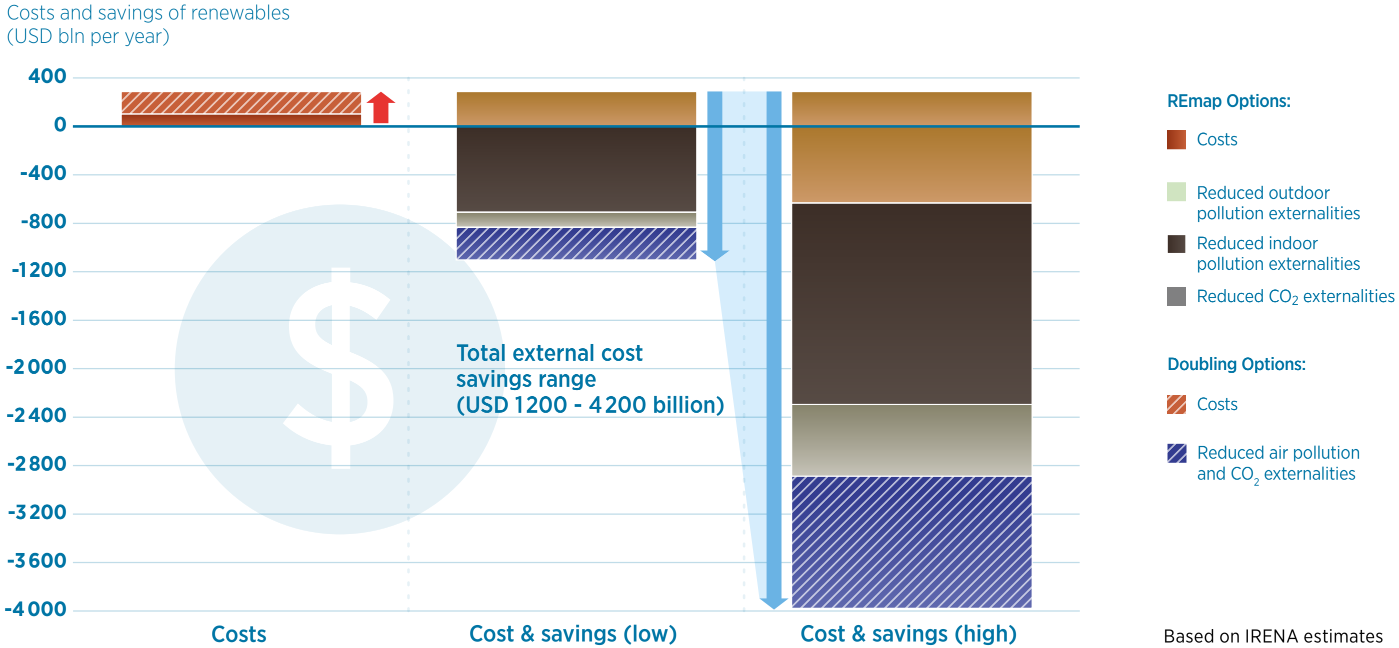
Based on IRENA estimates

On a sector level, the effect of implementing the REmap Options varies. In industry, transport, power and district heating, the REmap Options increase system costs. For buildings, the REmap Options actually lead to a reduction.

The largest savings in reduced externalities are found in the power sector, mainly due to the drop in the use of coal. Transport would see the second-highest reduction in externalities, largely because of the higher assessment of air pollution costs stemming from the combustion of fuels in urban environments. In buildings there are similar savings but the main driver is the substitution of traditional uses of bioenergy. The opposite is true in industry, where CO_2 related savings are higher than from air pollution. In district heating there is a slight overall increase in the external costs associated with air pollution, but savings resulting from CO_2 reductions. In total, if quantifying the cost and reduced externalities together, all sectors except district heating result in moderate to significant savings with the REmap Options.

Reduced externalities are valued at up to USD 4 200 billion per year with the Doubling Options.

Figure 40: Costs and savings with the REmap and Doubling Options, 2030



Based on IRENA estimates

More than half of the REmap Options are cost-effective without considering externalities; the rest are competitive when including reduced externalities. However, national policies heavily distort markets; policy adjustments are needed to reach fair pricing of renewables.

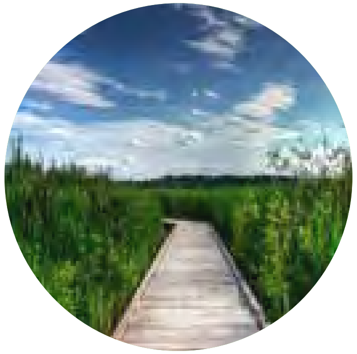
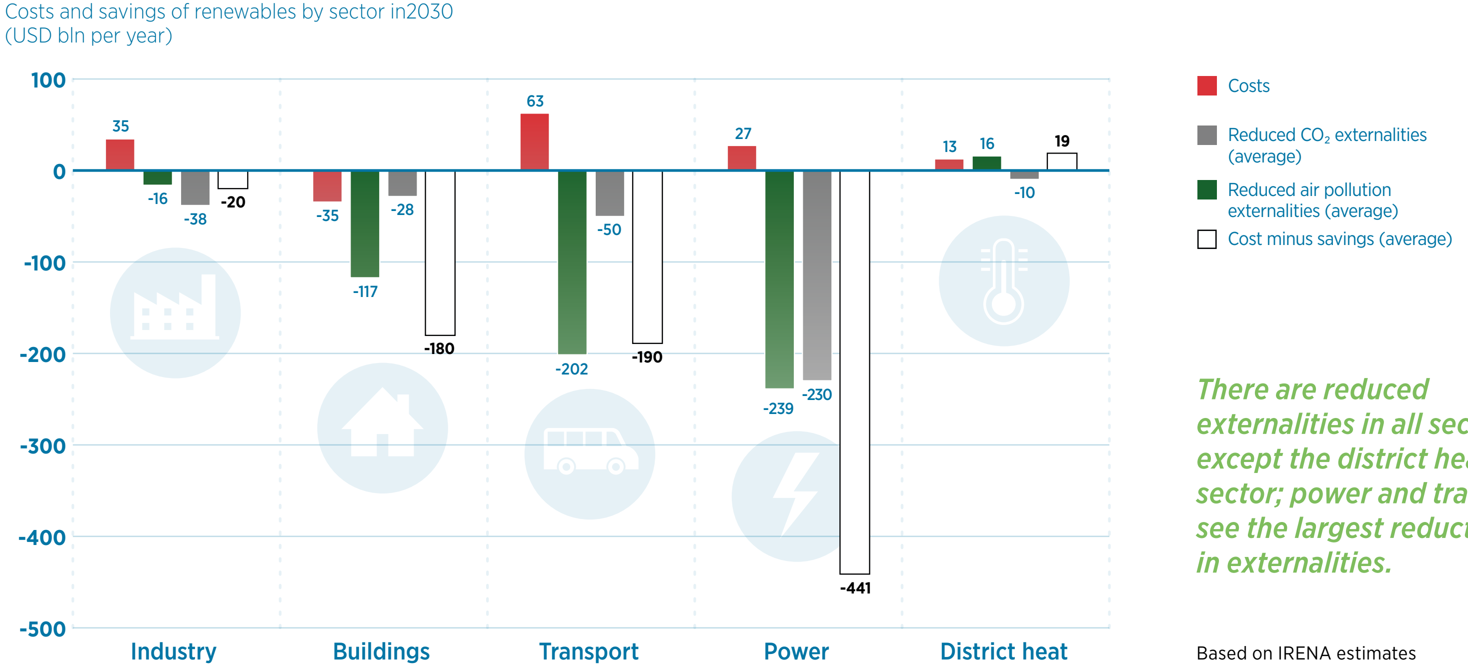


Figure 41: Cost and savings with REmap Options, by sector, 2030



There are reduced externalities in all sectors except the district heating sector; power and transport see the largest reductions in externalities.

Based on IRENA estimates

TECHNOLOGY-LEVEL COSTS AND SAVINGS BY DOUBLING RENEWABLES

The REmap cost supply curve provides insight into how the potential of technologies and costs interrelate. It also shows how the renewable energy share increases by each successive step from today's modern renewable energy share of 9% to 36% in 2030.

The cost supply curve shows the substitution cost and the relative contribution of each REmap and Doubling Option at a global level as the share of modern renewable energy increases. The cost of each Option at country level has been aggregated to arrive at a global average which is displayed in the curve.

The renewable energy share shown in the figure accounts for reduced energy demand in 2030 consistent with the SDG goal of doubling the rate of energy efficiency improvement. The result of this reduction is that the relative share of renewable energy in 2030 for each option is increased slightly. Therefore the end shares for the options are higher than presented elsewhere in this report which shows shares before the effect of energy efficiency improvement.

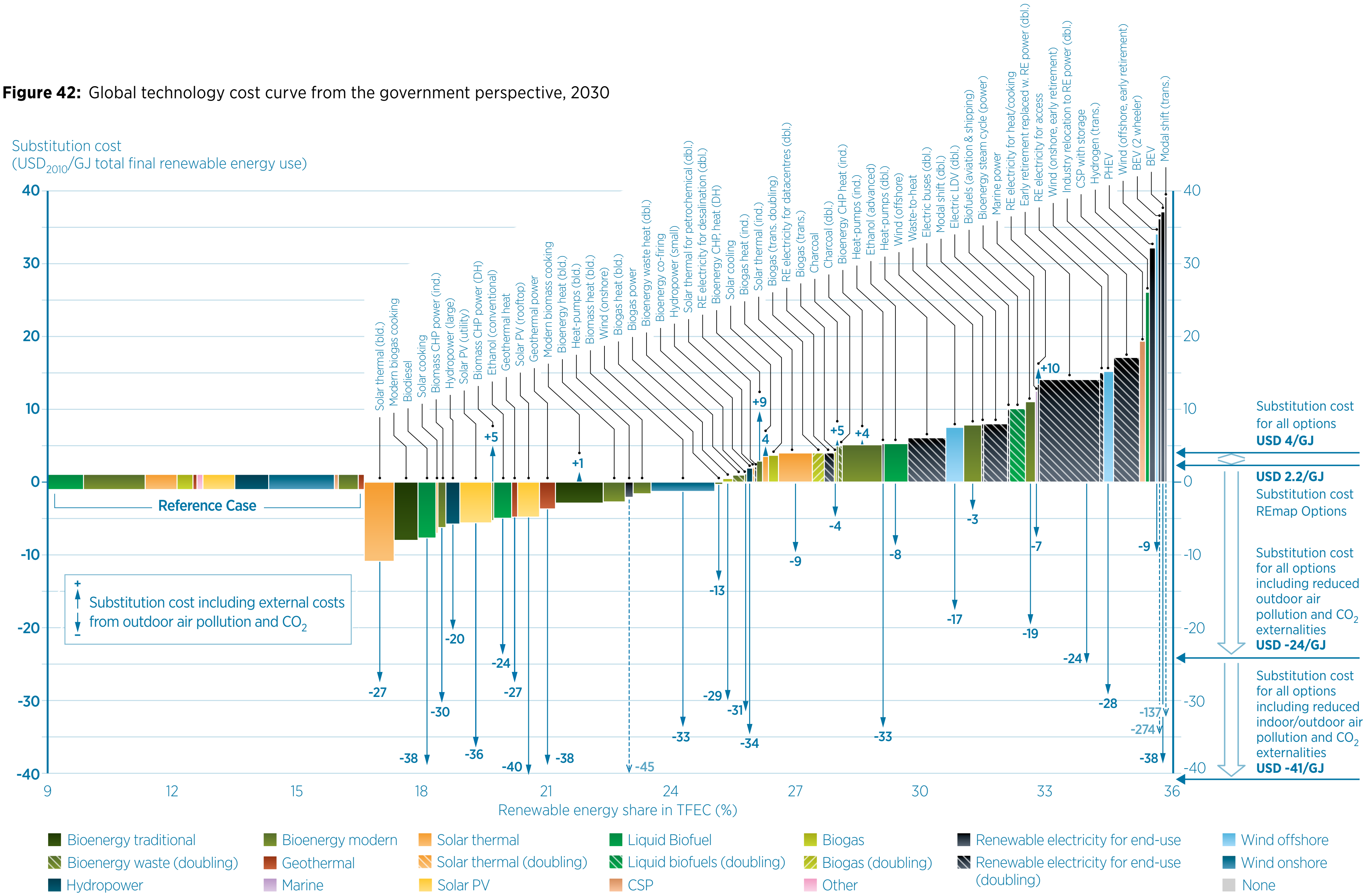
The figure starts with the bars on the left that show the growth in modern renewable energy share according the Reference Case, which rises from around 9% in 2010 to just under 17% in 2030 (including the gains from energy efficiency). The cost impact was not determined for the Reference Case, as this growth is assumed to take place in any case. Various forms of bioenergy in different applications accounts for just under half of the final renewable energy use.

The Reference case is followed by bars showing the contribution of the REmap Options, Doubling Options and energy access through renewables. When all the Options are combined, the renewable energy share increased from 17% to 36%. The cost of the REmap Options ranges from USD -10 to USD 15 per GJ of final renewable energy use. Negative substitution costs mean a saving relative to the non-renewable counterpart whereas a positive cost indicates additional costs. The average cost of all REmap Options is estimated to average USD 2.2/GJ, which result in a system cost of USD 105 billion per year in 2030. Of the REmap Options around 60% are cost-competitive – meaning their substitution cost is negative.

The Doubling Options are also in the curve and indicated with a patterned colour. All Doubling Options have positive substitution costs ranging from USD 1 to 17 GJ, with an average of USD 10/GJ. With the REmap Options and Doubling Options combined, the average cost is USD 4/GJ, resulting in a system cost of USD 290 billion for all the Options. Around 40% of the REmap and Doubling Options are cost competitive.

The cost of doubling modern renewable energy in the energy mix is negligible, at USD 2.2 per GJ or under USD 1 cent per kWh, and significant savings in reduced externalities relating to outdoor air pollution and CO_2 are included.

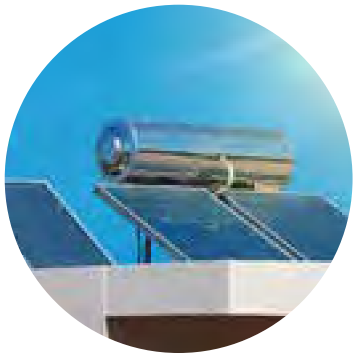
Figure 42: Global technology cost curve from the government perspective, 2030

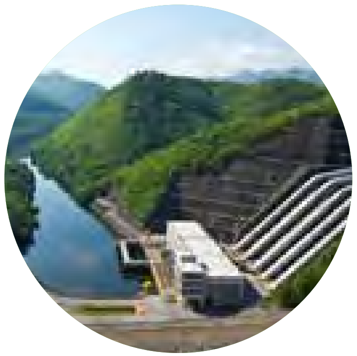


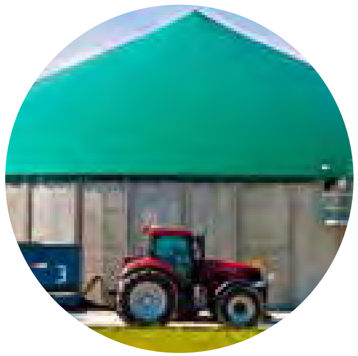
Based on IRENA estimates

Decision makers will be tempted to pick low-cost options, from the left end of the curve, and to skip high-cost options on the right side; but the figure gives a global perspective, and not all options are available everywhere and mask differences in technologies on a country or regional level. Therefore, the cost curve should not be misinterpreted as a series of steps from left to right, in order of costs that can be chosen in isolation; rather, there are interactions, and all of these options need to be exercised together to achieve this level of costs and the indicated renewable energy shares.

The figure also shows how the cost of substitution change on a technology level for the REmap Options when the externalities relating to outdoor air pollution and CO_2 are included. The external costs for the Doubling Options is also assessed, but not shown on a technology level in the curve. In almost all cases, the cost of substitution moves to a saving when reduced externalities are accounted for. The average cost of substitution of the REmap and Doubling Options moves from USD 4 to USD -24 per GJ when reduced externalities related to outdoor air pollution and CO_2 are included. The savings are at USD -41/GJ when indoor air pollution is also included. There are a few exceptions where externalities result in higher costs, for example where modern bioenergy in emerging economies substitute natural gas. This points to the need for investing in highly efficient bioenergy combustion technologies with strong pollution control.







COUNTRY-LEVEL COSTS FOR A DOUBLING

Incentives to use renewables differ by country, but in all of them the societal advantages are compelling, particularly when the costs associated with externalities are included. However many countries need to adjust their policies and markets to take full advantage of renewable energy.

The government perspective provides a view on the savings of renewables to the society as a whole. By comparison, the business perspective shows if the marketplace is aligned to attract investment into renewables. Some country-specific findings offer examples of how government policies affect the marketplace for renewables.

In Germany, the government perspective estimates a substitution cost of USD 4/GJ. If the low assessment of external costs is included, which is done in part through the European Union Emission Trading Scheme (EU ETS) (European Commission, 2016), this cost flips to savings of around USD 2/GJ. Renewables are also increasingly cost-competitive today in the United States from a business perspective with an average substitution cost just above USD 0/GJ but with many technologies in the negative. This is also be reflected in the market, as seen by investment flow, helped by the availability of policy instruments such as the production tax credit (DSIRE, 2015). The country has a slightly positive substitution cost from the government perspective, how like all countries it is negative when external costs are included.

In Mexico, costs are negative in government perspective and just above zero in the business perspective, reflecting an increasingly attractive marketplace for renewables investment. The difference between the government and business perspectives are more pronounced in the United Arab Emirates. The government perspective is based on higher fossil fuel prices that also include the recent marginal gas cost in the United Arab Emirates, which has increased over previous years. The business case includes significant fossil fuel subsidies resulting in a slightly positive cost of substitution. If the subsidies were removed, as the country has in part done on gasoline and diesel very recently, the result would be a shift well into the negative territory of substitution cost from a business perspective.

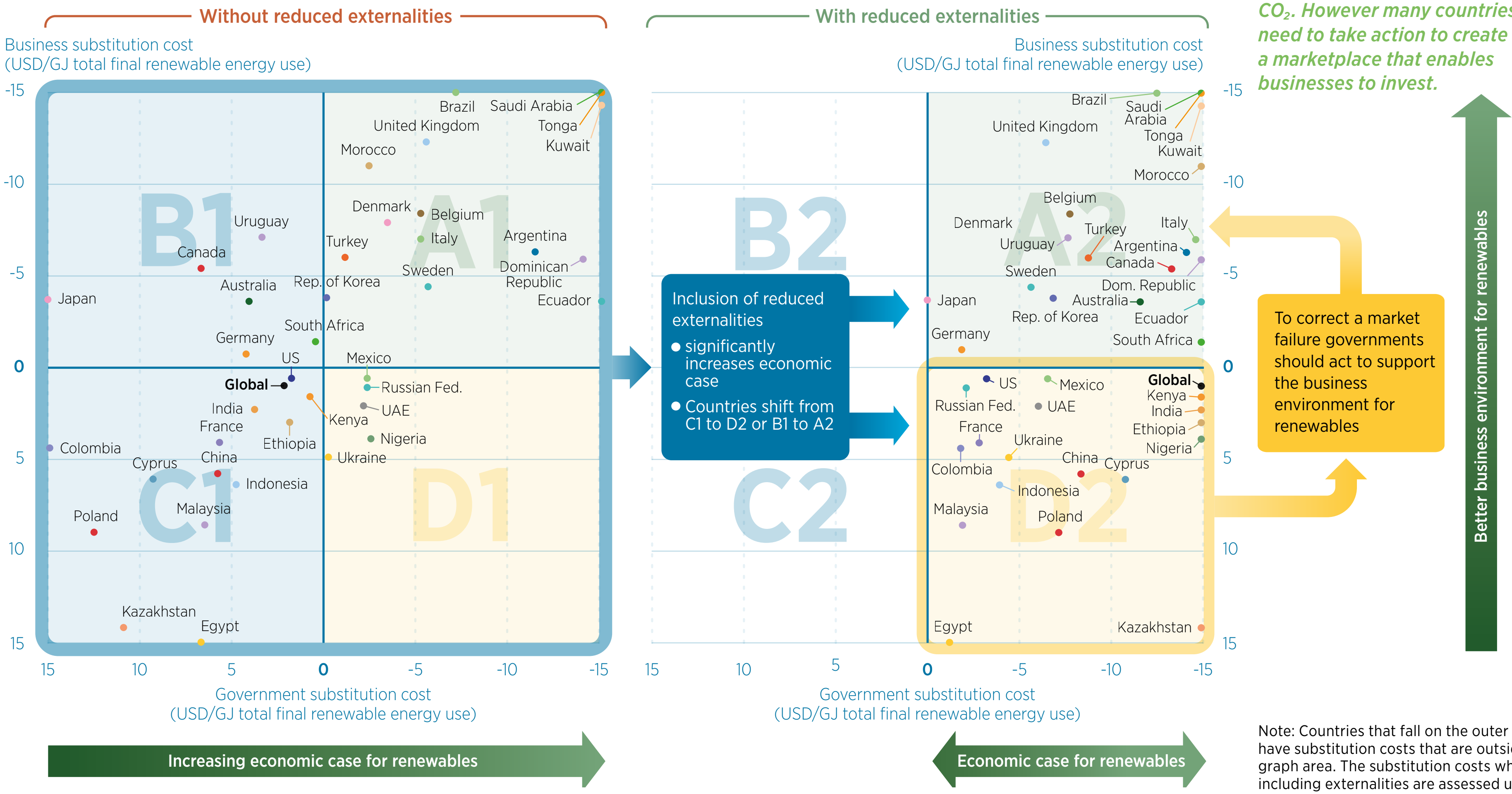
In China and Poland, renewables result in higher substitution costs in both perspectives as a result of the availability of cheap coal and its ubiquity in the power sector and for heating in buildings and industry. However, the substitution costs turn significantly negative if externality reductions are included.

Figure 43 shows the substitution costs of renewables for each REmap country, from the perspectives of business and government. It also shows how the substitution costs change when accounting for externalities, and therefore provides insight into how renewables compete in the energy marketplace if governments have policies or tax rules aligned with the societal advantages of renewable energy that result in increases in human welfare and environmental quality. Other benefits include additional jobs and potential increases in GDP; however these are not quantified in this section as it is difficult to factor their impacts into the technology substitution costs.

As discussed earlier, substitution costs vary, and drivers depend on factors including what types of non-renewable technologies are substituted, local resource quality and availability, and whether more options are deployed in competitive sectors, such as buildings and power, or in less competitive sectors like industry and transport. However, strictly from a business perspective, the main determinant is whether fossil fuels are taxed or subsidised. From the government

Figure 43: Substitution costs in REmap countries from the business and government perspectives, with and without externalities, 2030

Renewables have a compelling economic case for all countries, particularly when factoring in the external cost of air pollution and CO_2. However many countries need to take action to create a marketplace that enables businesses to invest.



Based on IRENA estimates

Note: Countries that fall on the outer axis have substitution costs that are outside the graph area. The substitution costs when including externalities are assessed using the lower estimates for all countries except for Canada, France, Japan, Poland, which use the median estimates.

perspective, the key drivers are resource availability factors, which impact affordability.

The figure breaks down the countries into four main quadrants, indicated with letters from A to D. The boxes on the left hand side marked with "1" show the cost of substitution excluding the effect of reduced externalities. The boxes on the right hand side marked with "2" show how the substitution cost changes when they are included. The change presents how costs should be assessed by governments, which should include the externalities associated with energy technologies. To address shortcomings, policies that align the business and government perspective would result in moving countries from quadrants D2 to A2.

To clarify further:

Quadrant A1: These countries have aligned business and government perspectives, even with reduced externalities excluded from the assessment. The implication is a competitive business environment for renewables. Some factors that enable countries to achieve this include high renewable energy potential, lower capital costs, and expensive fossil-fuels.

Quadrant B1: These countries have established a competitive market for renewables. When externalities are assessed in the cost of substitution, all countries that have competitive markets for renewables (A1 and B1) would fall in Quadrant A2. Ultimately, this is where all countries should end up: externalities are correctly re-cognised by governments and reflected in the market-place for renewables.

Quadrant C1: Many countries that fall into this area do not have markets that attract investment in renewables. Countries here may have low renewable resource availability, or cheap and plentiful supply of fossil fuels, especially coal. Either condition results in high substitution costs. However, the REmap Options still make sense economically if externalities are internalised moving these countries into quadrant D2.

Quadrant D1 The few countries in this quadrant have strong cases for renewables, which are competitive even without the consideration of externalities, but these are not yet reflect in the marketplace. The main culprit here are fossil-fuel subsidies.

Countries that fall in categories C1 and D1, end up in **Quadrant D2** when externalities are accounted for. If viewed from the government perspective, these countries all have a compelling case for renewables, which are not reflected in the market. As a first step in policy-making, governments in these countries should start with internalising externalities, followed by reducing subsidies on fossil fuels if they exist.

Ideally, the substitution cost from the business perspective should be the same as the substitution cost from the government perspective when it includes externalities. An example where this is the case is Sweden, which has a substitution cost of around -5 USD/GJ from both perspectives. How this can be achieved depends on the sectoral breakdown of energy demand energy and the mix of fossil fuels used to supply energy. Importantly the situation in countries differ based on national circumstances, and efforts to enable a market correction will vary by country. As many countries are just starting their transition to an energy system with higher levels of renewable energy penetration, it is likely that renewables will continue grow despite complete internalisation of externalities. In the power sector, for example, renewables have been deployed at a large scale in numerous countries, even in the absence of carbon prices or full internalising of the costs association with air pollution. However, not only in the power sector, but especially in areas where renewable energy uptake has been limited (e.g. industry and transport), correct internalising of external effects would be step towards enable a doubling of the renewable energy share.

SENSITIVITY ANALYSIS FOR REMAP FINDINGS

Many variables affect the cost-competitiveness of renewables. The most important are the price of fossil fuels and bioenergy, and the cost of capital. This section details how changes in these variables affect the substitution costs of the REmap Options.

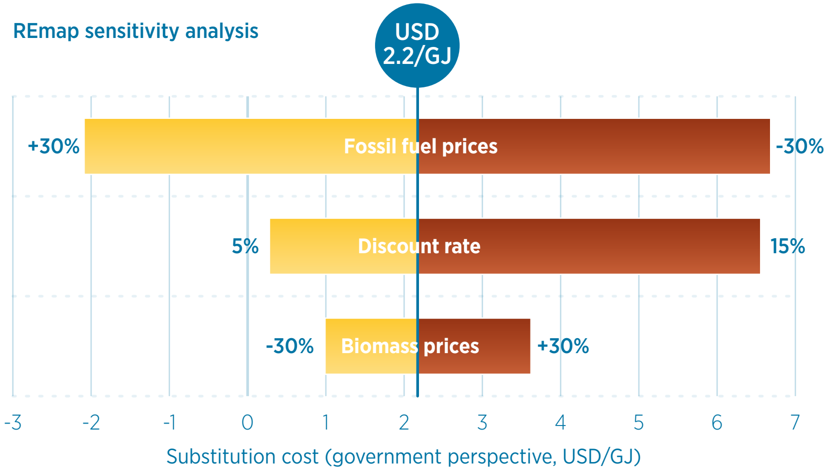
The global substitution cost from the perspective of governments averages USD 2.2/GJ. Two of the most important factors that drive these costs are fuel prices and the costs of capital (represented by the discount rates here).

To reveal the effect that changes in fuel prices and discount rates have on the substitution cost, a sensitivity analysis was conducted. The most pronounced change occurs when the price of fossil fuel is varied. A rise or drop of 30% was assumed (around the mean value of USD 105/barrel crude oil price and USD 7/GJ cost of bioenergy supply). The result is an increase of more than USD 4.5/GJ in the substitution cost when fossil fuel prices are lowered by 30% (USD 74/barrel). If the price of fossil fuels increases by 30% (USD 137/barrel), the effect is similar in the opposite direction. The shift is smaller if bioenergy prices change (USD 5 to 9 per GJ), because of their more limited use compared to fossil fuels overall.

Changes in the discount rate can affect both fossil and renewable technologies. Since many renewable technologies have higher capital cost, a higher discount rate tends to disadvantage renewable technologies, thereby driving up the substitution cost. The relationship depends on the relative capital cost of the renewable technology and the substituted fossil technology. In this roadmap, the assumed discount rate for OECD countries is 7.5%, while for non-OECD countries it is 10%, in line with IRENA's Costing work (IRENA, 2015i). The result of changing the discount rate is a reduction in the substitution cost of USD 1.8/GJ with a rate of 5%, and an increase of USD 4.5/GJ with a rate of 15%.

Figure 44: Sensitivity analysis for REmap findings

Fossil fuel prices have the largest impact on the substitution costs of REmap Options.



Based on IRENA estimates

ROADMAP FOR A RENEWABLE ENERGY FUTURE

Electricity cable trench for a new wind farm, The Netherlands

VARYING COUNTRY POTENTIAL FOR RENEWABLE ENERGY GROWTH

If the renewable energy share in the global energy mix doubles between today and 2030, the share of renewables worldwide would between now and then grow at an average of 1% annually, with significant variance in rates by country. It would not be more equitable to expect every country to grow at the same rate. The chart shows how some countries would have higher shares of modern renewable energy with a 1% growth rate than they would if they were to follow the REmap Options.

Below the 1% line three groups of countries exist: those that already have high shares of renewables; fossil fuel producers; and countries with limited renewable energy potential. For these three groups costs of renewables in realising a doubling can be expected to be higher either because energy needs to be imported or because investments in renewables will offset domestic fossil energy production. The group with renewable energy growth rates above 1% includes a wide range of countries that have yet to exploit their most potential-rich renewable energy resources, which are often least expensive to develop.

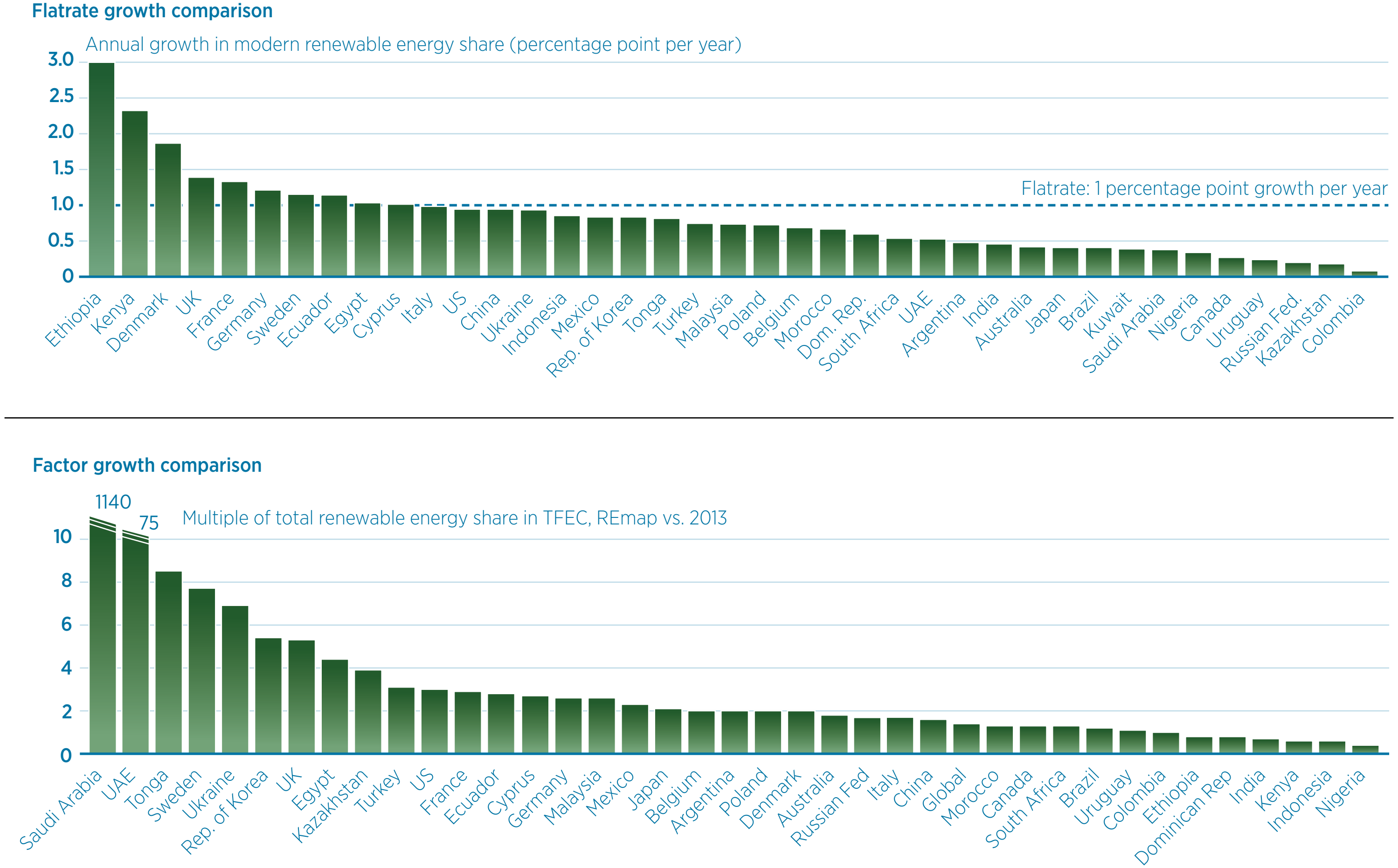
REmap shows how a doubling of the renewable energy share between 2010 and 2030 can be reached. If all options are implemented the share for modern renewable energy, which excludes traditional uses of biomass, would quadruple.

In short, REmap findings do not represent abstract renewable energy potential. These are options that have been estimated to the extent possible through country consultation and as much as possible account for political realities and national circumstances. To be sure, setting options according to facts on the ground is not the only way. Renewable energy expectations for countries could be set based on projected GDP in the year 2030, or based on the availability of renewable resources in each country. Assumptions could also include that renewable energy growth stops once targets are met. However, none of these are a cut-off criteria in the REmap assessment.

The journey for getting to a doubling by 2030 will set countries on different paths, and from different starting points. To realise a doubling of the global renewable energy share, efforts need to start now and significant progress needs to be made within the next five years. Without short term action, the years from now to 2020 will likely only show modest growth in the total share of renewables, making the doubling target nearly impossible to achieve by 2030.

Hence, we cannot wait for another five years to monitor what we have achieved and re-plan, as it will take time to change policies, set new targets, and build the required infrastructure and renewable energy capacity. The REmap solutions and policy recommendations provided in the next chapter should therefore be acted upon as soon as possible. Key short term actions identified through the REmap analysis include correcting for market distortions to create a level playing field for renewable technologies, implement power sector solutions (including grid measures and flexibility options for higher shares of variable renewable energy), and creating new markets for biofuels by expanding the enforcement of blending targets.

Figure 45: Different perspectives on the REmap journey to 2030:
annual growth rate in renewable energy share versus a flat 1% annual increase (top graph); multiple of the renewable energy share in 2030 versus 2013 (bottom graph)



* Kuwait not shown as 2013 RE share reported at 0, y-axis with a maximum of 10, which is exceeded by Saudi Arabia (1140x) and UAE (75x)

Based on IRENA estimates

Different perspectives portray different journeys on the road to 2030: some countries will grow rapidly in terms of annual growth, others have large ambitions when considering their low starting points.

Note: the flatrate growth comparison shows the annual growth in the modern renewable energy share for countries based on the REmap Options.

Table 3: Summary of results

	Units	2013/ 2014	Reference Case	REmap	Doubling
POWER					
Hydropower	GW	1170	1830	1995	2245
- Large hydropower	GW	*890*	*1330*	*1450*	*1670*
- Small hydropower	GW	*130*	*200*	*220*	*250*
- Pumped storage	GW	*150*	*300*	*325*	*325*
Wind	GW	370	1070	1990	2500
- Onshore	GW	*361*	*990*	*1710*	*2000*
- Offshore	GW	*9*	*80*	*280*	*500*
Solar PV	GW	175	780	1760	2520
- Utility scale	GW	*79*	*350*	*1180*	*1680*
- Rooftop	GW	*96*	*430*	*580*	*840*
Concentrated solar power	GW	4	45	110	385
Bioenergy	GW	95	250	430	430
- Co-firing	GW	*24*	*65*	*110*	*110*
- CHP	GW	*47*	*125*	*215*	*215*
- Power-alone	GW	*23*	*60*	*105*	*105*
Geothermal	GW	12	42	92	152
- Flash steam, dry steam	GW	*11*	*35*	*95*	*95*
- Binary	GW	*1.4*	*7*	*27*	*57*
Ocean	GW	0.5	2	7	7
Battery storage (incl. EVs and 2/3 wheelers)	GWh	130	1580	4000	5100

	Units	2013/ 2014	Reference Case	REmap	Doubling
TRANSPORT					
Electric Vehicles	million vehicles	0.8	60	160	173
- Passenger vehicles	million vehicles	*0.8*	*59*	*158*	*158*
- Buses	million vehicles	*0.01*	*0.5*	*1.4*	*11*
- Light duty vehicles	million vehicles	*0.004*	*0.3*	*0.9*	*5*
2/3 wheelers	million vehicles	200	500	900	900
Bioliquids	billion litres	129	250	500	520
- Conventional biogasoline	billion litres	*93*	*185*	*283*	*283*
- Advanced biogasoline	billion litres	*1.0*	*10*	*94*	*94*
- Conventional biodiesel	billion litres	*35*	*55*	*93*	*103*
- Advanced biodiesel (incl. bio jet kerosene, drop-in)	billion litres	*0.01*	*0.3*	*30*	*42*
Biomethane	billion m^3	0.01	0.3	0.9	24

	Units	2013/ 2014	Reference Case	REmap	Doubling
INDUSTRY					
Bioenergy heat (incl. CHP)	EJ/yr	8	11	17	18
- Residues	EJ/yr	*6*	*9*	*13*	*13*
- Pellets	EJ/yr	*2*	*2*	*3*	*3*
- Biogas	EJ/yr	*0.2*	*0.6*	*1.4*	*1.4*
Solar thermal - concentrated	GWth	0.1	8	105	110
Solar thermal - flat plate, evacuated tube	million m^2	1	50	660	690
Geothermal (direct heat)	EJ/yr	0.02	0.05	0.4	0.4
Heat Pumps	million units	0.2	3	18	34
BUILDINGS					
Bioenergy – traditional	EJ/yr	35	21	0	0
Bioenergy – advanced cooking	EJ/yr	2.5	4	13	13
Modern cookstoves (incl. only intermediate and advanced biomass)	million units	35	190	840	840
Bioenergy heat	EJ/yr	4	10	15	15
- Pellets	EJ/yr	*0.5*	*1.3*	*2*	*2*
- Chips	EJ/yr	*3*	*7*	*10*	*10*
- Biogas	EJ/yr	*0.4*	*1.4*	*3*	*3*
Solar Thermal	million m^2	534	2020	3230	3230
Geothermal (direct heat)	EJ/yr	0.3	0.7	0.8	0.8
Heat Pumps	million units	4	32	42	102

	Units	2013/ 2014	Reference Case	REmap	Doubling
REmap TOTAL					
Total final renewable energy use	EJ/yr	69	89	116	135
Renewable energy share in TFEC	%	18%	21%	25%	36%
FINANCIAL INDICATORS					
System costs (in 2030)	USD bn/yr			105	287
Average investment needs (2015, 2016-2030)	USD bn/yr	360	375	770	913
Savings resulting from reduced externalities (in 2030)	USD bn/yr			950-3070	1200-4200
Investment support for renewable energy (in 2030)	USD bn/yr	137		229	414

Note: All data refers to the capacity in operation in stock in that year.

Sources: IRENA statistics (IRENA 2015b); IRENA estimates

TEN SOLUTIONS TO CLOSE THE GAP

03

01 Electric vehicle and biofuels

02 Renewable applications in industry

03 Renewable heating and cooling in buildings

04 Accelerated renewable energy investment

05 Internalizing external cost

06 Variable renewable electricity integration

07 Synergies with energy efficiency

08 Sustainable bioenergy markets

09 Universal access to modern energy with renewables

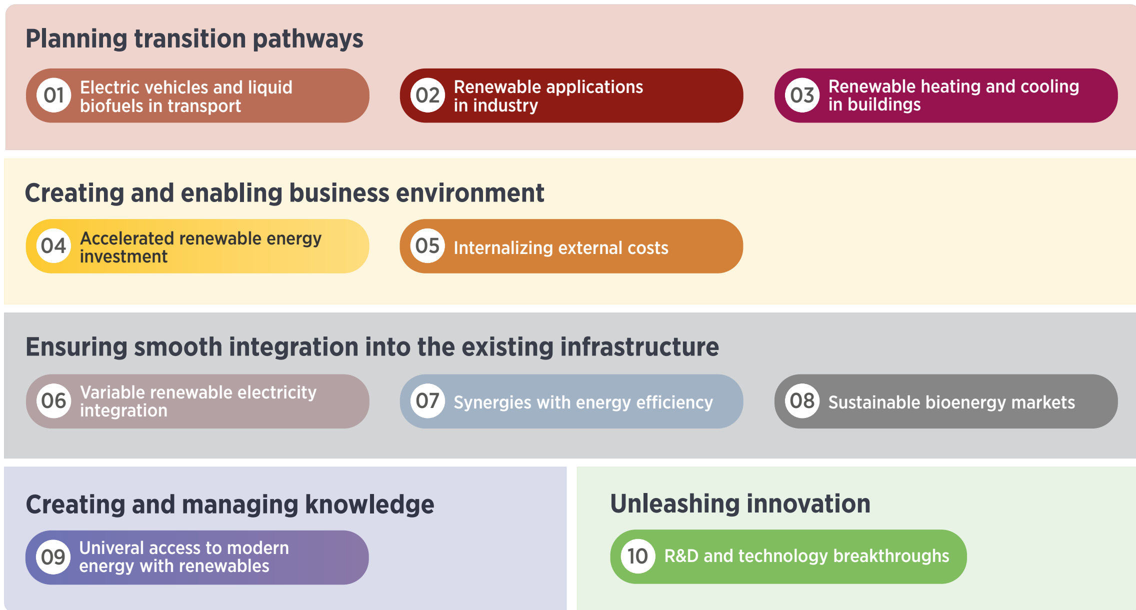
10 R&D and technology breakthroughs

The REmap findings show that a doubling of the renewable energy share in the global energy mix is feasible if combined with accelerated energy efficiency improvements and modern energy access. The doubling is affordable when all reduced externalities related to non-renewable energy use are accounted for, related to climate-change and air pollution. Modern renewable energy can put the world back on track to limiting global warming to 2°C by the end of this century, the target agreed by all countries at the COP21. Finally, the REmap analysis shows how we can operationalise the United Nations' Sustainable Development Goal call on Energy of "ensuring access to affordable, reliable, sustainable and modern energy for all". However meeting these targets will require long-term planning.

This chapter identifies 10 technology and innovation solutions crucial to realise a doubling. They have been selected based on the REmap findings, and they complement the Lima-Paris Action Agenda for reducing carbon emissions. For each solution, barriers and opportunities to increase renewable energy uptake are identified, followed by a list of recommendations for policymakers and stake-holders.

The REmap country analyses present national policy actions needed to overcome existing barriers often specific to a technology, sector or country. Supported by consultations with national experts, the 10 solutions are categorised under the five areas of REmap national policy action. These policy actions include the planning of transition pathways for the development of national plans and targets, creating an enabling business environment, ensuring the smooth integration of renewables into existing infrastructure, creating and managing renewable energy knowledge, and promoting continuous innovation. Each of these phases should be supported with up-to-date and well-managed knowledge about renewables (including skills and capacity building). Finally, innovation in new and existing technologies as well as in policies and finance schemes will support market creation and renewable energy integration.

What needed is engagement from a broad set of stakeholders across sectors and regions where political leadership and high-level decision making prioritise renewables and energy efficiency.



01 SOLUTION 1: ELECTRIC VEHICLES AND LIQUID BIOFUELS IN TRANSPORT

Transport has the potential to grow faster than any other: from its currently small base renewable energy share a quadrupling is possible by 2030. But tapping this potential requires thinking across sectors, beyond present-day business plans, and with an appreciation for long-term benefits. The level of EV sales would increase from the current level of 500 000 per year to an average of 10 million per year between today and 2030, and EVs would then represent 10% of the total passenger vehicle stock. The production of liquid biofuels would climb to 500 billion litres by 2030, representing 10% of the sector's total fuel use. Significant effort is needed to boost renewable energy penetration in aviation, shipping, and road freight, which would imply biodiesel and biomethane use.

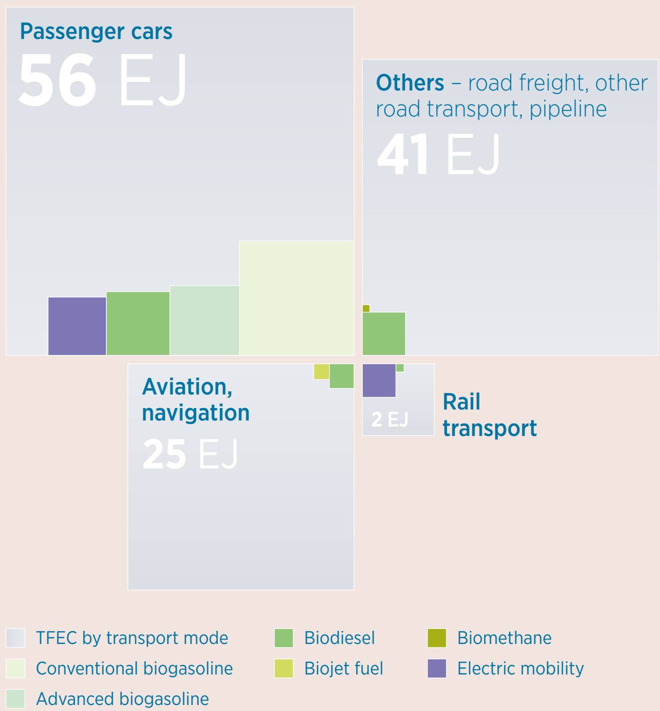
Understanding the challenge

Realising an 11% renewable energy share in transport as identified in this roadmap, requires significant deployment of liquid and gaseous biofuels and EVs. In reality, sales of EVs have been sluggish, with countries such as China, Norway, the Netherlands, and France (IEA, 2015e) standing out as exceptions where growth has been faster. Globally, 2015 sales are estimated at around 500 000 vehicles, less than one percent of the estimated total of 66 million passenger cars sold (OICA, 2016) despite targets and support from countries and local governments. A similar market expansion would be on the cards for electric two and three-wheel vehicles, for which a potential of 900 million units by 2030 is identified in this roadmap, with Asia being the biggest market.

Despite the significant growth in EVs, which are increasingly fuelled by renewable power, their contribution to total renewable energy use in transport is marginal. Partly this is explained by the higher efficiency of EVs compared to internal-combustion engines (ICE), as well as the fact that the share of renewable energy in power generation is still less than 25% globally. Hence, if the share of renewable energy use was based on other indicators, such as passenger kilometre (p-km) travelled with EVs, or the percentage of EVs in total car stock, the contribution would be higher.

In view of the sustainability concerns about conventional liquid biofuels, more deployment of advanced liquid biofuels will be required. Currently, markets for advanced liquid biofuels are largely shaped by policy, primarily because products are not yet produced at commercial scale and therefore have higher production costs than fossil fuels and conventional liquid biofuels. Price sensitivity has become more prominent since oil prices fell in mid 2014, and the lack of long-term policies to support advanced liquid biofuels means that the market outlook and potential product value remain uncertain.

Global renewable energy use in TFEC by transport mode in REmap



Electric vehicles

Cost reductions are important to improve the attractiveness of EVs. Cost-competitiveness largely depends on the price of batteries, which have dropped from USD 1000/kWh in 2007 to as low as USD 300/kWh today (IRENA, 2015k). A further decrease to about USD 120/kWh could put the price of EVs on par with conventional cars. According to a study that estimates learning rates of electric vehicles (Weiss *et al.*, 2012), that would happen if cumulative EV production reaches 50-80 million, at which point manufacturers will have achieved economies of scale. The associated learning costs to reach this level are estimated at USD 120-180 billion according to the same study. Although the technology solutions are developing rapidly, it may require more than a decade to reach this point. In addition to the challenges of commercialisation there are supply risks, such as the prices for inputs like lithium carbonate which recently tripled.

Another important focus area is infrastructure. In many countries charging points are uncommon, making EVs an unattractive option. Therefore, without more charging points consumers are unlikely to buy EVs, but charging points will also not be an attractive investment until there are more EVs to create that demand for infrastructure. Infrastructure development is important to increase the number of early adopters, and could be one way of achieving a breakthrough in this regard. Increasing the availability of home, public, and workplace charging options is crucial. In addition to the number of charging points, the process also needs to be fast. Given current technology, speeding up the time it takes to top up a battery comes at the expense of its lifespan, so further efforts at research and development (R&D) efforts are required.

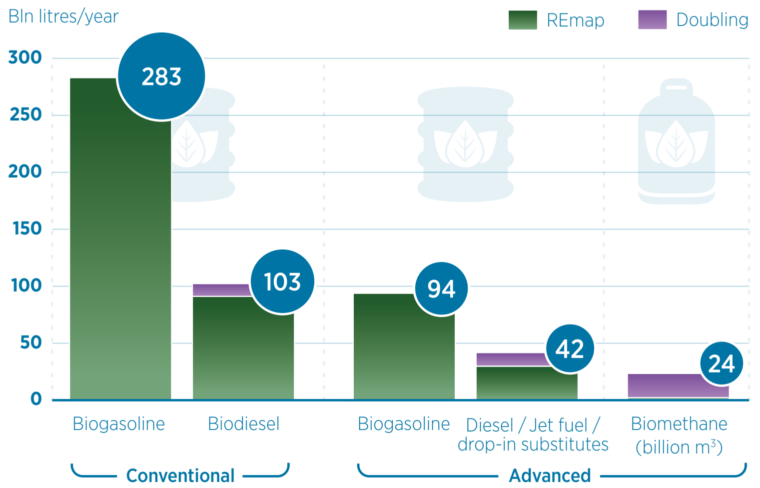
01 SOLUTION 1:
ELECTRIC VEHICLES AND LIQUID BIOFUELS IN TRANSPORT

Liquid biofuels

Demand for liquid biofuels would reach 500 billion litres per year in 2030 if all REmap Options are implemented (Figure 47), and rise to approximately 520 billion litres with the Doubling Options. Both conventional biogasoline and biodiesel use would triple from today's levels, and demand for advanced liquid biofuels (including advanced biogasoline, diesel, jet fuels, and drop-in biofuels) would reach about 136 billion litres per year, up from about 1 billion today.

If the average biofuel processing plant produces around 200 million litres per year, on average 40 advanced liquid biofuel plants and over 75 conventional liquid biofuel plants will need to be built annually to 2030. Some of these advanced liquid biofuel plants will be used for drop-in fuel production combined with green chemicals and other materials (*e.g.,* paper). Currently, however, there are less than 10 commercial-scale advanced liquid biofuel plants. Long-term policies to create markets and mobilise investments will be needed.

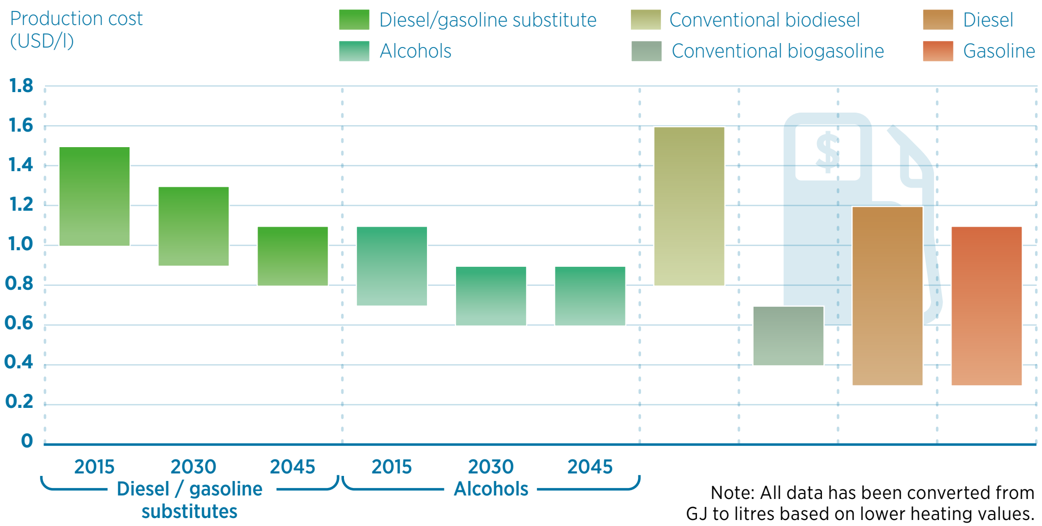
Figure 46: Liquid biofuel production with REmap Options and Doubling Options, 2030



Advanced liquid biofuels account for a quarter of the total biofuel demand in 2030.

Based on IRENA estimates

Figure 47: Production costs of advanced liquid biofuels, 2015-2045



Several methods for advanced liquid biofuels can be cost-competitive with fossil fuels by 2030.

Note: All data has been converted from GJ to litres based on lower heating values.

Note: Diesel/gasoline bars indicate the range based on a USD 40-140/bbl crude oil price. Ranges for biodiesel and ethanol refer to a USD 700-1500/tonne vegetable oil price and a USD 150-300/tonne corn price, respectively.

IRENA (2016c forthcoming)

Today, the production costs of advanced biofuels are much higher than those of conventional liquid biofuels and fossil fuels, but promising pathways can lead to cost-competitiveness by 2030 and 2045. Recent progress with the first commercial-scale cellulosic ethanol plants (mainly using corn cobs, leaves, husks, and stalks), may enable a learning-by-doing process. As the scale of production for these new products is still small, the learning rate would need a rapid acceleration for breakthroughs to be achieved, as estimated by the REmap Options (IRENA publication on this issue forthcoming). R&D funding programmes for demonstration projects and financial support for feedstock supply chain development are needed.

Markets and fuels that require further attention

Today shipping and aviation sectors each contribute 10% to the total global energy demand of the transport sector. The aviation sector alone represents 2-3% of total global CO_2 emissions worldwide. These two segments are mostly used for long-distance transport, and fuel represents a large share of total costs: one third of operational costs for aviation, for example. Energy demand in these segments will only grow, given increasing populations and economic activity, and biofuels represent the main alternative to non-renewable fuels.

Following the COP21, the Nordic ministers for climate and environment issued a statement calling for increased focus on emissions from the transport sector, including aviation and shipping (Norden, 2015). This could lead to the creation of new markets.

Thus far, however, there has been limited deployment of biofuels in these sectors. In aviation, this is despite the fact that numerous organisations strongly advocate the uptake of more renewable fuels (*e.g.,* Aviation Initiative for Renewable Energy in Germany, the Environmental Protection Agency in the United States). Limited progress with the use of renewables in aviation is not only due to technical issues, but also because of institutional barriers. In the aviation sector there is fierce competition between national airlines, discouraging countries from adopting biofuel mandates that could hurt the airline's competitive positioning.

For shipping, renewables-based electrification, hybrid technologies, and modern sails are options in addition to biofuel alternatives. The main barriers to increased penetration of renewable energy in shipping are the lack of commercial viability of such systems and the existence of split incentives between ship owners and operators, as the costs and benefits of introducing renewable energy are different for the two. Support should be scaled up now to demonstrate and increase the role of renewables in shipping the future. In particular, policies and incentives to promote research, innovation and proof-of-concepts are crucial in order for renewable energy shipping solutions to achieve commercial viability. Support could focus on small ships, which are more prevalent worldwide, transporting less of the total cargo but emitting more of the greenhouse gases per unit of cargo and distance travelled, compared to larger ships (IRENA, 2015l).

01 SOLUTION 1:
ELECTRIC VEHICLES AND LIQUID BIOFUELS IN TRANSPORT

Modal shift

A large share of transport happens within urban areas, using passenger cars powered by internal-combustion engines. In addition to EVs, strategies to further support electrification are important. Including a modal shift is one of them: people taking more of their daily trips using public transport and electric or pedal-powered bicycles. For trips beyond cities, high-speed long-distance trains can substitute for planes. Trains can also replace trucks in many cases.

Modal shifts such as these will require early planning that encompasses stakeholders beyond the energy sector, especially by considering the variations in different urban settings. People should be able use of cars, bikes and public transport in a seamless and efficient manner, so that efficiency and renewables are perceived as convenient, as opposed to a sacrifice for the greater good. In addition, continued cost reductions and performance improvements are required.

Recommended for further reading:

Renewable Energy Innovation Outlook: Advanced Liquid Biofuels *(IRENA, 2016c forthcoming)*

REmap 2030 Transport Action Team: Transport Sector Working Paper *(IRENA, 2016d forthcoming)*

Renewable Energy Options for Shipping *(IRENA, 2015k)*

Recommended actions for policymakers and stakeholders	Examples and regional applications	Timeframe
Promote EVs by simultaneously incentivising car sales as well as investment in charging points. Promote car-sharing schemes and electric two and three-wheelers. Switch fleets of buses and trucks from internal-combustion engines to electric ones.	**China** is introducing electric buses (80 000 by end of 2014) and electric two wheelers (20 million sold each year); **Japan** has 2 800 fast charging EV stations now. The Electric Vehicle Initiative aims for global deployment of 20 million EVs by 2020. Industry leaders have pledged to reach a share of 15% for EVs in total vehicle stock by 2030.	For REmap Options before 2030
Require non-renewable fuels to be blended with liquid biofuels. Accelerate production and R&D for advanced liquid biofuels. Promote the use of biogas to complement liquid biofuels.	The **European Industrial Bioenergy Initiative** aims for the first commercial advanced liquid biofuel plants to be in production by 2020, which could meet 4% of European Union transport energy needs. The first commercial cellulosic ethanol plants opened in the **United States** in 2014.	For REmap and Doubling Options before 2030
Tap the potential of niche markets in the more difficult sectors of shipping and aviation, such as electric ferries, hybrid drives for short sea shipping, and drop-in biofuels in aviation.	**Airports Council International**, the **International Air Transport Association** and others (CIANSO, IATA, IBAC, and ICCAIA) have committed to reducing global aviation emissions by 50% from 2005 levels by 2050. No similar initiatives exist in the shipping sector.	For Doubling Options and post-2030
Recognise potential breakthrough vehicle technologies for which mass production would reduce costs and boost market prospects, such as mobile batteries and fast-charging stations. Provide manufacturing support to complement R&D funding.	**Nevada** supported the Tesla Gigafactory for batteries with tax breaks and incentive grants. By hosting the Gigafactory the state stands to attract more than 6 500 jobs over the span of eight years.	For Doubling Options and post-2030

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02

SOLUTION 2: RENEWABLE APPLICATIONS IN INDUSTRY

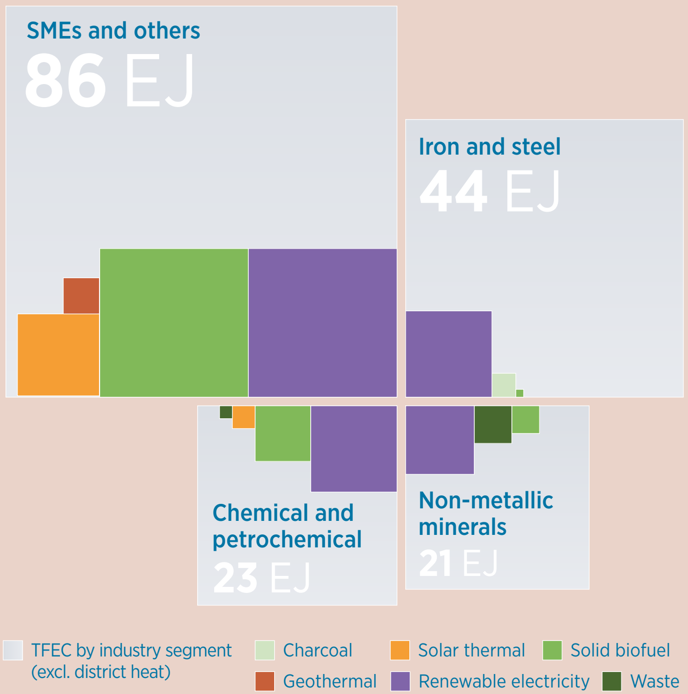
The bulk of industrial energy use is represented by the three energy-intensive sectors of iron and steel, chemicals and petrochemicals, and pulp-and-paper production. The potential to significantly scale up renewable energy use across industry is possible. Bioenergy is by a large margin the main renewable energy fuel use as it allows the production of low, medium and high temperature process heat. The REmap Options include a doubling of its use, and significant growth in solar thermal process heat and introduction of some industrial heat-pump applications. These renewables will need to be complemented first and foremost with energy efficiency measures and eventually with industrial CCS if the aim is to significantly reduce industry's CO_2 emissions in the long term.

Understanding the challenge

Buildings, industry and transport are overlooked when it comes to the potential of renewables, and industry in particular is one area where more attention is needed. None of the REmap countries have specific targets for renewable energy in industry, although REmap analysis shows great potential. Industry is a complex sector with a large variety of inputs and final products, from megatonne-size integrated iron-and-steel plants to small textile workshops. The heat required for various industrial applications, known as process heat, varies by activity, and ranges from 50 °C to more than 1 000 °C.

Bioenergy (including renewable waste) is a renewable energy solution that can provide process heat at all temperatures and scales, but comes with challenges. Its use in other sectors mean competing demand for this limited resource, and supply logistics can be a challenge. Sufficient on-site storage is required, and often customised solutions are needed. The potential of solar thermal and geothermal heat is also large, along with electrification (*e.g.*, heat pumps) coupled with renewables for low and medium temperature heat. However, their integration has been limited up until now as a result of a lack of awareness about their capabilities and costs, which continue to present an important barrier to deployment.

Global renewable energy use in TFEC (excluding district heat) by industry segment in REmap

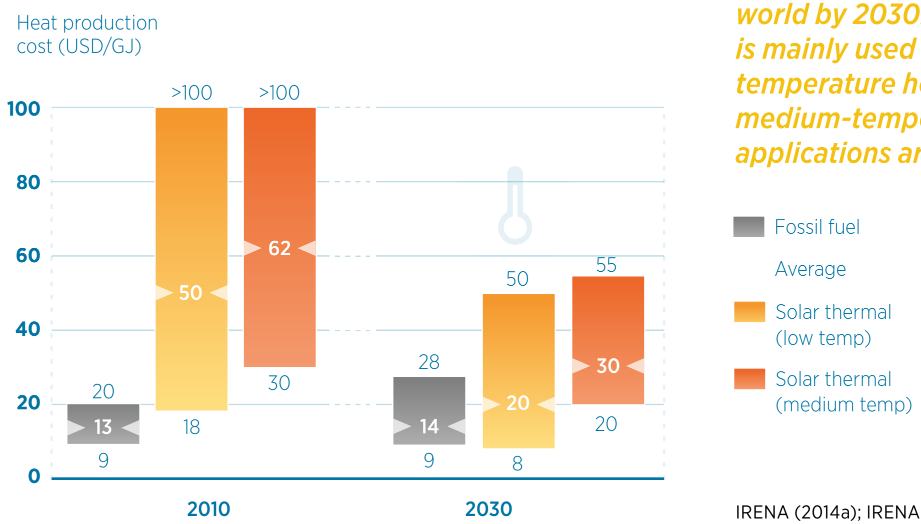


Energy-intensive sectors

Much of industrial energy demand comes from the energy-intensive sectors such as cement, steel and chemicals. Production of these commodities often takes place in large-scale plants. Despite large energy use, the total number of energy-intensive plants makes up less than 5% of total industrial production sites. Additionally these plants and equipment have long service life and are very capital-intensive. By 2030, more than half of current global manufacturing capacity in these sectors will still be in operation. Heating equipment in existing capacity can be retrofitted with bioenergy-based heating, for new capacity different types of renewables can offer potential depending on the process heat temperature requirements.

Bioenergy and renewable waste offer the greatest potential to provide high-temperature process heat that often represents a large share of the total heat demand of these sectors. One example is renewable waste incineration in kilns. Another technology is charcoal use in blast furnaces and other operations of iron and steel making. In view of the limited bioenergy potential, one potential solution for the future is the use of polygeneration plants, which combine production of heat with electricity, transport fuels, chemicals, and

Figure 48: Heat production cost projections from fossil and solar thermal sources, 2010-2030



Solar thermal will be cost-effective in parts of the world by 2030. Today it is mainly used for low-temperature heat, but medium-temperature heat applications are emerging.

IRENA (2014a); IRENA (2014c)

other material. Related technologies and process innovations need further commercialisation and already the well-integrated energy and material flows in production processes of large scale industry plants need to be modified to accommodate renewables equipment.

While planning for renewables, the circumstances that are unique for different production hubs need to be considered as well. Such circumstances typically include energy pricing, for example. In China, India or Russian Federation industrial energy prices are low, providing little incentive for fuel switching. In Japan, the main focus is on maximising energy efficiency driven in part by high energy costs, hence the renewables often play a secondary role. In developed economies, industrial activity is not growing as fast as in emerging ones, so the case for capital expenditure or replacement is difficult to make.

Recent years have witnessed an important relocation of the production of bulk materials such as cement, ammonia and steel from developed countries to developing ones. This is an outcome of economic growth in the latter group and of the rising costs of production in the former. If relocated plants run on power and heat sourced with more emission-intensive fuels, the result will be greater emissions. This problem is known as carbon leakage. There is a risk of more plants being relocated from countries implementing strict climate policies to those with weaker policies. This risk, however, also creates an important opportunity for renewables because relocation can also work the other way around. Plants can move to countries with carbon-free, low-cost renewable electricity (large hydropower, wind, etc).

Small and medium-sized enterprises

More than 90% of all manufacturing plants globally are owned by SMEs (its definition differing somewhat between countries). Energy costs are a substantial part of overall expenses, even for SMEs operating outside energy-intensive sectors. Given the small energy demand per SME plant and the range of process heat temperatures across plants (mainly low and medium temperature), all types of renewable energy technologies are available, and the potential for integration is significant. For example, solar thermal process heat options are particularly suitable for SMEs, because integrating them is much easier compared to, for example, a large-scale chemical plant. This would allow SMEs to reduce their dependency on fossil fuels, which are an important source of uncertainty due to volatility in pricing and changing tax/subsidy regimes. The sheer number of SMEs worldwide offer a customer base large enough for suppliers of renewable energy solutions to scale up production and lower costs as a result. A virtuous cycle could be triggered, similar to the one that has led to significant drop in costs for solar PV technology in the recent years thanks to its increased use for power generation. Leading to economies of scale and speeding up the learning processes of manufacturers and users.

The main barriers to SMEs in adopting renewable energy technologies include the use of aging and inefficient equipment, and awareness of the potential benefits. As SMEs are often organised in clusters and participate at specific stages in the value chain of a particular product, identifying renewable energy options to integrate at all steps in that process, and on a regional level, could prove to be an effective strategy. Table 4 provides an example of such a cluster-specific approach for selected sectors in India.

Table 4: Renewable energy use by India's foundries and dairies: opportunities and barriers

Sector-specific opportunities in selected sectors in India

	Opportunities	**Barriers**	**Solutions/strategies**
Foundry	Short payback times	Small percentage of costs	Technology transfer between clusters
	95% of SMEs in clusters	Highly competitive	
Dairy	Production in areas with hight solar resource	75% of farms are small scale	Renewable energy technologies can support changes in supply chain structures
	6% reaches market place	Highly diverse players	
	Hot water for hygiene	Quality is important	
		Limited measurements	

IRENA (2014c)

A combined-technology approach for industry

Renewable energy will go a long way toward reducing industrial emissions, but cannot alone meet the long-term goals of climate policy. Implementing CCS and continued improvements in energy efficiency will be equally important. How these two approaches are used will differ across the industrial sector, depending on factors such as plant size, local temperatures, fuel availabilities and what technologies are best suited to local conditions.

Recommended for further reading:

Renewable Energy in Manufacturing Technology Roadmap
(IRENA, 2014c)

Production of Bio-ethylene Technology Brief
(IRENA and IEA-ETSAP, 2013)

Production of Bio-methanol Technology Brief
(IRENA and IEA-ETSAP, 2013)

Solar Heat for industrial Processes Technology Brief
(IRENA and IEA-ETSAP, 2015a)

02 SOLUTION 2: RENEWABLE APPLICATIONS IN INDUSTRY

Recommended actions for policymakers and stakeholders	Examples and regional applications	Timeframe
Create SME clusters to bundle expertise. Promote renewable energy use along supply chains. Explore efficiencies and renewable energy synergies, such as using heat pumps.	Best suited to developing countries with large SME bases.	For REmap Options before 2030
Use more renewable waste fuel for cement, lime, and other non-metallic mineral production kilns.	Applicable everywhere. Regional and national sector specific initiatives, similar to best-practice exchanges, as well as data-and-technology information collection efforts are required to promote renewable energy use in the industry sector.	For REmap Options and Doubling Options before 2030
Locate energy-intensive industries near renewable energy resources or supply routes.	Hydropower cluster incentive plan in **Ontario**, Canada; locating servers in cold climates to lower cooling costs; RE100, a collaboration between some major multinational corporations, aims to increase the use of renewable electricity in companies.	For Doubling Options before 2030
Where no other renewable alternatives exist, use bioenergy for high value-added application, such as high-temperature heat generation or as raw material for chemicals	A **Chilean copper factory** has the largest installed solar process heater. **India** operates a number of concentrated solar thermal plants for process heat. **Brazil** runs blast furnaces on charcoal. These technologies are especially relevant for countries with major energy-intensive industrial activity, such as **China, India, Russian Federation, Brazil, Japan**, and the **United States**	For REmap Options before 2030
Foster the use of biogas and continue to develop and deploy solar thermal for higher process-heat temperatures. Electrify high-temperature processes (such as blast furnaces) where possible.		For Doubling Options and post-2030
Incentivise the user of heat pumps and create awareness about their capabilities for low-temperature process heat.	The food industry in **Japan** is leveraging more heat pumps	For REmap Options before 2030
Develop polygeneration for bioenergy use to combine the production of electricity, heat, transport fuels, chemicals, paper, food and other materials.	Several bio-refineries operate in **Canada, Finland** and the **United States**	For Doubling Options and post-2030

03 SOLUTION 3: RENEWABLE HEATING AND COOLING IN BUILDINGS

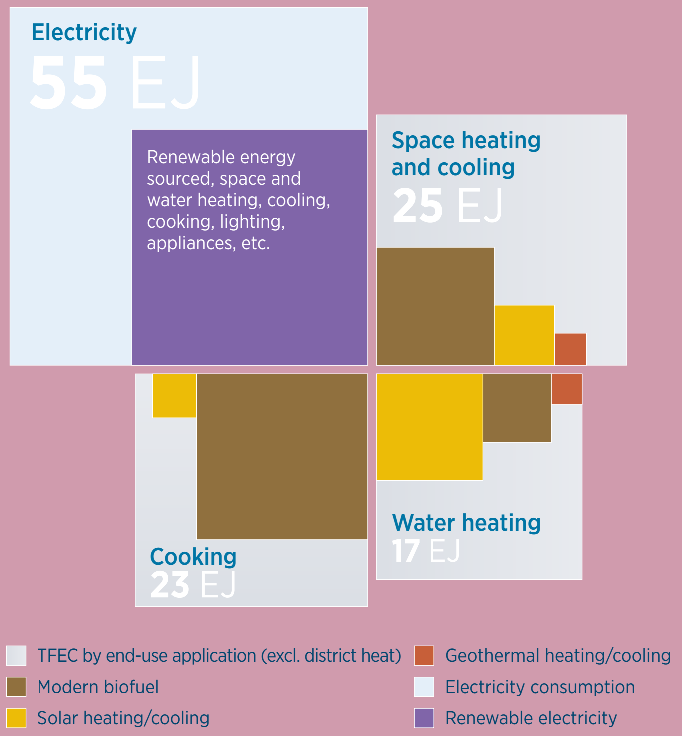
Demand for both water and space heating and cooling are rising fast. With the REmap Options, 38% of buildings' total energy demand can be met by renewables, a higher share than for industry and transport. Renewable energy can be a main solution through district heating and cooling. In addition to increased energy efficiency, would allow renewable-sourced energy meets a greater share of the growing energy demand in buildings. With implementation of the REmap Options, modern bioenergy use for heating in buildings would double to 1.1 billion tonnes between today and 2030, and installed solar water heater capacity would grow six-fold from 530 to 3 200 million square meters (m²).

Understanding the challenge

Despite the considerable potential for heating, only about 50 countries have supported the sector with policies specific to buildings. That stands in contrast to the power generation sector, where more than 120 have established renewable energy policies (IRENA, 2015m; REN21, 2015). Renewable cooling is another area with significant potential that remains largely unaddressed.

One explanation is that there are some significant challenges. One is the mismatch between expenditure and benefits – it would typically be the owners of buildings who would make the improvements, but the tenants of them would see the savings. Some early-stage solutions that could overcome this issue include green leases, which factor in these considerations by aligning financial incentives so that both parties benefit from adopting measures.

Global renewable energy use consumption in end-use applications (excluding district heat) and in electricity for buildings in REmap



03 SOLUTION 3:
RENEWABLE HEATING AND COOLING IN BUILDINGS

The turnover rate of the building stock is also a key factor, as it is easier to build for renewable energy use than to retrofit an existing building to do so. In certain countries where energy demand is either growing slowly or projected to decrease (such as some of the European Union countries), building renovation rates are generally low. Instead, reducing demand for energy is typically a first choice.

District heating and cooling as the main technology options

According to the findings of REmap, buildings have a large potential to benefit from a wide range of renewable technologies to realise a tripling of their modern renewable energy share between today and 2030. These include all forms of modern bioenergy, solar water heaters, geothermal heat pumps and renewables-based electricity.

Typically an overlooked strategy to increase buildings renewable energy share is district heating and cooling, which at the wider neighbourhood level can play a key role, especially in areas where building stock is growing. Seasonal storage for both cold and heat will also allow excess energy to be collected for use later.

Energy demand for heating is highest in most parts of North America, Europe (including Russian Federation) and northern areas of Asia, such as in China. The demand is increasingly met with district-heating networks, as opposed to individual boilers. District heating currently meets almost all demand in cities like Helsinki, Finland, and Copenhagen, Denmark. Overall, these systems cover 13% of the current European heat market for buildings in both residential and commercial sectors.

District heating networks can recover and reuse waste heat from distributed cogeneration units and heat plants, thereby increasing efficiency. These networks can also enable larger amounts of renewable heat to be consumed. Furthermore, district heating networks can also serve to store renewable heat, thereby playing the role of a facilitator similar to the function of an electricity grid for renewable electricity. As such, district heating networks will play as important a role in the heat sector as grids do in the power sector. A mix of renewable energy technologies including bioenergy, solar thermal, geothermal and heat pumps can provide district heating to buildings and industry. A number of countries already use bioenergy in existing networks, including Denmark, Russian Federation, Sweden and Ukraine.

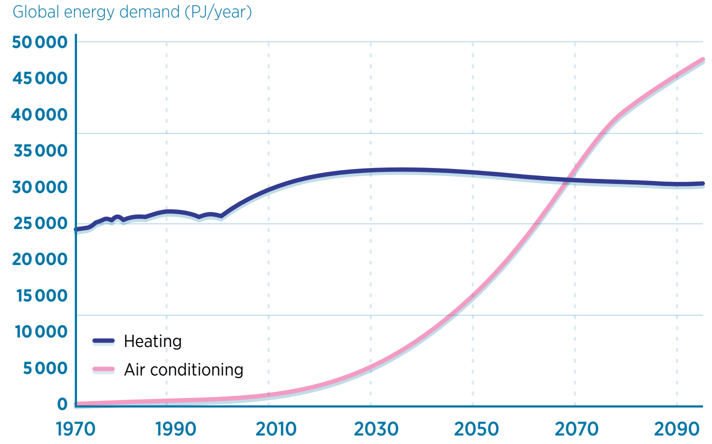
District heating can also help to accommodate higher shares of renewable-powered facilities in which output varies with weather conditions, such as solar or wind power. This can be handled with large-scale thermal storage, which is cheaper and more effective than building-level storage. District-heating networks are also needed for large cogeneration units, which can be an important source of balancing power in the electricity grid.

The growing demand for cooling

Space cooling demand is generally high in hot regions, and demand for cooling is growing rapidly worldwide as more people in developing countries can afford air-conditioning. Household appliances are another source of demand for energy as people move from poor to middle-class. The share of Chinese households with refrigerators grew from 7% to 95% from 1995 to 2007, for example (IRENA, 2014b). In 2010, 50 million new domestic air-conditioning units were installed in China (Cox, 2012). While the total number depends on the number of units installed per home, at most 50 million homes or less have air-conditioning units today. This compares with the existing level of 100 million air-conditioned homes in the United States in total, illustrating the scale of demand growth. In Mumbai, India, electricity demand for space cooling requires 40% of peak power demand, and the number rises to almost 75% in Saudi Arabia. Because cooling demand peaks when the greatest amount of electricity is generated from solar PV, there could be an important synergy here that makes solar PV a solution.

District cooling networks cut energy consumption by 40-45% as well as reducing noise pollution. Similar to district heating, district cooling can also facilitate VRE by functioning as a storage element or providing flexible loads for utilities. This method is increasingly popular in several Middle Eastern countries, but not necessarily linked to renewables. In the United Arab Emirates, district cooling accounts for 10% of the space cooling market. The cooling sector in the country as a whole is estimated to be worth around USD 1.5 billion annually. This district network will not use renewables directly, but link to the country's power grid, which is sourcing an increasing proportion of electricity from new solar PV plans in the planning stages now.

Figure 49: Projected global energy demand for heating versus cooling, 1970-2100



Source: Isaac and van Vuuren (2009)

Energy demand for cooling in buildings will overtake demand for heating.

The role of cities

In developing countries with fast-growing and often urban populations, infrastructure development must meet that pace. Globally, about 5 billion people are expected to live in cities by 2030. That compared with less than 4 billion at the end of 2014 (UN, 2014b). Today cities represent over 70% of global energy consumption and provide a roughly equivalent share of energy-related CO_2 emissions (The New Climate Economy, 2015). As population and economic growth accelerate urbanisation, the demand in cities for clean, reliable and affordable energy will increase exponentially. Significant efforts in urban planning are therefore key in addressing the greater integration of renewables in heating and cooling.

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03 SOLUTION 3:
RENEWABLE HEATING AND COOLING IN BUILDINGS

Local governments can play an important role here, by encouraging, enabling, and regulating the increased uptake of renewable energy. Even for cities that do not directly control power generation, options exist to drive clean energy use. Cities and local governments, as managers of local infrastructures, can develop solutions that integrate energy for users in as buildings, industry, transport, waste, or sanitation.

The New Urban Agenda – the outcome document that is to be agreed upon at UN Conference on Housing and Sustainable Urban Development (Habitat III) in October 2016 – will guide the efforts of cities and a wide range of other actors for the coming years (Habitat III, 2016). This agreement could have sustainable energy as one of its integral parts. Effective ways to pursue renewable energy specific objectives, which could be embedded in this document, include the introduction of solar water heating requirements, the establishment of mandatory and enforced disposal fees for municipal solid waste (in order to drive waste-to-energy solutions), and the enactment of public-private partnership frameworks in order to increase financial resources and expertise.

Recommended actions for policymakers and stakeholders	Examples and regional applications	Timeframe
Focus on efficiency as a first step to lowering demand for heating and cooling, so that the same amount of renewable energy can meet as much of demand as possible.	A number of **East Asian countries** lead the way in the energy efficiency of buildings, which is relevant for all countries but especially those with fast growing building stock and new urban areas.	For REmap Options before 2030
Consider mandates for district heating-and-cooling systems where they make economic sense, particularly in order to expand renewables in urban areas. Use district heating and cooling networks for energy storage.	**Denmark** promotes district heating based on renewable energy; the **United Arab Emirates** is developing several district cooling plants powered by a grid that is set to be supplied by an increasing share of solar PV. Sector specific regional and national deployment of technology initiatives are required.	For REmap Options before 2030
Use solar water heaters and heat pumps. Design new buildings for low-temperature heating and cooling. Maximise building-integrated photovoltaics.	For buildings, **Barcelona** and **Sao Paolo** have recently implemented solar thermal ordinances, which establish a minimum share of heating demand which must be met by solar energy. **Denmark** and **Germany** have both banned oil-fired heaters in new buildings and renovations. The **European Union**'s Nearly Zero-Emissions Buildings will include on-site solar power production. **China** has installed more solar water heaters than the rest of the world combined.	For REmap Options before 2030
Utilise synergies between cooling demand and solar energy availability.	Two renewable cooling schemes in **United Arab Emirates** with absorption chillers using Fresnel parabolic troughs and evacuated flat panels	For REmap Options before 2030
Develop geothermal heating and cooling for space heating and for seasonal storage options.	**Switzerland** operates a number of modern geothermal seasonal storage systems.	For REmap Options & Doubling Options before 2030

04

SOLUTION 4: ACCELERATED RENEWABLE ENERGY INVESTMENT

Implementing the REmap Options would require investments of USD 770 billion per year on average between 2016 and 2030, implying that renewable energy capital expenditure should increase by about 9% a year from current levels. Although in absolute amounts the renewable energy investment requirement is rising, there will also be savings from fossil-fuel investments as a result. Hence, additional investment needs to 2030 are estimated to be on average less than USD 100 billion per year.

Global investment needs for renewable energy capacity

Since 2011 there has been little growth in overall renewable energy capacity investment (Figure 50). This is more a function of falling costs for solar PV than the number of project shrinking. In the Reference Case for 2030, this trend is expected to remain unchanged; the continuing reductions in the cost of renewables largely offset increasing installations. IRENA's preliminary estimate of investment in renewable energy capacity in 2015 is around USD 360 billion, of which about USD 330 billion went to the power sector and the rest to buildings, industry and transport. For the latter, only the spending on liquid biofuel processing plants is included.

Implementing REmap Options, however, would require an annual investment in renewable energy capacity averaging USD 770 billion per year from 2016 to 2030. This represents an increase of about 9% per year from 2015 levels, reaching USD 1.3 trillion in 2030, if a linear growth path is assumed (green bars in Figure 50). IRENA's analysis found that this rate of increase is realistic based on recent precedent: from 2007 to 2011, the increase was 13% per year.

The total required investment up to 2030 amounts to USD 11.5 trillion, USD 5.9 trillion more than the USD 5.6 trillion estimated for the Reference Case. The difference equates to on average USD 375 billion per year in 2016-2030. No additional infrastructure investments are taken into account in these figures to accommodate the higher shares of renewables in the energy mix. Infrastructure related to additional electrification, such as EVs and heat pumps, are also excluded.

In assessing the feasibility of this level of investment, it is important to understand that investment needs will decrease along the fossil-fuel supply chain when all REmap Options are implemented. Avoided investments in non-renewable power capacity alone are estimated at USD 1.5 trillion to 2030, or about USD 100 billion per year on average in the 15-year time period. Almost half of these savings would come from not building coal-fired power plants; another 30% from nuclear investments seen as no longer necessary.

Another source of avoided investment is on the supply side, including extraction, refining and transport of oil, gas, and coal products, which is estimated at USD 150-250 billion per year. Up to two-thirds of this total is from infrastructure for new oil production. While the impact of the REmap Options on oil demand in energy terms is much lower than that on gas and coal, in terms of investment these impacts outweigh those on other fuels. In North America, Europe, and parts of Africa, it is estimated that close to USD 400 billion in capital expenditure on oil supply has been shelved since 2014 due to oil prices falling below

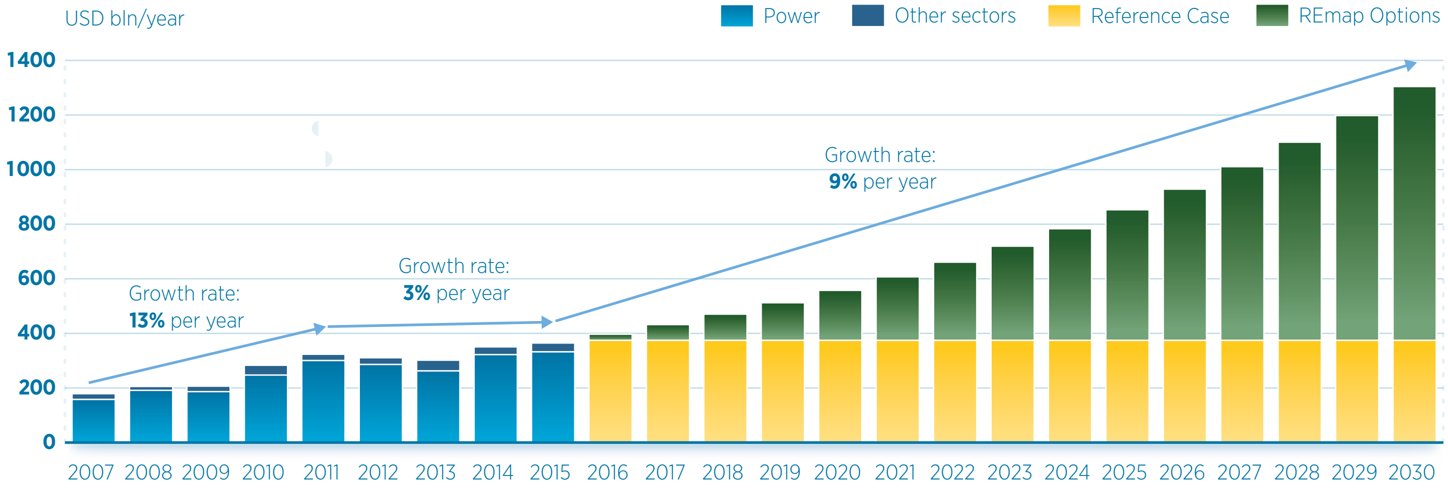
03

Investments in renewable energy capacity have to return to a steady growth path.

Note: Historical power numbers are based on BNEF estimates for asset finance and investment in small distributed capacity, and IRENA estimates of investment in large-scale hydropower. Other sectors as estimated by IRENA; estimates include renewable energy investments in district heat, transport (liquid biofuel production), industry and buildings (geothermal, solar thermal, and bioenergy).

Based on IRENA estimates and Bloomberg New Energy Finance (BNEF, 2015)

Figure 50: Renewable energy capacity investments, 2007-2030



extraction costs (Wood Mackenzie, 2016). With a growing share of renewables in the energy mix, the oil industry in these regions will be further impacted in the future.

When avoided investments in non-renewable power capacity and the supply chain are accounted for (total of USD 4.5 trillion), the net additional investment needs to implement the REmap Options amount to USD 1.4 trillion, or about USD 100 billion per year on average between 2016 and 2030. A majority of the additional investment needs for REmap Options can thus be mobilised by reallocating investment funds from fossil fuels to renewables. One important consideration is that these calculations do not account for savings in operating and fuel costs, but merely refer to upfront capital expenditures.

Investment needs by technology, sector, and country

The power sector would account for more than 80% of the total investment needed annually to 2030, averaging USD 634 billion per year. Wind would provide about a third of that total, at just over USD 200 billion per year. This represents a doubling of the estimated USD 100 billion that was invested in wind power in 2015. The required investment needs for solar energy (including PV and CSP) capacity almost equals that of wind, at USD 196 billion per year from 2016 to 2030. In 2015, investments in solar PV were estimated at close to USD 150 billion, implying the increase needed to meet the targets is larger for wind than it is for solar. This is because of the expectation of a continued and sharp decline in PV costs. In terms of GW required, solar PV installations are required to increase significantly with REmap Options (up to about 92 GW per year); the additional volume is largely offset by the lower capital expenditures per installed GW.

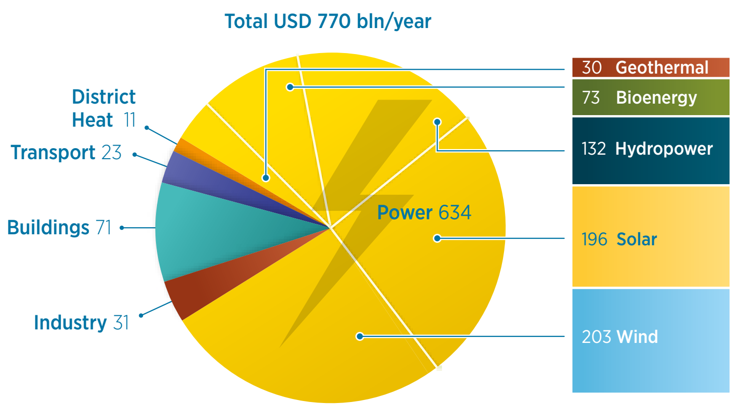
Hydropower accounts for another USD 132 billion per year from 2016 to 2030. With annual financing of hydropower at around USD 60 billion per year in 2011 to 2015, this implies investment more than doubling from current levels. The capital cost for hydropower is not expected to decrease significantly going forward. Lower technology costs over time are offset by an increase in site-specific costs; as low-cost locations are likely to be exploited first, with higher-cost ones to follow.

Beyond the power sector, buildings require the largest amount of investment, at USD 71 billion per year on average between 2016 and 2030, implying a tripling of historical levels. Solar water heaters account for the majority of the required investment in buildings. For industry and transport the investment opportunity is less, at around USD 31 billion and USD 23 billion per year on average, respectively. That includes capital expenditure related to biofuel processing plants but does not account for the investments needed for EVs and related infrastructure (*e.g.,* charging stations). The required investment in the power sector is higher compared to the rest of the energy system because the REmap Options in power are more ambitious in absolute terms, and because the sector is more capital-intensive. Fuel substitution is often more relevant in buildings, industry and transport.

Three countries account for nearly half of the total estimated investment needs: China, India and the United States. In China, financing of renewable energy projects in the power sector alone reached close to USD 130 billion in 2015, which is on pace with the REmap Options. China's rapid increase in renewable investments (which more than doubled between 2011 and 2015) demonstrates the feasibility of achieving the investment path demonstrated according to REmap. In the United States, investment in renewable power has remained stagnant in recent years at around USD 30 billion per year, and would need to roughly triple from current levels to implement the REmap Options. India would need to catch up as well: the country has financed less than USD 10 billion per year of renewable power projects in recent years. With the REmap Options, this amount would increase to close to USD 60 billion per year until 2030.

SOLUTION 4: ACCELERATED RENEWABLE ENERGY INVESTMENT 04

Figure 51: Investment in renewable power generation capacity with REmap Options, 2016-2030



The power sector represents more than 80% of required investment to implement the REmap Options.

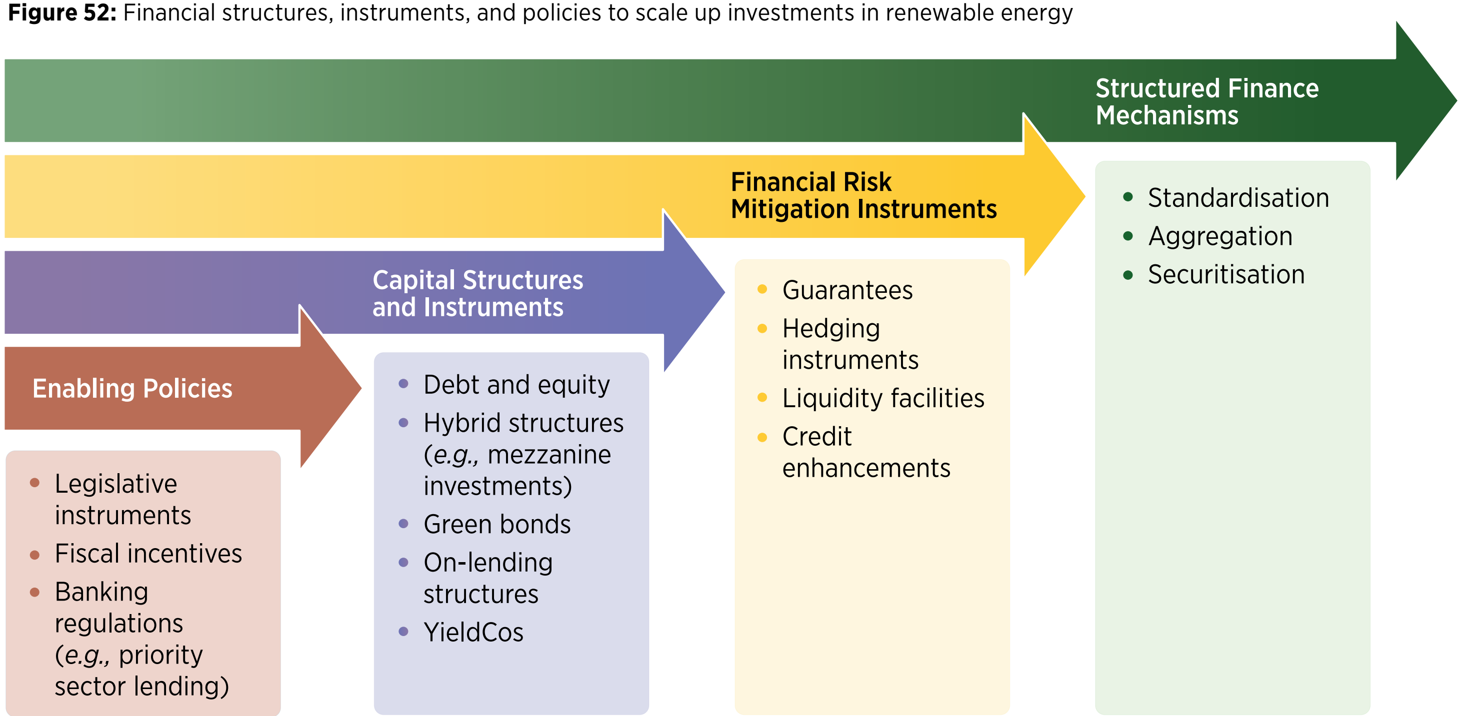
Based on IRENA estimates

Mobilising investments

Renewable energy is recognised as one of the primary ways to reach the targets set at the COP21, in part because implementation can be scaled up relatively quickly through technologies available today. The private sector will be important to achieve the required additional investment needs, and though significant progress has been made in specific geographies and sectors, there is potential still to be met. To a large extent this is due to the perceived risk associated with renewable energy investments. Especially in developing countries, macro-economic risks such as political instability and currency volatility combine with project-specific risks like off-taker reliability and grid connectivity to cause investors to demand a return higher than what is on offer.

Policy makers have an important role to play in closing this gap. The share of public funding for renewable energy is not expected to increase above the current level of 15% (IRENA, 2015n). Policy makers are instead expected to use the instruments at hand and partner with international organisations to mobilise private capital (see Figure 52).

Figure 52: Financial structures, instruments, and policies to scale up investments in renewable energy



IRENA (2016e forthcoming)

To start, governments must put in place enabling policies and regulations to ensure stable and predictable investment environments. Setting clear renewable energy targets and formulating dedicated policies to implement them will provide strong market signals. While countless examples exist of countries that in recent years have accelerated renewable energy uptake through dedicated and stable policies, there have also been numerous cases where sudden changes in policy support have had a detrimental impact on investor confidence and, as a consequence, on renewable energy installations. Policies that are efficient and effective are key; IRENA is supporting policy makers in this regard (IRENA, 2015o).

It is also important to provide active support beyond the power sector, for renewable energy investments in transport, industry, and buildings. Harmonising targets and initiatives at national, regional, and municipal levels is crucial. German state-level renewable energy plans, for example, collectively exceed national targets, and there is a similar lack of co-ordination between federal and state governments in Canada, Nigeria, Russian Federation and the United States.

Policy makers should also focus on reducing the duration of project implementation by improving regulatory frameworks. Streamlined planning procedures greatly reduce "soft costs" such as permitting and paperwork. In Germany, for example, a homeowner can receive approval for a solar rooftop unit in just a week, whereas such a project can take months in other countries. At the same time, creating public support for renewable energy early on is important. Resistance of local populations to infrastructure expansion, such as opposition to unsightly wind turbines in residential areas, could pose barriers to executing plans later on. To increase awareness, and to support workforce requirements for the energy transition, policy makers can facilitate the inclusion of renewable energy in existing and new educational programmes, and increase awareness of the career opportunities in renewable energy to attract young people entering the sector, as well as experienced workers from other industries with relevant skills (IRENA, 2015c).

Second, capital structures that allow for an optimal balance of equity and debt - and include hybrid structures such as subordinated debt and convertible loans - should be made available to renewable energy project developers. This is especially relevant in developing countries, where access to affordable financing options is often relatively limited. The availability of risk capital (investors tolerant of high-risk projects) could be increased through public-private co-lending structures between international financial institutions (IFIs) - such as development banks, green banks, and climate funds - and commercial banks and institutional investors. IFIs could develop or expand existing renewable energy equity funds or use dedicated funds to support existing private equity investments in renewables. Likewise, institutional investors could increase their capacity to lend to renewable energy private equity funds, potentially via IFI-led fund-of-fund structures.

IFIs can also help with technical assistance and developing pilot projects to could serve as examples for commercial banks. In this way the number of planned projects that qualify as bankable could be increased. This is especially important in order to mobilise investment in new technologies, sectors, and markets. IRENA's Project Navigator (**https://navigator.irena.org**) and Sustainable Energy Marketplace (**http://marketplace.irena.org**) tools are useful to support early-stage development of renewable energy projects, and to bring together projects and investors.

Third, existing financial risk-mitigation instruments could be scaled up and new ones could be developed. These products include

04 SOLUTION 4: ACCELERATED RENEWABLE ENERGY INVESTMENT

credit enhancements (*e.g.,* loan-loss reserves), guarantees, hedging instruments, and liquidity facilities. Guarantees, for example, can leverage between 1:3 and 1:15 of investment, including in markets with challenging political and regulatory environments. IFIs and export credit agencies could both make an impact here by expanding their offering, while insurance companies could scale up existing policies for renewable energy construction, especially in developing markets.

Finally, structured-finance mechanisms play an important role in broadening the investor pool to institutional and other large-scale investors. Refinancing vehicles that pool assets such as climate bonds are primary examples in which the standardisation, aggregation, and securitisation of assets lowers transaction and due diligence costs for investors. The expansion of their use in new sectors and regions should be promoted. Experienced financial institutions have an important role to play, especially in emerging markets, in sharing expertise in these more complex financial structures.

Recommended for further reading:

Renewable Energy Auctions: A Guide to Design *(IRENA, 2015o)*

REthinking Energy: Renewable Energy and Climate Change *(IRENA, 2015n)*

Unlocking Renewable Energy Investment: The Role of Risk Mitigation and Structured Finance *(IRENA, 2016e forthcoming)*

Recommended actions for policymakers and stakeholders	Examples and regional applications
» Countries should put in place enabling policies to support a stable environment for investment in renewables. » Long-term stability is crucial for policies, the harmonisation of policies at different levels of government, and the streamlining regulatory frameworks.	**China** has more than doubled renewable energy investment over the past 5 years; **Germany** has some of the most efficient markets for rooftop solar PV. Policy makers in countries new to renewable energy or that plan to stimulate renewable energy in new sectors can learn from these kinds of examples.
» Increase the availability of risk capital in renewables through public-private partnerships. » International financing institutions play an important role in leveraging investments made by private investors. » Use IRENA's Project Navigator to support early-stage developments. » IRENA's Sustainable Energy Marketplace identifies attractive projects as well as potential investors, allowing both types of actors to connect with each other.	Especially relevant in emerging markets, and to increase investments in technologies and sectors that are currently lagging, such as buildings, industry, transport and niche power technologies. New Deal on Energy for **Africa** by the African Development Bank is an example of an initiative that can lead to new renewable energy markets.
» Mitigate risks to attract private investors by using existing mitigation instruments and public guarantees and by providing technical assistance in developing countries.	The **Mexico** Geothermal Financing and Risk Transfer Program expects to use USD 120 million in public financing to catalyse USD 1 billion in private sector geothermal investment.
» Promote the use of structured-finance mechanisms that bundle projects together for investment and in turn lower due diligence and transaction costs. » Leverage the expertise of financial institutions in new sectors and regions.	Solar companies in the **United States** have created investment vehicles to fund construction costs and acquire operating assets, and this model could be expanded in different markets and for other technologies. One of the five options outlined in the G20 Toolkit aims for the development of a renewables-specific risk mitigation facility.

THE IMPORTANCE OF COST OF CAPITAL

The cost of capital is an important driver in the competitiveness of renewable energy across time, regions, and technologies. With record-low interest rates, especially in developed countries, the required return on capital today is at historically low levels across investment opportunities, including renewable energy. In comparison with fossil fuels, the impact of a lower cost of capital particularly favors renewables, as typically more is invested upfront, while operating expenditures throughout the project lifetime are lower.

Nevertheless, investments in renewable energy are still perceived as more risky than investments in conventional technology, generally leading to higher cost of capital. The sector is still relatively new, and long-term track records are lacking; standardized methodologies are still rare compared to conventional technologies, and regulatory frameworks are not yet well established in many countries. Financial risk mitigation mechanisms could help increase levels of investment and lower costs.

Across regions, there are significant differences in the cost of capital for renewable energy, linked to differences in borrowing cost, inflation expectations, availability of capital, and the market acceptance and policy stability related to renewable energy. Low interest rates in Germany, for example, partly explain why the cost per produced kilowatt-hour of a solar PV plant there is similar to that in Jordan, a country with a much better solar resource. REmap addresses these country differences by assuming interest rates that range from 3% in Japan to 20% in Iran when calculating the substitution cost to businesses of identified REmap Options. These data points, mainly obtained from country experts, are benchmarked against country bond yields to make sure no major inconsistencies between countries are included. A recent study focused on the EU (Noothout *et al.,* 2016) confirmed that large differences exist across countries, with the rates between member states varying due to different debt cost, leverage ratios, and country and policy risks.

In addition, there are differences in the cost of capital between technologies. Solar PV projects, for example, structurally come with a lower cost of capital than wind power projects. Although more wind power has been installed globally than solar PV, it therefore seems that inherent risks related to wind power (such as more moving parts and more difficult resource predictability) outweighs technology and market maturity. Differences in the cost of capital between technologies are not yet addressed in REmap. Obtaining technology-specific cost of capital data across technologies for all 40 countries would be a huge undertaking. However, it is one area in which IRENA plans to add more detail in 2016/2017. For a typical wind project, for example, assuming a 10% instead of a 5% discount rate increases the estimated generation cost by more than one third.

05 SOLUTION 5: INTERNALISING EXTERNAL COSTS

If the external cost of fossil fuels were adequately reflected in energy prices, the additional cost of the REmap Options and Doubling Options would be more clearly cost-effective in comparison. Whilst quantifying externalities remains challenging, it is clear that renewable energy can save up to an estimated 4 million lives by 2030 related to air pollution from fossil fuels.

Understanding the challenge

The external costs related to the use of fossil fuels stem from many sources, such as the pollution and environmental degradation caused by the extraction of resources, indoor and outdoor air pollution, and the negative economic impacts of extreme weather events caused by global warming, such as its impact on agricultural yields.

According to the World Health Organisation's (WHO) latest estimates, household air pollution has resulted in the premature deaths of 4.3 million people in 2012. The South East Asian and Western Pacific regions (according to the WHO's geographical groupings) have the highest number of premature deaths with 1.7 and 1.6 million, respectively. One third of the total is caused by strokes, and about a quarter from ischemic heart diseases. Ambient air pollution also results in premature deaths. The total number of premature deaths worldwide has reached about 3.7 million in 2012. Nearly all of this occurred in low- and middle-income countries, with Western Pacific and South-East Asia accounting for by far the largest share. Similarly strokes and ischemic heart diseases account for a large share of the total premature deaths related to outdoor air pollution (WHO, n.d.).

What is clear thus far as renewable energy integrates into the global energy mix is that its costs and savings from reduced externalities are not valued adequately in current market frameworks. If external costs are taken into account, non-renewable energy technologies would be more expensive than renewables. And that is before even considering the significant positive externalities of renewables, such as macro-economic impacts through job creation or trade (IRENA, 2016a).

Reduced cost associated with avoided externalities

According to the Reference case, traditional use of bioenergy, which is a major cause of indoor air pollution, is not yet phased out in 2030. With renewables it can be significantly reduced. Moreover, more than 20% of total coal demand and approximately 10% of the total natural gas and oil demand are substituted with the REmap Options in 2030 compared to the Reference Case. The Doubling Options can increase these savings even further to 36% for coal and to 20% and 15% for oil and gas, respectively.

As a result of these substitutions, a doubling of the global renewable energy share results in reduced externalities of anywhere between USD 1.2 trillion and USD 4.2 trillion per year.

These savings associated with doubling the renewable energy share are 4 to 15 times larger than the cost of implementing them. Arguably, a sizable portion of the externalities related to the traditional uses of bioenergy will shrink anyway under the Reference Case, as households use more modern forms of energy: moving from burning bioenergy in low-efficiency cookstoves to using petroleum products such as kerosene or LPG. However, even when these savings are included in the analysis, renewables still result in a significant reduction of costs associated with externalities.

Without considering the reduced externalities more than half of REmap Options would be cost-effective (*i.e.,* negative substitution costs), and significant investment support would be required, especially if the Doubling Options are implemented. If externalities remain unaccounted for, there is a need for investment support of more than USD 400 billion per year to realise a doubling of the global renewable energy share.

Whilst a tighter range of cost estimates it not yet possible, it is necessary that these costs are internalised in energy prices. This will help save up to an estimated 4 million lives by 2030 and mitigate climate change. It is clear that internalising the costs of pollution provide a more accurate guideline for making policy priorities today.

Oil, gas, and coal prices are currently low and could remain so as renewables continue to grow. Governments should take advantage of this window of opportunity to internalise these large external costs.

One early attempt to incorporate these costs into typical market structures has been carbon pricing, but European Union's attempt to establish a market and a carbon price has demonstrated the pitfalls of this approach when the price of carbon had gone down significantly due to economic crisis in the European Union and associated oversupply of certificates. INDCs do not necessarily take into account the deployment of least cost-effective renewables options. What is important instead is to further reduce the costs of renewable energy technologies, and to set targets for both energy efficiency and renewable energy.

Regulations can also play a role, such as EURO 6 in the European Union (emission standards) or the Corporate Average Fuel Economy (CAFE) fuel efficiency standards in the United States for cars. Regulations are also typical for the manufacturing industry and power plants, but do not necessarily exist in the building sector. Urban regulations, freight transport levies, and so on can also be adjusted to accelerate implementation.

Recommended actions for policymakers and stakeholders	Examples and regional applications
Design energy and environment policies that correct for externalities by considering a carbon price to serve as a proxy for all of them.	**39 countries** and **23 cities**, states or regions are using a carbon price today. **Cyprus** has a flexible levy on energy that is based on oil prices and supports energy efficiency and renewables.
Devote some of the revenue from reduced externalities to support low-income households by compensating them for having to pay higher energy prices.	**British Columbia** has imposed a carbon tax and pays the revenue back each quarter to households with income below a certain level.
Impose specific regulations by transport mode for air pollutants.	The **European Union**'s EURO standards, **Swiss** transit freight transport regulations and the **United States**' CAFE standards.
Present targets for renewable energy and energy efficiency as an alternative to carbon targets. When communicating these targets, raise awareness about how external costs are not included in market prices currently.	Policy alignment for renewables, efficiency, emissions-reduction targets and energy pricing that consider the benefits of sustainable energy technologies.

Recommended for further reading:

Study on external effects of replacing fossil fuels and traditional bioenergy with renewable energy
(IRENA, 2016f forthcoming)

Renewable energy benefits: Measuring the economics
(IRENA, 2016a)

03

06

SOLUTION 6:
VARIABLE RENEWABLE ELECTRICITY INTEGRATION

Solar and wind power are booming worldwide, offering low-carbon electricity at affordable prices. In most countries, significantly more deployment is possible with few technical or economic challenges. Steps can be taken today to pave the way through energy planning, the strengthening of grids, promoting demand side management, and recognising the increasing importance of energy storage.

Understanding the challenge

Currently, the most widely developed VRE technologies are solar PV and wind. Output is correlated to the intensity of the resource at any given time, as opposed to demand for power, and therefore cannot be controlled. Consequently, wind and solar generators cannot follow power demand in the same way as thermal or hydropower generation. This poses specific challenges for grid integration.

Countries that already have high shares of renewable energy contributing to electricity supply have largely relied on dispatchable sources (reservoir and run-of-river hydropower, bioenergy, and geothermal). The share of power generation from variable renewables is still modest or even negligible in many countries. However countries like Denmark, Germany, Greece, Italy, Portugal, and Spain have boosted VRE shares well above 10% by the end of 2014, and the Reference Case shows that 15 out of 40 countries examined will have a VRE share above that threshold by 2030. If all REmap Options identified in this report are implemented, the number jumps to 21 countries with VRE share beyond 20%. For example, the contribution of VRE to total power generation in the United Kingdom could increase from 10% in 2014 to 56%, clearly representing a major challenge. Other countries with high VRE shares when REmap Options are included are Cyprus, Denmark, Egypt, and Germany.

VRE is unfamiliar territory for most utilities and grid operators. Furthermore, the growth of VRE will also attract new stakeholders, including households producing their own electricity, into a sector that traditionally has been dominated by government-owned or private utilities. This will affect grid operations, require new regulation, and updated policies to ensure that both existing and new stakeholders can co-exist. This is why policy makers will have to consider the impacts of VRE well before any potential technical challenges emerge.

One of the broad indicators of the technical challenge is the share of VRE in annual power generation. The influence of VRE becomes noticeable in specific sections of the grid or on certain days when its shares of power generation is equivalent to between 5% and 10% of the annual total (IRENA and IEA, 2016 forthcoming). Beyond these levels a lack of sufficient grid infrastructure may potentially become a problem, leading to for example curtailment of power generation from solar PV and wind. However in most cases no special grid operation measures should be needed until VRE contributes 15% of the total or more. Otherwise specific grid integration measures for different stakeholder groups (*e.g.,* generators, customers, regulators) will be needed (IRENA, 2015p).

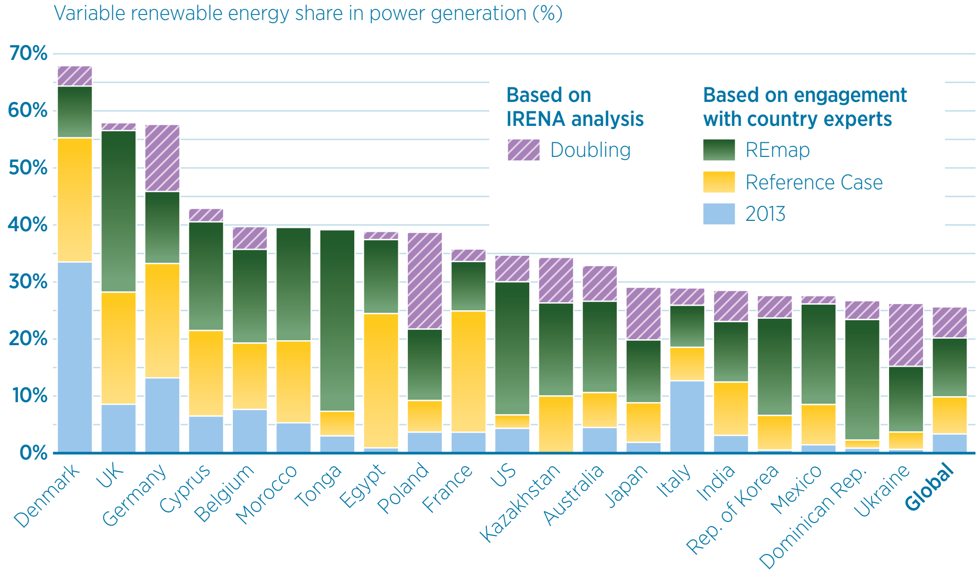
The main technical challenges begin when VRE, because its output level cannot be controlled, pushes demand for non-renewable generation below the minimal operating level of a country's dispatchable fleet. That point – at which production cannot slow any further in those non-renewable energy plants without a complete shutdown – differs from one country to another. But by requiring plants to produce less or switch off entirely in times of abundant renewable power supply, generators are presented with a difficult challenge in balancing supply and demand. Those situations may also have financial implications, depending on the remuneration schemes or market design. In some cases another potential problem is the speed at which non-renewable energy plants can increase production as output from VRE plants drops, and more dispatchable power is needed, including CSP.

How to accommodate higher shares of VRE?

The different levels of VRE shares do not only correspond to technical challenges, but are also associated with the different ownership models available for VRE technologies, the relative ease and speed with which VRE can be installed, the location at which VRE power generation is connected to the grid, and their impacts on price dynamics.

Countries like Denmark, Portugal, and Spain have shown that it is possible to manage systems with more than 25% VRE share in the power supply. The general lesson from the experience so far is that specific sequences and measures for power-sector transformation are highly dependent on local conditions. Policy makers should start early and create national roadmaps reflecting a holistic approach to planning, governance, management and operation. This includes changes to the institutional processes for data collection and energy

Figure 53: Variable renewable energy in power generation by country, 2013-2030



In the Reference Case, 15 of 40 countries will have a VRE share larger than 10% by 2030. With the REmap Options, 20 countries will have a share larger than 25%.

Based on IRENA estimates

planning, an early assessment of and more focus on enhancing existing flexibility options (*e.g.,* flexible generation with fossil fuels, but also range of renewables from bioenergy to CSP, enhanced grid infrastructure (including interconnectors), demand response, energy storage), and to develop experience in applying new technological solutions like smart grids and energy storage. Smart grids incorporate information and communications technology into every aspect of

06 SOLUTION 6: VARIABLE RENEWABLE ELECTRICITY INTEGRATION

electricity generation, delivery and consumption in order to minimise environmental impact, enhance markets, improve reliability and service, and reduce costs and improve efficiency (IRENA, 2013a). These technologies will support new business models and enable the coupling of the power sector with heating and cooling in buildings and industry as well as transport.

Different options can be considered to accommodate higher shares of VRE, which generally fall into four groups: strengthening the grid and interconnectors, flexible generation, demand-side management, and storage.

From a system perspective, research has shown that enhanced flexibility options to accommodate very high shares of VRE can provide reliability at the same costs or cheaper as the existing power generation mix. But for countries with existing electricity-system infrastructure there are costs associated with transforming the existing non-flexible electricity systems. According to the REmap findings, the cost of VRE integration measures by 2030 are at between USD 30 billion and USD 130 billion on an annual basis. These numbers could be somewhat higher if additional transmission investments are needed, for example if the case of the United Kingdom with much higher VRE shares compared to today's level is considered. To put these figures in perspective; the IEA (New Policies Scenario) estimates USD 8.4 trillion of spending on power transmission and distribution lines between 2025 and 2040, or close to USD 340 billion per year (IEA, 2015b).

Strengthening grids

In power systems with increasing shares of VRE, one of the main challenges is to ensure that the grid infrastructure is sufficient to geographically match supply and demand, and smart-grid technologies can help. Grids can also be enhanced and expanded to increase the capacity to move loads over long distances when necessary. China has built 5 000 kilometres of Ultra High-Voltage Direct Current (U-HVDC) transmission lines across the country to connect resources to demand centres, and Germany is discussing similar lines to ensure that wind power in the north and solar power in the south can be transmitted to different consumption centres (IRENA, 2014b).

Using interconnectors more effectively to move power between regions and countries, creating power pools in which they are members, is also a flexibility option to be considered to better integrate VRE with non-renewable power by allowing the use of a diversity of different systems that bring synergies. Hence VRE sources can complement each other at different times and in different regions, in the process reducing the need for back-up capacity and congestion management (IRENA and IEA-ETSAP, 2015b). For example, the European Union has agreed that all members should develop interconnection capacity that represents at least 10% of total installed electricity production by 2020, with an aspirational target of 15% by 2030. The Scandinavian Nord Pool power exchange is a best-practice example of how interconnections in combination with regional markets can help renewables.

Data collection on existing bottlenecks and long-term grid infrastructure planning are important to ensure the adequacy of transmission and distribution capacity at all times. For example, new grids can be planned and deployed in line with VRE targets, avoiding the need for later retrofits. Energy efficiency policies can be used to reduce grid investment needs, and smart grids can reduce the costs of asset management. Planning can also facilitate the necessary investments in grid infrastructure to modernise or expand existing grids to meet these new requirements. Investment of at least USD 4 trillion for grid expansion and USD 2.7 trillion for grid refurbishments is expected on a global basis by 2035 (IRENA, 2015p), demonstrating that governments view grid development as an important part of future energy plans. However, there is a need to improve the time required for administrative authorisation processes when adding long-distance transmission capacity.

Flexible generation

Flexible generation of electricity using non-variable renewable energy is another important option to complement VRE. Bioenergy and large-scale hydropower facilities (excluding run-of-river installations) can serve this purpose. Denmark has been able to reach its unsurpassed level of wind power (at close to 40% in 2014) thanks to hydropower imported by Norway. Hydropower can play a primary role in the transition towards clean energy because where it exists it is usually on a very large scale and production can be lowered easily, so it can stabilise electricity systems in countries with very large shares of renewables.

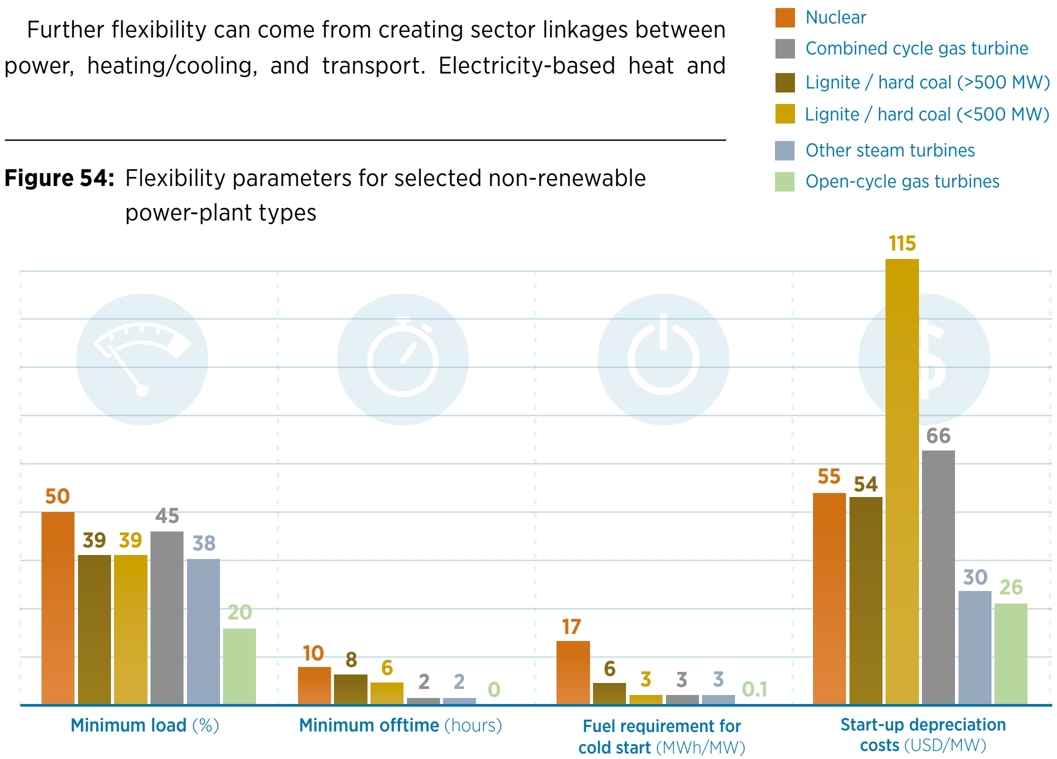
Amongst non-renewable options, open-cycle natural gas turbines are the most flexible, by a wide margin, and typically the least expensive (Figure 54). A bank of reciprocating engines can provide even more flexibility as they start quicker and employ lower turn down and steeper ramps. Coal plants are less flexible because boilers first have to be heated with oil. Nuclear reactors are generally the least flexible. The downside to open-cycle natural gas turbines is lower efficiency and higher CO_2 emissions compared with combined-cycle systems.

Demand-side management

Demand-side management can take the form of encouraging system customers to maximise their use when supply is naturally high, for instance when wind and solar PV are producing at their peak on windy or sunny days. This may require using smart meters (a technical measure) and/or setting prices to incentivise customers (a market measure).

Further flexibility can come from creating sector linkages between power, heating/cooling, and transport. Electricity-based heat and

Figure 54: Flexibility parameters for selected non-renewable power-plant types



There are significant differences in the flexibility parameters of different non-renewable power-plant types; open-cycle gas turbines are the most flexible.

Source: DIW (2016)

transport capacity are expanded greatly in REmap Options. EVs can allow for additional flexibility through smart charging. Demand response also can occur through electrification of the heating sector, for example, by shifting the supply of heat in the building sector to account for peaks in electricity supply. A common method of implementing such sectoral linkages is to use heat pumps that can operate on a flexible schedule to supply heating or cooling services. Moreover, smart thermal grids (district heating and cooling) can effectively connect the electricity and heating sectors, adding flexibility through thermal storage.

Role of electricity storage

For the countries in which VRE shares are estimated to reach high levels, electricity storage options are becoming increasingly relevant. These include three types of countries, namely with a VRE share estimated to exceed 30%, those at 20% or higher but with constrained grid infrastructure, and countries that are islands, or have islands within their own systems, or those that rely on remote off-grid systems. Except for pumped hydropower, however, the cost of storing electricity for later consumption is generally higher than the cost of new production (except for very short-term storage for grid stabilisation).

Worldwide, total storage capacity reached 150 GW of pumped-storage hydropower and 2 GW of stationary battery storage by the end of 2014 (IRENA, 2015k). Assessments of pumped hydropower plans in the 40 REmap countries suggests that global capacity will double to 300 GW in 2030. While other storage technologies such as super capacitors are still relatively expensive, they are developing rapidly. Storage technologies can also be used to provide a range of grid-support services, such as improving stability (IRENA, 2015k).

Another development that will impact the integration of VRE is the use of batteries to increase on-site consumption. It will be crucial to ensure that these systems are used effectively in aggregated fashion to support the grid when needed.

In developing countries, PV with storage is becoming increasingly popular to provide electricity to rural regions without any transmission or distribution networks. Although these systems are relatively small (often only one solar panel), new distribution network technologies are being developed to connect these solar home systems in order to create local community networks. As such, this emerging infrastructure could become the basis for rural grid infrastructures.

Solid biofuel or biogas-based CHP can be switched on any moment to supply renewable power and heat. EVs provide opportunities for storage in two ways. First, batteries that have reached the end of their useful lifetime in vehicles can still be attached to the grid for a second life. Already, car makers in Germany are looking at recycling batteries that are too depleted to be used in cars in meeting the growing demand in the country for residential battery storage systems (Mearian, 2015). As batteries have 8 to 10 years of warranty in vehicles, discarded batteries from EVs are likely to become available on a large scale in the mid-2020s. For 2030, REmap findings show that around 150 GW of additional storage would be available from them, already equal to around 4% of installed VRE capacity if REmap Options are implemented. Such storage units could play an important role in soaking up extra power production when solar and wind resources are particularly abundant. However, among different grid integration measures, including curtailment of production where possible, a full cost-benefit analysis would be required to rank which options are most suitable for the power system of any given country.

Moreover, electricity storage capacity will become available through the active stock of two, three and four-wheel EVs used worldwide. According to the REmap findings, these vehicles could provide an additional 600 GW of storage capacity, raising the total to about 1 000 GW by 2030. Clearly, electric mobility will play an important role for countries in coping with higher shares of VRE.

Recommended for further reading:

The Age of Renewable Power: Designing national roadmaps for a successful transformation. *(IRENA, 2015p)*

Renewables and Electricity Storage: A technology roadmap for REmap 2030 *(IRENA, 2015k)*

Adapting Renewable Energy Policies to Dynamic Market Conditions *(IRENA, 2014d)*

Renewable Energy Integration in Power Grids *(IRENA and IEA-ETSAP, 2015b)*

SOLUTION 6: VARIABLE RENEWABLE ELECTRICITY INTEGRATION 06

Recommended actions for policymakers and stakeholders	Examples and regional applications
Identify country specific VRE integration hurdles in a power sector-transformation roadmap, as different countries can absorb different levels of VRE, and flexibility options, including storage, will differ by country.	**Denmark, Germany** and several others have experience with high shares of VRE that is applicable to all countries with increasing VRE shares. Several initiatives such as the **Africa Renewable Energy Initiative, Global Geothermal Alliance, SIDS Lighthouse Initiative** and the **International Solar Alliance** have announced renewables initiatives that target renewable energy capacity increases in different regions and worldwide.
Upgrade interconnections with neighbouring countries where possible. Expand high-voltage grid lines to connect cities and industry with large wind farms and solar plants.	The **Africa Clean Energy Corridor** aims to provide better connection of the power systems in eastern and southern Africa. The **European Union** targets 10% interconnection by 2020.
Redesign markets and remuneration schemes so that demand and supply peak at the same time. Consider smart grids to help shift flexible demand (for example batch production in industry).	Advanced demand-response management and time-of-use pricing has been implemented in **Republic of Korea.**
Tailor electrification of heat and transport to times of high VRE generation. Use electricity to generate heat and cold at times of high wind and solar power production.	German cities such as **Augsburg** and **Frankfurt** have set up power-to-heat systems.
Focus power storage in distributed batteries on grid stability. Where possible, EVs should charge flexibly based on grid needs, and residential battery units should store based on grid needs rather than primarily helping households go off-grid.	In **California** a pilot project was set up to investigate the role of distributed battery storage in stabilising the grid.

07

SOLUTION 7: SYNERGIES WITH ENERGY EFFICIENCY

Leaps in energy efficiency that are realistic and feasible will be important to reaching a doubling of the global renewable energy share and goals of climate change mitigation. The rate of energy-intensity improvements would need to double from the current level of 1.3% per year, to 2.6% per year between 2010 and 2030.

Understanding the challenge

An analysis of ten scenarios shows a clear correlation between primary energy supply and the share of renewable energy in the primary energy supply. If there is no change in the rate of efficiency improvement, the world can reach a 10% share of renewable energy in TPES. If the rate of efficiency improvement doubles or more, renewable energy could reach more than a 30% share of TPES.

With the REmap Options, the renewable energy share grows from 21% in the Reference Case to 25% by 2030. Energy efficiency gains and access further increase the share to 30%. A focus on energy efficiency alongside renewables is crucial in achieving a doubling of the share of renewable energy.

Energy efficiency potential and synergies with renewables

Doubling energy intensity from the historical rate of 1.3% (1990-2010) to 2.6% (2010-2030) is something few countries have accomplished. One is China, which averaged a 4% annual improvement in energy intensity from 1990 and 2010. Nonetheless, there are plenty of measures that are easy to implement and will make a difference.

The two main sources of energy efficiency improvements are to improve how primary energy is used through implementation of energy efficiency technologies, and structural economic changes that result in the production and consumption of goods with lower energy intensity. An example in transport means switching to a fuel-efficient vehicles that uses less energy, but also a structural or behavioural change like switching to using a non-motorised vehicle, like a bicycle. An example of structural change in industry is shifting from the production of primary steel (from iron ore) to secondary steel (from recycled steel), which results in energy-use reductions. At the household level in developing countries, efficient cookstoves allow a switch from the low-efficiency traditional method of burning bioenergy to modern fuels, boosting efficiency while at the same time reducing health issues from pollution.

Efficiency is measured in primary energy, however this report focuses on final energy. The former is the lumps of coal that go into a power plant or the oil put into a car; the latter, the electricity that comes out of the plant or the motive force that reaches the car's tires. In the power sector, the transition to renewables will result in a drastic reduction in primary energy supply as wind and solar replace coal. Primary energy is a tally of natural resource consumption; whereas with wind and solar no resource is exhausted, so the conversion from primary to final energy is considered 100% efficient. That compares with a rate between 33% and 45% for coal plants. There is thus a two to three-fold efficiency improvement when solar and wind replace coal. It is therefore important to measure energy efficiency in primary energy terms, and in terms of technology deployment. That means focusing not just on the role of efficiency to reduce energy demand in buildings, industry and transport, but also on the consumption of resources for power generation. For these purposes therefore, CHPs are, when operated in an efficient manner, able to deliver primary energy savings when compared with separate production of heat and power from stand-alone steam boilers and power plants.

Efficiency gains could be significantly high in new buildings, as Passive House architecture is a method proven to reduce needs by 90%. The European Union's Nearly-Zero-Energy building standard takes effect at the end of this decade and will produce similarly efficient buildings. The Passive House approach can be used in renovations as well, as numerous successful projects have shown, and the focus can also be shifted from retaining heat in cold places to staying cool in hot climates.

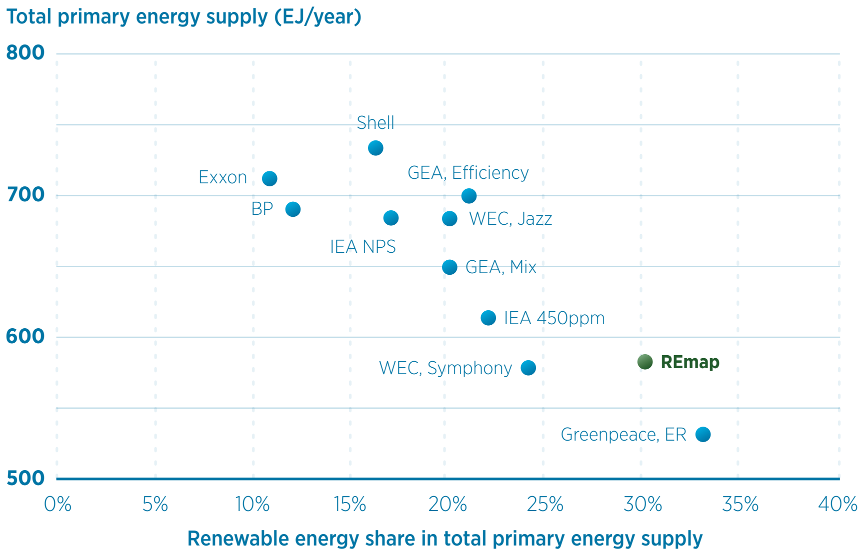
While these tremendous gains are clearly within reach, they will not come about automatically. The transition is well underway in the power sector, but lagging in buildings, industry and transport. The benefits of Nearly-Zero-Energy buildings in Europe will likely remain limited to new builds and a small number of refurbishments. Countries adding more new buildings could therefore implement advanced architecture more quickly, and enforce such rigorous building codes to improve efficiency of the stock.

Current best practices offer energy efficiency improvement potential above 25% in industry, through more efficient heat generation, overall process improvements and integration and more-efficient combined heat-and-power plants. About 75% of this overall potential is located in developing countries.

Beyond simply reducing energy use, electrification is important also for renewables when coupled with renewables-based power supply. Heat pumps, for example, operate much more efficiently than non-renewable alternatives. If additional demand for electricity comes from renewables, extra gains are made for the total share of renewables in total final energy consumption. Likewise, in transport, efficiency can come from modes of transport powered by electricity sourced from renewables. EVs are some two to three times more efficient than the conventional cars.

Like with the overall adoption of renewables, one thing important for policy makers to do is to set targets. Where they exist today they are not very ambitious and often not properly enforced. Many countries have yet to adopt any efficiency targets.

Figure 55: Renewable energy share and total primary energy supply (estimates in global studies), 2030



Based on BP (2016), Exxon (2016), GEA (2012), Greenpeace (2015), IEA (2015b), Shell (2009), WEC (2013) and IRENA estimates

Note: unlike in the rest of this study, here renewable energy share has been expressed relative to TPES with the purpose of including data from more studies which also express their findings based on this metric.

The less energy we consume, the greater the renewable energy share will be.

03

Table 5: Efficiency gains from renewable energy technologies

	Conversion efficiency		Efficiency gain (in final energy terms)
	Renewable	Non-renewable reference technology	
Efficient cookstove	30-50%	10-20% (traditional)	150-200%
Electric vehicle	0.7-1.0 MJ/p-km	1.7 MJ/p-km	40-60%
Heat pumps	350-450%	80-90%	340-400%
Solar / wind power generation	100%	30-55%	80-230%

Source: IRENA and C2E2 (2015)

Recommended for further reading:

Synergies between Renewable Energy and Energy Efficiency *(IRENA and C2E2, 2015)*

07 SOLUTION 7: SYNERGIES WITH ENERGY EFFICIENCY

Recommended actions for policymakers and stakeholders	Examples and regional applications
Adopt and regularly improve device design standards to increase the efficiency of appliances.	**Japan**'s Top Runner program, Energy Star in the **United States**, and the **European Union**'s Eco-design serve as examples.
Adopt strict and efficient requirements for new buildings and increase renovation rates for existing building stock that promote individual renewable energy heating and cooling systems and renewable energy district heating and cooling.	**Abu Dhabi**'s Pearl Rating System serves as example to improve efficiency in new buildings; **China** is leading in adding solar thermal to existing buildings; the **United States** offers incentives and online tools such as the 179d DOE Calculator to support improving efficiency in existing buildings
Focus on using renewable energy to handle energy demand once efficiencies have been implemented, along with space heating from solar thermal and bioenergy, and heat pumps.	**Denmark**'s plan for 100% renewable energy by 2050 focuses on power-to-heat and sustainable local bioenergy, including renewable waste, in CHP.
Promote the electrification of transport to increase efficiency, and then generate that electricity with renewables.	Various national and international initiatives (*e.g.,* **Clean Energy Ministerial Electric Vehicle Initiative, C40 City Leadership Low Emission Vehicle, UEMI**) already promote the use of EVs; consider more prominently targets for providing the additional electricity demand from renewables.

08

SOLUTION 8: SUSTAINABLE BIOENERGY MARKETS

A cost-effective doubling of the renewable energy share of the global energy mix by 2030 would imply a tripling of modern bioenergy use, with its use across all applications of power generation, heating and transport. It is important that bioenergy be sourced from sustainable and affordable feedstocks. Implementing all REmap Options requires bioenergy feedstock supply to increase by approximately 70% between today and 2030.

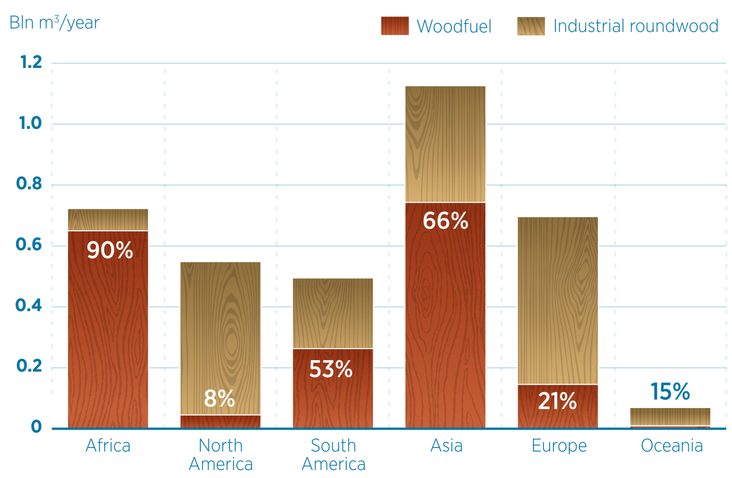
Understanding the challenge: supply potential and its costs in 2030

Only about 17% of global biomass supply is used as bioenergy at present, mostly from wood products and harvest residues. Of 11.4 billion tonnes of supply for all uses in 2011, harvested crops accounted for 40%, grazed bioenergy for livestock 30%, wood products 18% and harvest residues 12%.

Bioenergy accounts for three-quarters of total final renewable energy use currently. Roughly half of the total renewable energy use worldwide is from traditional use of bioenergy from burning wood in rural areas of developing countries for cooking and water heating. Modern bioenergy use for transport fuel, electricity, and heat accounted for 21 EJ in 2014 and is estimated to expand to 62 EJ in 2030 if all REmap Options and Doubling Options are implemented, with traditional use of bioenergy declining during the same time frame. In primary energy terms 62 EJ equates to 93 EJ of primary bioenergy feedstock.

Affordability and sustainable feedstock supply will be key to meet the estimated demand of 93 EJ of primary bioenergy in 2030. IRENA estimates show a sustainable-bioenergy supply potential of between 75 EJ and 140 EJ per year in 2030, which falls within the range published by the Intergovernmental Panel on Climate Change and others at the global level. Figure 57 shows IRENA's supply costs and potential estimates in 2030, with a breakdown by feedstock type (for the high end of the total supply range). The largest potential supply is from agricultural residues and food waste, at 16 EJ to 56 EJ.

Figure 56: Share of industrial and fuelwood production by region, 2013



Wood fuel for energy production dominates in Africa and Asia, industrial roundwood is more common in North America and Europe.

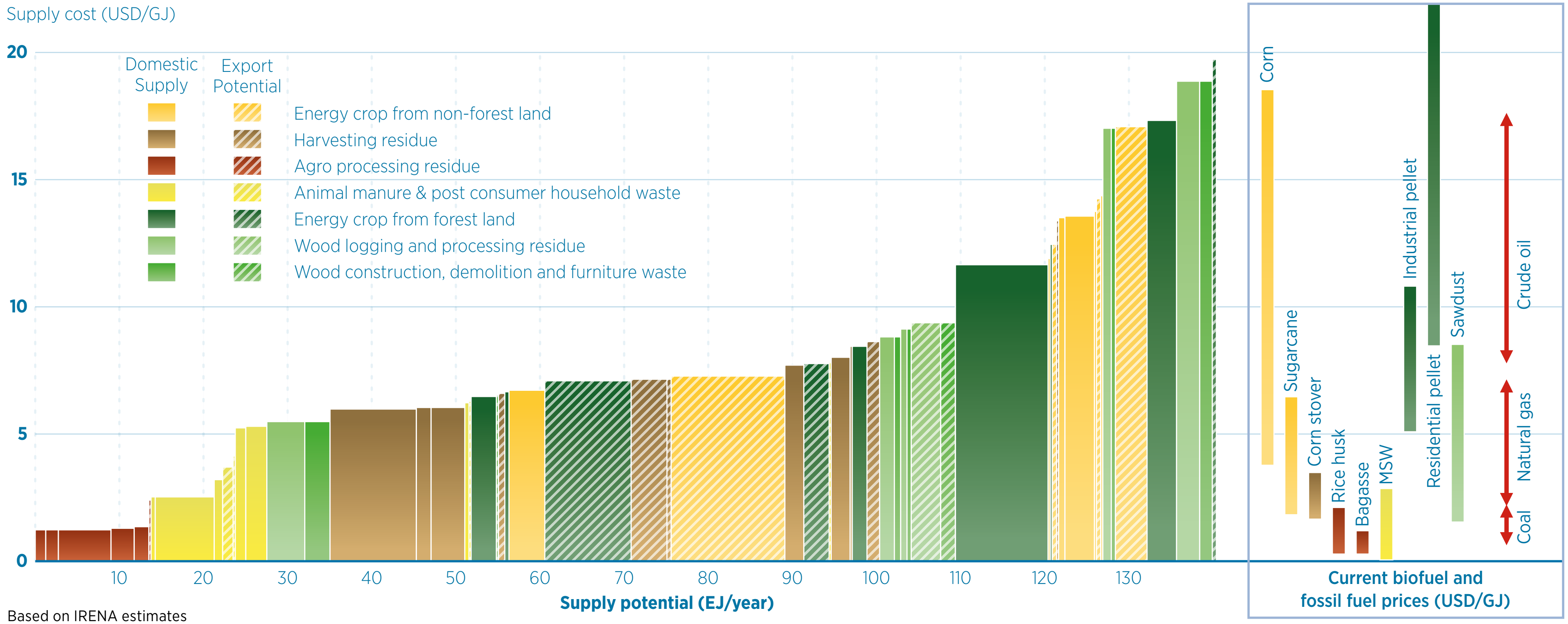
Source: FAO (n.d.)

The potential of forestry products is estimated at 41 EJ to 57 EJ. Bioenergy crops follow the potential of residues and forestry products at about 19 - 27 EJ. The focus for renewable energy should be on residues and waste recovery, which can account for a large share of total bioenergy demand. Much of the remainder would come from energy crops for liquid biofuel production. These ranges are determined by changes considering in land availability, agricultural yield improvements, residue generation and collection rates as well as food demand.

REmap estimates that up to 140 EJ of bioenergy could be supplied by 2030 at an average cost of USD 7 per GJ (including pre-processing costs for residues and wood products). The domestic supply cost

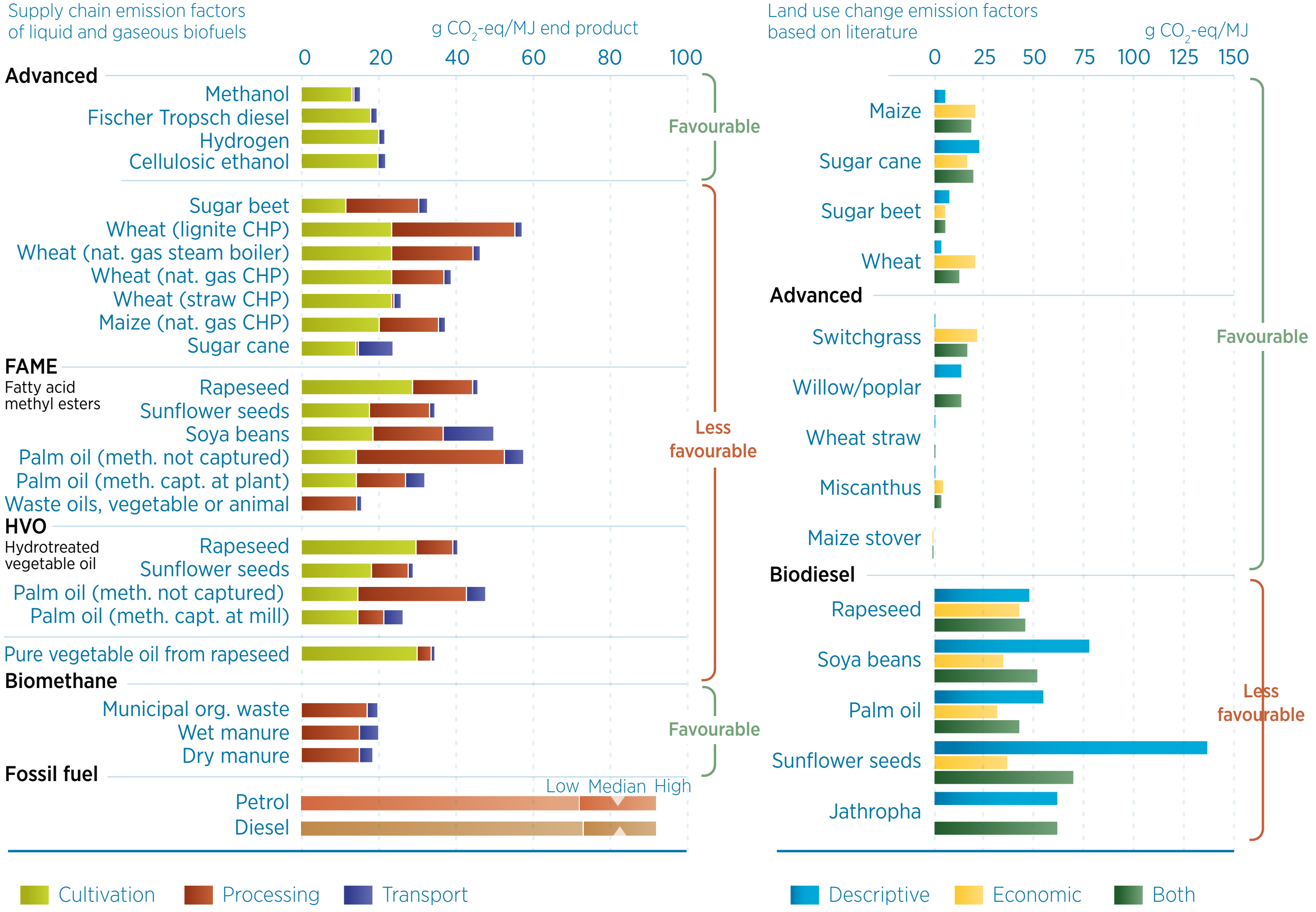
Sustainable sources of bioenergy can supply up to 140 EJ by 2030 at an average cost of USD 7 per GJ.

Figure 57: Global bioenergy supply potential and cost, 2030



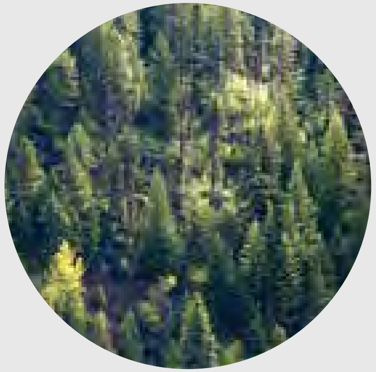
Based on IRENA estimates

Figure 58: Supply chain for liquid biofuel production and resulting emissions due to land-use change



Over an entire life cycle advanced liquid biofuels can cut GHG emissions between 60% and 90% compared with fossil fuels, even when supply-chain and land-use change emissions are accounted for.

Source: European Commission (2015), PBL (2016)



of bioenergy ranges from as low as USD 1 per GJ for agricultural processing residues to USD 35 per GJ for wood fuel. Though the latter represents the upper end of global prices, in certain regions the same type of bioenergy can be cheaper. For example in central Europe solid biofuels are produced at around USD 8/GJ. Production costs are even lower in Brazil. Supply costs are lowest for agricultural residues and biogas from food waste and animal manure, and highest for energy crops. The low-cost group consists of processing residues and gases such as bagasse. The medium-cost group consists of harvesting residues collected from fields, and the high-cost group consists mainly of energy crops and wood fuel. Residues could be supplied at very low cost if supply chains are efficient, however, currently utilisation is mostly limited to areas close to sources, as collection and transport are costly. For crop-based bioenergy, logistics are relatively well-developed to supply agricultural commodities for consumption by humans and animals.

Surplus bioenergy available for export amounts to 26% of the total supply potential. Costs related to inter-regional transport of this bioenergy to different world regions could add an average of USD 3 per GJ (from USD 0.5 via rail to USD 4 per GJ via ship, depending on the distance) to these domestic supply costs (IRENA, 2014e). There are further investments needs associated with increasing volumes of trade, related to storage, port facilities and so on, which are excluded from this assessment. Residues will likely increase in price if successfully marketed for international sale, as today these resources are typically unused, so there has not yet been a global valuation process. Optimising inter-regional markets, to bring down these costs in some cases and create demand in others, will play a key role in creating an international bioenergy market. These can be complemented by efforts in fossil fuel pricing. As experience in Denmark and Sweden has shown, highly taxed oil and gas was an effective strategy to promote bioenergy for heating.

Greenhouse-gas impact of bioenergy pathways

Besides affordability, ensuring sustainability is the other major objective. The key sustainability concern is related to climate change. Depending on the production practice, application and feedstock, bioenergy may result in significant GHG emissions. From modern bioenergy feedstock combustion techniques, air pollutant emissions are expected to be significantly lower, however.

There are two components to GHG emissions: emissions from the supply chain (cultivation, processing and transport) and from land-use changes. In the case of supply-chain emissions, bioenergy productivity and transport distance are key issues, and the latter could in some cases eliminate any advantages of use.

GHG emissions from biofuels are often lower than those of the fossil fuels they displace. According to a recent review of literature by the Netherlands Environmental Assessment Agency, lifecycle GHG emissions range from roughly 20 grams of CO_2-equivalent per megajoule (g CO_2-eq/MJ) for advanced liquid biofuels from woody bioenergy, as well as for biogas from manure or organic waste, to as high as 60 g CO_2-eq/MJ for conventional biogasoline from wheat (PBL, 2016). Petroleum-based fuels typically emit more than 90 g CO2-eq/MJ, so the substitution of biofuels would reduce net GHG emissions. But if bioenergy feedstock production causes a (direct or indirect) increase in land use, emissions may be substantially higher, so it will be environmentally advantageous to pursue feedstock strategies that rely on sustainable intensification of agriculture, producing more food and fuel on the same land through higher yields.

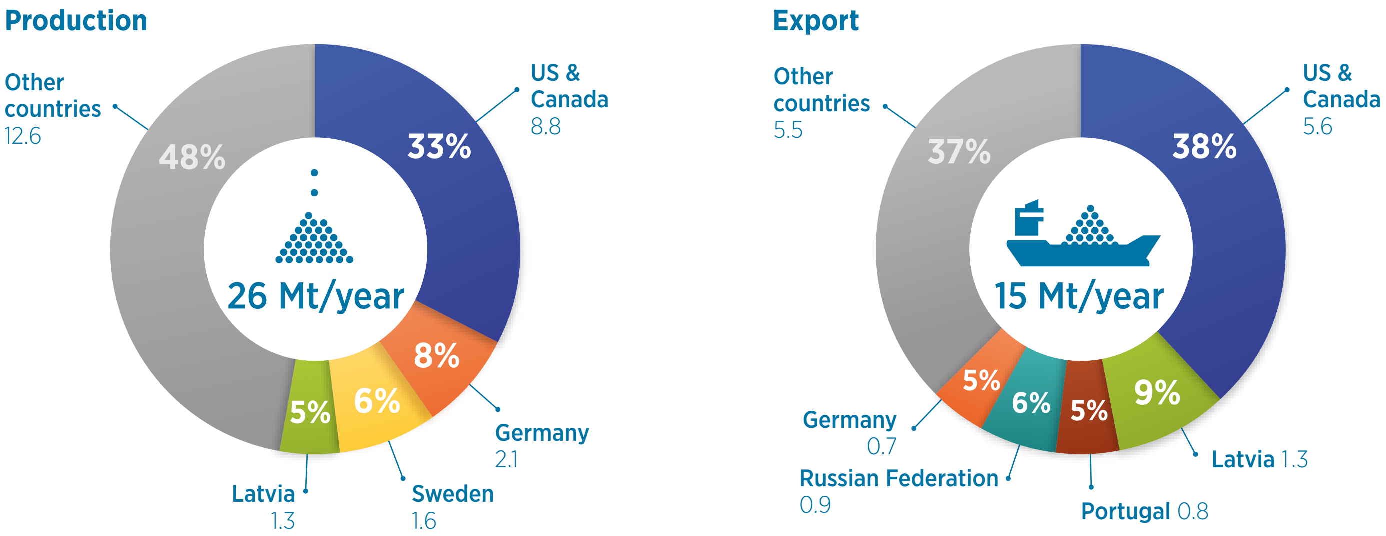
Bioenergy from forestry and agriculture can feed humans and animals and serve as raw materials for numerous commodities and for energy supply. Approaches to bioenergy development will need to emphasise feedstocks that can be raised sustainably, to ensure a contribution to climate change mitigation without endangering food security.

The importance of international bioenergy markets

Though countries plan for increased bioenergy use, not all have the resource potential to meet the growing demand. International trade of both solid and liquid biofuels will help to ensure affordable feedstock supply and increase energy security if domestic production falls short due to poor harvests.

Even though wood fuel and other solid biofuels are primarily used for domestic energy supply, trends in the last decade show an increase in international trade. In 2004, 0.23% of 18 EJ of globally produced wood fuel was traded internationally, whereas in 2013 volumes increased to 0.59% of 19 EJ (FAO, n.d.). This reflects increased volumes between European countries where policymakers

Figure 59: Global wood pellet production and export, 2013



More than half of all pellets are traded internationally today.

Source: FAO (n.d.)

have established effective incentives. The main object of trade is wood pellets – in 2014, more than half of total production was traded internationally before use.

For a number of exporting countries, biofuel market development is a driver for economic development, and supportive policies are boosting growth.

By 2030, most countries will be in a position to supply their bioenergy demand using domestic resources. However, the difference in production costs and uneven distribution of natural resources (land and water) among countries points toward the need for increased trade. To realise the potential according to the REmap Options, affordably and sustainably, up to 20% of total demand may need to be sourced through international trade – about 15 EJ to 20 EJ per year by 2030, a significant increase from current levels.

Following historic trends, the United States and Brazil will probably remain important suppliers of liquid biofuels for European markets. In Asia, intra-regional trade is expected to grow, with China being the largest importer and exporters led by Indonesia and Thailand. For trade in solid biofuels and bioenergy feedstock, Europe (including Russian Federation and Ukraine) and South America have the highest export potential. Economics will help determine which types of feedstock are traded and to what extent. Costs and prices may vary significantly by country and feedstock, providing an impetus to trade as countries seek the least expensive supplies.

The need for an integrated policy framework

The bioenergy supply chain has multiple stages that include creating markets, managing supply and demand to ensure sustainability and affordability, and to promote regional and international trade. Each component requires carefully designed policies encompassing energy, agriculture and forestry sectors. An integrated policy framework is required, across these areas, to meet the associated challenges (IRENA, 2016g forthcoming).

To be more specific, given the complexity of bioenergy as a resource, the creation of bioenergy markets will require various policies that address different challenges. While in the heating sector, policy action could include grants for equipment on the demand side, for markets, taxing policies will be needed, and, for suppliers, help with logistics.

Recommended for further reading:

IRENA's Global Bioenergy Working Paper: Supply and Demand Projections *(IRENA, 2014e)*

Greenhouse Gas Impacts of Bioenergy Pathways *(prepared by the Netherlands Environmental Assessment Agency) (PBL, 2016)*

Boosting Bioenergy: Sustainable Paths to Greater Energy Security *(IRENA, 2016g forthcoming)*

Recommended actions for policymakers and stakeholders	Examples and regional applications
Weigh the carbon balance of bioenergy and consider local air-pollution benefits.	Advanced biofuel targets in the **European Union** or the **United States** are determined based on life cycle GHG balance of biofuels by considering indirect land use change impacts.
Focus on waste and residue recovery for bioenergy production, and reduce non-sustainable bioenergy use.	**Brazil** phased out pre-harvest burning of cane leaves to instead use them in power generation.
Improve the harvesting of farm and forest residues along with post-consumer waste. Explore agroforestry approaches and the regeneration of degraded lands.	Standardisation and market efficiency of biogasoline trading, mainly from **Brazil** to the **United States** or the **European Union**, could serve as an example of what is needed for other bioenergy inputs.
Collect data on land that could be used for sustainable biofuel crops, including likely yields and the potential to sequester carbon and enhance biodiversity for different crops and tree plantations.	Development of national and regional standards and certification processes will help ensure feedstock sustainability. The **European Union's RED sustainability certification**, the **United Kingdom forestry standard**, and the **Rainforest Alliance FSC Forests standard** are examples; International collaboration platforms such as the **IEA Bioenergy** allow for best practice exchange, data collection and development of methodologies.
Avoid conflicts between bioenergy and food security by increasing productivity in agriculture and forestry.	
Establish or expand registers of origin to ensure sustainable feedstock. Promote the development of cross-border bioenergy trading.	
Work with neighbouring countries to create larger bioenergy markets that are more stable in times of locally fluctuating harvests.	Standardisation and market efficiency of biogasoline trading, mainly from **Brazil** to the **United States** or the **European Union**, could serve as an example of what is needed for other bioenergy inputs.

03

09

SOLUTION 9: UNIVERSAL ACCESS TO MODERN ENERGY WITH RENEWABLES

Traditional use of bioenergy damages the environment and presents considerable health impacts for humans. This inefficient burning of often unsustainably sourced bioenergy could technically be eliminated by 2030 and replaced with a mix of modern energy both from fossil fuels and renewables in line with the SDG target. With REmap Options the use of modern cookstoves can increase to more than 800 million. Besides the large number of traditional users of bioenergy, worldwide, some 1.1 billion people lack access to modern energy. Providing these populations with access to renewable energy, rather than fossil fuels, is the best option for developing local skills and resources will be spent locally, instead of being exported.

Volume of traditional bioenergy consumption

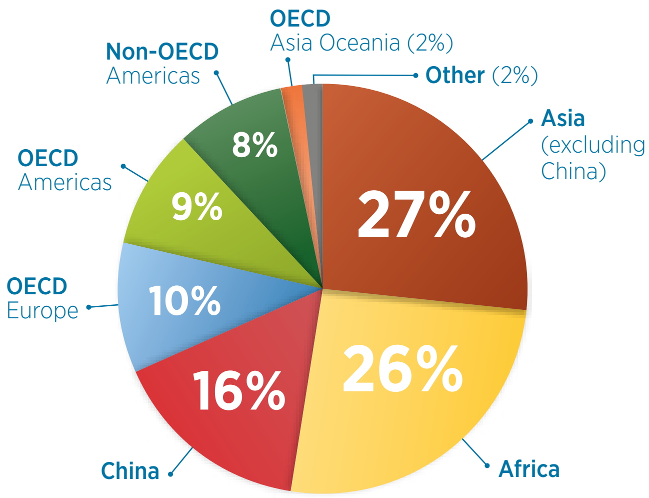
About 12% of total global energy use is accounted for by bioenergy, with Asia, Africa, and Latin America accounting for a majority (see Figure 60). Three quarters of total bioenergy demand, or about 9% of global energy, comes from traditional uses. Around 3 billion people cook and heat their homes using solid fuels (*i.e.*, wood, charcoal, coal, dung, crop wastes) in open fires or traditional stoves.

The market potential for supplying reliable and affordable cook stoves is large. Clean cookstove penetration is particularly low in sub-Saharan Africa, with estimates suggesting that only one in six African households uses clean cooking energy (Lambe *et al.*, 2015). Shares in Southeast Asia and East Asia are higher, estimated at 27% and 51% in 2010 respectively, while in Latin America it was 80% in the same year (ESMAP *et al.*, 2015).

In total, by 2012, about 35 million households worldwide had owned a modern cookstove sourced with bioenergy or solar (including both intermediate and advanced cookstove) (ESMAP *et al.*, 2015). The target is 100 million by 2020 (Bailis *et al.*, 2015). Today's annual sales of modern cookstoves have reached 14 million, but were much lower before 2013, at around 4 million per year (Masera *et al.*, 2015). In addition, another 50 million households (majority in China) rely on biodigesters and 2 million households use solar cookers worldwide (ESMAP *et al.*, 2015).

Around one billion modern cookstoves are needed by 2030. The effort required to reach more than 800 million users by 2030 with the REmap Options requires sales of about 50 million units per year, a tripling of the current level. Challenges include raising awareness of modern options as well as the pricing of the stoves and fuels, which are an obstacle given that no additional expenditure is required for those who continue using unsustainable methods. One potential way to convince users is to stress that foraging for wood takes time, and if they no longer need to do this then that time can be redirected to other profitable activities.

Figure 60: Breakdown of global primary bioenergy use by region, 2013



Source: IEA (2015a)

Asia, Africa, and Latin America account for a majority of total bioenergy use worldwide.

Charcoal use

In terms of traditional use of bioenergy, wood is used either directly as firewood or to make charcoal. It is estimated that about one fifth of harvested wood is converted to charcoal, which is a popular fuel because of its high energy content, clean burning characteristics, and easy storage. In urban areas charcoal is available for sale, making it more accessible than firewood. It is the main fuel of the urban poor and will probably remain so during the transition to modern fuels. Its relative importance has been rising: over the past 40 years annual production of charcoal has grown at a rate of 6.3% (FAO, n.d.). Attempts to impose requirements on charcoal producers and markets, such as mandating sustainable feedstock sourcing and formalising charcoal markets, have not always been successful. The reasons include poor enforcement, complex ownership rights and prevailing socio-economic conditions, in particular given the earnings potential that charcoal affords rural households.

Impact of traditional bioenergy use

Traditional use of bioenergy results in high levels of indoor air pollution, with direct impacts on the households from fine particles and carbon monoxide. In poorly ventilated dwellings, smoke in and around the home can reach levels 100 times larger than acceptable levels for fine particles. Exposure is particularly high among women and young children, who spend more time near domestic hearths.

The traditional use of bioenergy accounts for 2-8% of total anthropogenic climate impacts. In particular traditional use of bioenergy accounts for a high share (18–30%) of global black carbon emissions (a fine particulate matter emitted as a result of incomplete combustion). These emissions are excluded from the REmap accounting framework. However, in absolute terms, black carbon emissions from wood fuels alone have reached 1.0–1.2 Gt of CO_2-eq/yr (Bailis *et al.,* 2015).

Important sustainability concerns also arise from the traditional uses of bioenergy. Although little is currently known about the exact magnitude of the impact, traditional use of bioenergy is estimated to account for more than half of global wood harvest. With almost 300 million rural people living in wood fuel "hotspots," mainly concentrated in South Asia and East Africa, there are on-going risks from wood-fuel-driven degradation and deforestation (Masera *et al.,* 2015). REmap estimates show that the total cost of traditional use of bioenergy on human health and the environment is about 0.5-1.3%

of global GDP today, excluding hidden items such as the opportunity cost related to time spent on collecting wood fuels.

Statistical issues related to traditional uses of bioenergy

Traditional use of bioenergy is defined both in terms of the unsustainability of its harvesting and the inefficiency of its consumption. A classic example of traditional bioenergy is wood collection, often in rural areas, used to make open fires. Sustainability is not a consideration for harvesters. In contrast, wood from sustainably-managed forests (or waste wood from timber production) used in modern, efficient applications is considered modern renewable energy, even though the physical properties of the feedstock are similar.

There are important issues around the quality and availability of data. As a practical convention, traditional uses of bioenergy – use of bioenergy in inefficient equipment – is associated with unsustainable bioenergy. The sustainability matters, particularly for bioenergy sources, however, there are no current statistics available to quantify what portion of bioenergy use is sustainable.

Because it is difficult to assess how much bioenergy is used traditionally, the common practice used by the IEA is to assume that all bioenergy used in households in non-OECD countries counts as traditional use (IEA, 2012), whereas all bioenergy use in industry is considered modern. The Global Tracking Framework, which measures progress towards the UN SE4All goals, follows this IEA practice, while noting the caveat that residential uses may not necessarily be unsustainable (IEA and the World Bank, 2015).

One ongoing issue related to traditional bioenergy uses in cooking is data availability. The distribution of modern cookstoves is not monitored to the extend required, nor is the deployment of non-sustainable solutions, so the success rate of modern cook stove programs and the scope of the challenge remaining is not fully known.

Better statistics are needed to come to a more precise understanding in transitioning to a sustainable energy system in parts of the world reliant on traditional uses of bioenergy.

Accelerating the transition to sustainable forms of bioenergy

Traditional use of bioenergy can often be transformed into modern bioenergy, for example by replacing a traditional bioenergy stove with a modern one. While this change does not affect the sustainability of the bioenergy supply per se, it reduces impacts associated with it, notably those on human health. In addition, conversion efficiency gains reduce the need for feedstock, which in turn contributes to improving sustainability. Successful deployment and utilisation of 100 million improved stoves could reduce the total GHG emission associated with traditional uses of bioenergy by 11 – 17% (Bailis *et al.,* 2015). However, modern cookstoves are one part of the solution only. In a similar way, technology solutions to improve efficiency in heating will be needed.

In the current policy climate, one factor supporting a switch to modern cookstoves is that countries often subsidise LPG/kerosene as an alternative to traditional uses of bioenergy. In principle, cooking and water heating through the use of non-renewable modern fuels can result in similarly high reductions in negative impacts associated with traditional uses of bioenergy. Likewise, various modern forms of bioenergy and other renewables can be used to further reduce traditional uses, with biogas being the most common. Briquettes are increasingly substituting for charcoal in Africa. Biogasoline gel can be produced from various crops and waste, and is cost-competitive in regions where feedstock is available. Cooking using electricity, popular in several developed countries, is another alternative.

SOLUTION 9:
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There is an important role that is played by various initiatives to promote the use of modern bioenergy equipment in shifting away from the traditional uses of bioenergy. The Global Alliance for Clean Cookstoves, a United States government initiative, the Clean Stove Initiative of China and the World Bank (The World Bank, n.d.), and the National Biomass Cookstoves Initiative in India (MNRE, n.d.) are some of these initiatives.

Similar programs are also required in Africa, where the majority of global traditional bioenergy is still used, and should be supported by government policies to ensure uptake and create a market that facilitates household access to affordable and reliable equipment.

Access to modern electricity

In the Reference Case, one billion people in 2030 will still be without electricity access. Africa is home to the largest number of people lacking energy access, estimated at about 600 million today. That number is expected to reach 700 million by 2030 (UNEP and GOGLA, 2015). Seven out of ten people without electricity access will live in Africa, and one-third of people using traditional bioenergy will live in Africa and India.

While ensuring access to reliable and sustainable modern energy services is central for development, there is a growing consensus that delivering these services requires a combination of distributed and centralised approaches, including off-grid solutions to complement centralised systems. Off-grid solutions can be deployed rapidly and customised to local needs, and are often the only option for electrification in areas where grid extensions are technically or financially unviable. Estimates suggest that nearly 60% of the additional generation required to achieve universal access to electricity in Africa will need to come from off-grid solutions (IEA *et al.*, 2010).

As renewable solutions generally tend to be significantly cheaper than diesel or kerosene-based energy-supply systems, solar PV, wind, small hydropower and bioenergy-based power are often among the best solutions for access to electricity in most rural areas. They are also cheaper than grid extensions in situations with low population density and low per-capita income.

This explains, for example, the increasing popularity of solar home systems in a country like Bangladesh. More than 65 000 of these systems are sold there every month, with 3 million systems installed till date and annual growth of nearly 60%. They provide electricity to 13 million people, representing 9% of the total population of the country. The target is to double this to 26 million by 2017, which would mean an estimated generation capacity of 220 MW (IRENA, 2015r). Solar lamps are also growing in importance. Based on trade data available, there has been a significant growth in their imports over the past five years, and a decrease in the trend of using oil- or kerosene-powered lamps as a result.

Table 6: Trade data for solar lamps in selected countries, 2010 and 2014

Country	Imports (,000 USD)	
	2010	2014
Ethiopia	0	9 757
India	2 632	24 207
Jordan	53	376
Mauritius	15	52
Zimbabwe	0	2 183

Based on IRENA estimates

09 SOLUTION 9: UNIVERSAL ACCESS TO MODERN ENERGY WITH RENEWABLES

Solar and wind-based hybrid mini-grids are making inroads on islands and in rural areas of Africa and Asia, and existing diesel-based supply systems are increasingly being retrofitted with renewables. Thousands of systems have been installed to date, and IRENA analysis for the Pacific has shown that retrofits of diesel mini-grids with renewables are technically and economically feasible in all cases. Full access would raise global electricity demand by only 1%, and more than half of this demand could be met with renewables through distributed solutions. In China, electricity access has been provided to more than 50 000 villages through mini-grids, primarily supplied by small hydropower, of which many have since been integrated in the centralised grid (IRENA, 2015s).

Accelerating efforts in renewable off-grid and mini-grid solutions

Overall, accelerating rural electrification through renewable energy will require more effort from both project developers and governments. Governments need to provide dedicated policies for off-grid renewable solutions and in mini-grids, as well as providing clarity on the long term rural electrification strategy. Subsidies on energy prices and grid access act as market distortions that pose barriers to the optimal deployment of renewable energy (IRENA, 2015r).

Limited access to financing remains an issue for the private sector in this field; transaction costs could be lowered and new investors might be attracted if projects, which are small-scale by nature, could be pooled in an effective and sustainable manner. For mini-grids, the creation of portfolios that strategically select projects to diversify risk and centralise fixed expenses could provide a solution (UNEP, 2015b). For off-grid solutions, such as a solar home system, vendors can use a model where the consumer only pays as long as the system works. This significantly reduces the risk to the consumer, who might otherwise be left with debt because of a poorly functioning system.

Creating awareness about the viability of renewable energy technologies is another important area to increase their adoption. The private sector plays an important role here; engagement with local communities by demonstrating renewable energy solutions and developing local skills go a long way in popularising renewable technologies such as solar panels. Training people to install, operate, and maintain systems is also critical in ensuring the scalability and sustainability of off-grid projects (IRENA, 2015r).

Finally, governments will have an important role in expanding data and methodological aspects of energy access. Data-collection methodologies need to be developed that can categorise systems by application, resource areas, uses, customers, system components and size of off-grid systems. Furthermore, country statistics will need to be improved for target setting and policy analysis, and will need to be complemented with regular monitoring (IRENA, 2015s).

Recommended for further reading:

Global bioenergy working paper: Supply and demand projections *(IRENA, 2014e)*

Statistical issues: bioenergy and distributed renewable energy *(IRENA, 2013s)*

Off-grid renewable energy systems *(IRENA, 2015n)*

International Off-Grid Renewable Energy Conference (IOREC) 2012 and 2014 *(IRENA, 2015r; IRENA, 2013c)*

Africa 2030: Roadmap for a Renewable Energy Future *(IRENA, 2015e)*

Recommended actions for policymakers and stakeholders	Examples and regional applications
Make a distinction between two different sources of problems when designing policies: sustainable fuel availability and affordable, reliable equipment (especially cookstoves).	**Global Alliance for Clean Cookstoves** has helped to install 28 million cleaner and/or more efficient cookstoves and fuels by 2014; the target for 2020 is 100 million.
Improve the efficiency of conversion technologies and appliances currently used with traditional bioenergy as well as the production of charcoal for clean cook stoves and water heating.	**China**'s biogas programme for past 40 years, trends in modern cookstove deployment in **Ethiopia** over the past years. Applies to all **Latin American, African** and **Asian** countries that rely on traditional uses of bioenergy.
Standardise cookstoves and modern biofuels, impose strict quality controls, and closely monitor progress. Use electric and biogas-based cookers as complementary strategies, along with briquettes and pellets from residues.	**China** has provided improved cookstoves to almost all homes.
Improve statistics on wood fuel production and consumption for better target setting for deforestation and monitoring efficiency improvements.	Data collected by the **Global Alliance for Clean Cookstoves** at global and region level.
Set up a database of cookstove technology providers and best practices, including key indicators for progress monitoring and country statistics.	
Educate the public so that people have the skillset needed to develop micro-grids and off-grid solutions on their own rather than waiting for grid expansion.	**African** start-up companies are marketing micro-grids across the continent, mainly using solar PV with storage.
Develop pooling facilities for mini-grids to mobilise investments system components, and size.	Mini-grid projects implemented by the World Bank across **Africa** could be assessed as a starting point. G20 Energy Access Action Plan: Voluntary Collaboration on Energy Access

10 SOLUTION 10: R&D AND TECHNOLOGY BREAKTHROUGHS

Most REmap Options identified for the transition are already widely implemented and proved. For these, innovation will continue through deployment, improvement and adaption to new operating conditions and novel applications. Governments will have to increase the investments in public R&D and create a stable policy environment that attracts private capital in innovation. Additionally, renewable energy technology breakthroughs are needed for a complete transformation of our energy system, requiring to intensify the efforts on basic R&D. Academia is an incubator of such promising innovations while governments should increase public funding to leverage the high risk associated to basic R&D, which the private sector is not willing to assume. Innovation will not emerge from implementing a unique policy or tool; rather a set of tools along the technology life cycle involving a wide range of actors will be required. Jointly, governments, private sector and academia can innovate our energy system by providing the know-how, funds and policy tools needed for the transformation.

The accelerated deployment of renewables, when combined with modern energy access and significant increases in energy efficiency, result in a doubling of the renewable energy share in the global energy mix by 2030 and will put the world on a pathway to limit global temperature rise to 2 °C or less. This potential can be achieved by a mix of existing technologies and those that are close to commercialisation today. Historical efforts in innovation and technology development in renewable energy have already yielded important results. However, planning for 2050 and going below the 2 °C target called for in the Paris Agreement will require significant additional effort. R&D and innovation will play a major role to materialise such breakthroughs.

R&D requires blue skies research, meaning efforts without a clear goal but with the potential to yield results that may benefit many industries. This type of basic research requires extra government support because the likelihood of commercially useful outcomes is smaller. In addition to blue skies research, applied R&D is required to focus on specific products and technologies. This approach attracts more private funding, as it has the potential to bring in revenue in a shorter timeframe.

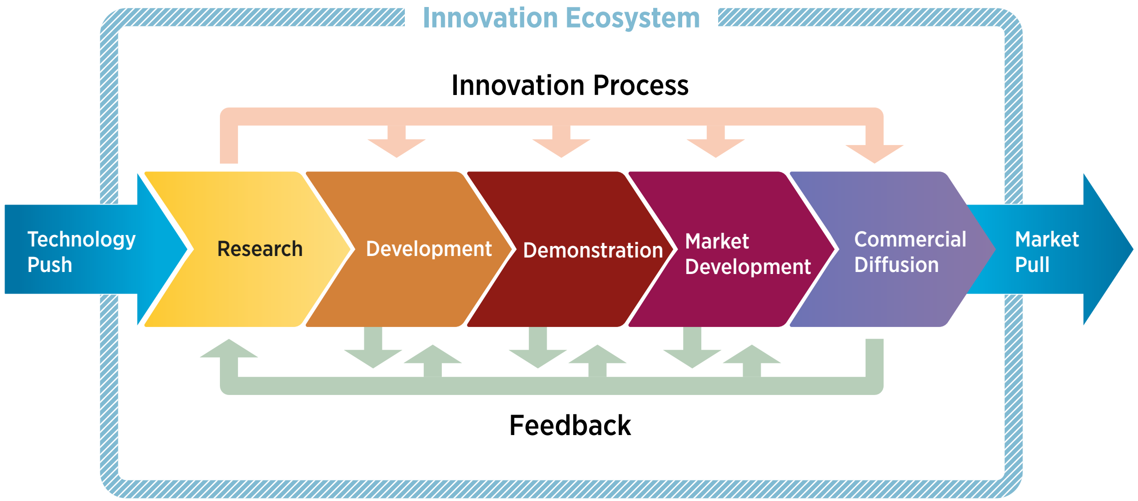
Innovation in the technology life cycle

The transformation of the energy sector will require continued improvements of existing renewable energy technologies as well as new breakthroughs. An innovation strategy focused narrowly on R&D may not help in deploying of innovative technologies. Similarly, implementing market incentives without R&D support would not create needed solutions. Technology innovation needs to be supported by a combination of various policy instruments across the technology lifecycle, from basic R&D to scaling up what works on a small scale. In addition to deploying such policy instruments, innovation policy frameworks have to be target oriented and include monitoring and performance indicators.

In REmap three key indicators were developed that guide governments in identifying R&D priority areas for public intervention: the annual growth rate in renewable energy deployment levels, the renewable energy share in end-use applications, and the cost difference between renewable energy and non-renewable energy technologies (the substitution cost). These indicators are helpful to develop R&D objectives, allocate R&D funds and to monitor the progress of innovation (Saygin *et al.*, 2015).

Commercialising innovative technologies requires strong entrepreneurial efforts. This can be managed by large companies, but major breakthroughs often come from SMEs. Policies should promote entrepreneurship and enabling mechanisms for these smaller private-sector actors to commercialise their innovations. The following sections explain how different policy instruments are required based on what stage a particular technology is at in its development.

Figure 61: Innovation in the technology life-cycle



Patenting and licensing, high-quality infrastructure, R&D cooperation, and technology transfer are the main means of innovation instruments in the technology life cycle.

IRENA (2015t)

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What is needed to improve existing renewable energy technologies?

R&D investment levels for renewables in recent years are increasing. In 2014, R&D spending reached USD 11.7 billion per year, about 4% of total annual investments in renewable energy capacity in the same year. From 2004 to 2014, R&D investments in renewable energy more than doubled, with a sustained incremental increase since 2005. Starting in 2013, private-sector investments have been close to 30% greater than funding from governments. In contrast, public and private sources were roughly equal from 2008 to 2012 period. China

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leads the world in public R&D spending for renewables, with USD 1.7 billion invested in 2014. The IEA estimates that public R&D spending on renewables accounted for 20% of total public energy R&D spending in OECD countries (IEA, 2015f). In comparison, nuclear power accounted for 23% of the total.

The climate change debate has also stressed the relevance of increasing R&D for renewables. Two important initiatives launched at the COP21 are of direct relevance. “Mission Innovation” is a joint initiative undertaken by 20 participating countries that have pledged to double their fundamental R&D investments in clean energy. The “Breakthrough Energy Coalition” is a network of 28 billionaire investors committed to provide venture capital to overcome the “valley of death” between technical viability and large-scale deployment on a commercial basis. These initiatives illustrate the widespread recognition for the role that innovation must play in dealing with the climate challenge.

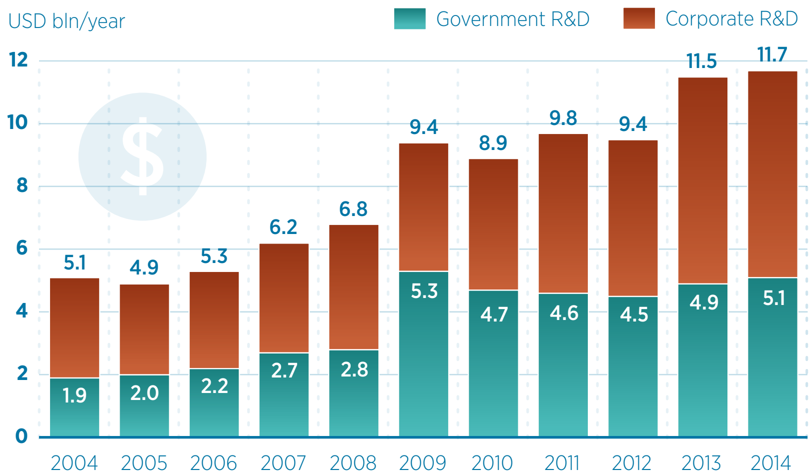
One example of how existing renewable energy technologies require improvement to make them more competitive is found in transport. Plug-in hybrid cars and battery-powered EVs are alternatives to internal combustion engine vehicles that would benefit greatly from improved battery technology. Batteries need to hold more power, charge faster, and do it at a much cheaper cost than current levels. Further R&D is urgently needed, as commercialisation may take more than a decade. Scale-up policies are needed today to convert these technologies into operational solutions in 2030. With government support the industry can continue reducing costs and improving the efficiency of these technologies by learning. Forging partnerships with academia and the private sector will also accelerate this learning process. The main role of governments will be the establishment of regulations and market incentives that drive evolution in technology, greater efficiency and cost reductions.

Both solar and wind are competitive today due to the persistence of pioneer countries in pushing their technological development over decades. During that time the price of these technologies was set not only according to the cost of electricity generation but also by the cost of learning by doing. Battery storage is in the midst of a similar learning curve. Other solutions are at earlier stages, such as advanced liquid biofuels and ocean technology. Progress will speed up further if a large number of countries join in efforts to share the cost of learning by doing.

Experience from the private sector in technology planning for 2050 has shown that international cooperation can create significant cost savings in the transition to a low-carbon economy. Notable opportunities include establishing a supply-chain sustainability strategy that identifies the greatest opportunities for cost saving and value creation; internal carbon pricing used by companies for future investment decisions; 100% renewable energy commitments and the RE100 campaign; and finally, science-based targets to understand what businesses need to achieve in terms of their carbon footprint (Carbon Trust, 2015).

In 2014, R&D spending reached 4% of total annual renewable energy investments.

Figure 62: R&D spending on renewable energy, 2004-2014



Source: Frankfurt School-UNEP Centre/BNEF (2015)

R&D AND INNOVATION FOR MATERIALS RESEARCH

According to a recent study by Gielen, Boshell and Saygin (2016), there are a number of important technology challenges in the context of realizing the long-term climate change mitigation goals specifically relating to materials. The challenge is twofold: new and improved engineering materials are needed for renewable energy equipment, and other innovations would improve commodity materials. Progress in these two areas are crucial to the rapid deployment of high-energy-density batteries, low-cost and long-range transmission lines, bio-based chemicals and polymers and new cementing materials.

The availability and management of primary resources are key aspects for large-scale development of renewables, in particular for bioenergy. It accounts for half of renewable energy use in 2013. Solutions to multiply its supply potential, include fast-growing feedstock materials such as bamboo, plants that can grow in saline-degraded soils, and improved techniques for algae production.

Other important materials challenges concern rare-earth metals supply which are basic ingredients for photovoltaic modules, wind turbines, EV batteries and energy-efficient electric motors. Reserves some of these metals are finite, and others are by-products with supply constraints. Research goals include finding alternative materials with fewer supply issues that would perform just as well, or technologies that make a more efficient use of these resources. For those materials for which alternatives cannot be found recycling will be increasingly important. Various simulation approaches and models in combination with actual measurements of materials utilisation will be essential to understand how to optimise the life cycles of these materials.

Timelines for this type of research are long – measured in years, and sometimes in decades. To have a substantial impact by 2050, production needs to be demonstrated in the next 10 to 15 years.

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The push for breakthroughs: Key role for governments

Innovations to improve existing technologies will not suffice to transform the energy system – new technologies are needed. R&D for advanced biofuels will be crucial to increase the share of renewables in freight, shipping, and aviation. REmap analysis also suggests a large gap in renewable energy technologies for high-temperature industrial process heat generation, which typically accounts for a large share of the heavy industry. For example, electricity-based iron production (electro winning) is an example of an alternative that can be further developed. As renewable energy technology uses scale up more R&D will also be needed to fill in gaps in these new supply chains, from manufacturers, component suppliers and installers to support, operation and maintenance.

The high risks and limited commercial applications associated with breakthroughs make government support essential until technologies are ready for commercialisation. But the role of government goes beyond financing R&D. Governments will need to develop human talent, support markets and entrepreneurship as well as mitigate risks and facilitate access to low-cost finance. Countries such as the and the United States, Japan and Republic of Korea also have setup Small Business Innovation Research (SBRP), which are programmes to provide funding to small, early-stage private sector businesses looking to accelerate commercialisation of new high impact technologies.

Universities and other research institutes also have a role to play. Technical universities in countries like Germany, Japan or the United States amongst others, have technology transfer or knowledge management offices, which assist researchers in commercialising their innovations. Strategies to do so may include forming companies, seeking patents, and guidance through administrative requirements. Initiatives, such as one from the Fraunhofer Society in Germany, aim at applying R&D and pushing it into the market place through funding support. Fraunhofer's funding model consists of 30% public funds and 70% private.

Innovation policies should link technology developers and researchers with companies, finance institutions and academia. An example in the United States is the ARPA-E, which was started in 2009 with an initial budget of USD 400 million. It partners with industrial innovators such as GE and Northrop Grumman and universities such as MIT and Caltech.

Sound regulations, elaborated with an engagement of all actors in the energy system, is a recipe to pull best-available technologies and push new technology developments. Just as energy-transition targets and policies for the power sector have accelerated a transformation there, governments need to set ambitious and specific transition targets for buildings, industry and transport, hand-in-hand with a portfolio of policy instruments that assure an economically attractive case for these breakthroughs.

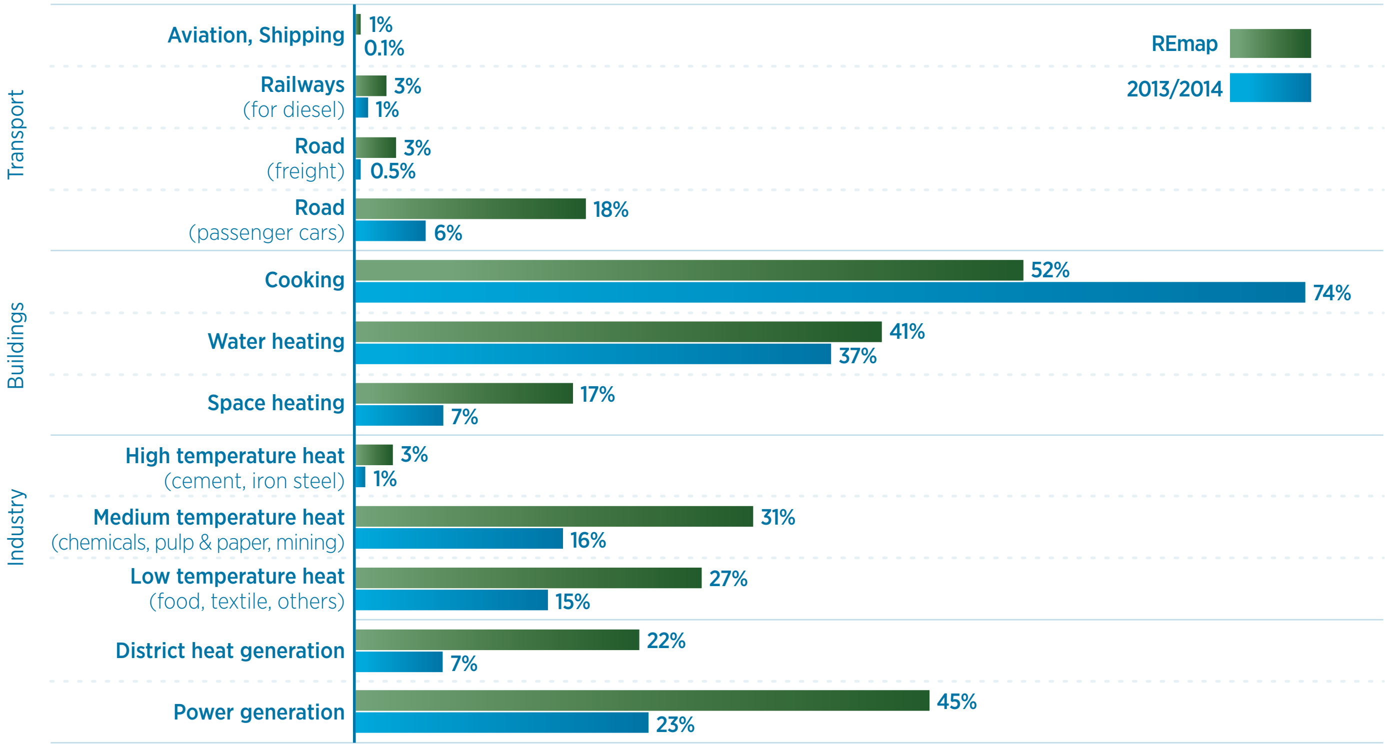
Integrating the beneficiaries as well as those in the private sector who will be negatively impacted is another challenge for governments. For every successful entrepreneur, there might be an incumbent seeking to protect their turf. Policymakers will need to encourage creative approaches that support innovation while also offering opportunities for those with business models in need of updating so they can also benefit from a renewable energy transformation.

The role of innovation beyond technology

Innovation involves more than basic research and further development of breakthrough technologies. Appropriate and stable policy developments and innovative business models and financial mechanisms which enable a massive deployment of renewable energy technology are also needed.

Companies like SolarCity and Sungevity, for example, did not come up with a more efficient or cheaper type of solar panel – they instead found a business model that would sell large numbers of small systems, thereby allowing the firms to purchase inputs at bulk rates. These examples show how innovative business models can create as much impact as breakthrough technologies.

Figure 63: Renewable energy share by application and sector in 2013/2014 and in REmap



Highest renewable energy shares exist in building applications.

Based on IRENA estimates

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TEN SOLUTIONS TO CLOSE THE GAP

Because innovation is not limited to technological advances, energy officials in government will need to work closely with those in other departments and ministries, such as in finance, industry, science and agriculture. A major challenge for policy-makers is to design and implement an institutional governance structure for innovation in the energy sector that includes all relevant actors but also limits the burden to innovators of heavy bureaucracy.

Recommended for further reading:

Renewable Energy Technology innovation Policy
(IRENA, 2015t)

Innovation Outlook: Offshore Wind Technology
(IRENA, 2016h forthcoming)

Renewable Energy Technology Outlook: Renewable Mini-Grids *(IRENA, 2016i forthcoming)*

RD&D for Renewable Energy Technologies: Cooperation in Latin America and the Caribbean
(IRENA, 2015u)

"Implications for Renewable Energy Innovation of Doubling the Share of Renewables in the Global Energy Mix"
(Saygin et al., 2015)

REmap

Recommended actions for policymakers and stakeholders	Examples and regional applications
Link R&D and innovation programmes to national macro objectives. Develop target-oriented support that include monitoring, reporting and verification of progress, and encompass the whole technology lifecycle from basic R&D up to commercialization.	**Republic of Korea** – National Strategy for Green Growth and the 577 Initiative: Economic growth via lead technology supplier in sectors with competitive advantage **Israel** – Fuel Choices Initiative: Energy security via alternative fuels to oil-based
Coordinate innovation across different sectors and governmental institutions. Determine the innovation needs across all sectors and energy services based on their annual growth rates, renewable energy shares and substitution costs. Systematically scan scientific progress and assess relevance for renewable energy deployment in the coming decades.	**United States** - Quadrennial Energy Review **Sweden** – VINNOVA **Chile** – InnovaChile
Invest in basic R&D, which has high risk and low interest from private sector	**Germany** – the German Research Foundation (DFG)
Support private sector innovation and entrepreneurship via small business programmers, promotion of start-ups. Focus R&D funding on technologies that are not yet market-ready, such as ocean energy and advanced liquid biofuels, and in sectors where RE penetration is especially low such as industry and freight transportation. As technologies become more mature, shift the support from supply side to demand side	**United States , Republic of Korea** and **Japan** - Small Business Innovation Research (SBIR) programmes **Israel** - Israel NewTech and Invest in Israel: business incubators
Establish knowledge management strategies that help researchers to bring their innovations into the market place, including training on business management and market assessment, technology transfer offices in universities, patenting and licensing, spin-offs	**United States , Germany, Republic of Korea, Japan** – Major technology universities have knowledge management and technology transfer offices to support their researchers in reaching commercialisation of their innovations
Develop stable incentive policies (FiT, PTC, Auctions), and long-term agreements that involve all partisan actors	**Germany** – cost reduction by learning by doing
Implement regulations to level the play field against non-renewable energy sources. Include standards for enabling technologies, such as HVDC lines, power electronics, smart grids, etc. as IT becomes more important in the power sector. Harmonize technology standards on international technology platforms, and promote quality assurance in development.	**United States** and **Republic of Korea** - Renewable Fuel Standard (RFS) and Renewable Portfolio Standard (RPS) programmes **IECRE** – Internationally harmonised standards and conformity assessment programme for renewable power generation technologies
Incorporate technology to market programmes	**United States** – ARPA-E **Germany** – ERP Innovation Programme **Switzerland –** CTI Start-up business coaching
Target oriented and coordinated international efforts	Mission Innovation and Breakthrough Energy Coalition

CONCLUSIONS AND NEXT STEPS

REmap shows how an objective of doubling the global renewable energy share, and quadrupling of the modern renewable energy share, can be achieved by 2030. In achieving this objective countries would create a more diverse and resilient energy system, increase GDP and employment, provide investment opportunity for businesses and local communities, and significantly reduce CO_2 emissions and harmful air pollutants.

IRENA
International Renewable Energy Agency

This roadmap has shown that the reduced externalities resulting from lower levels of air pollution and CO_2 would be up to 14 times greater than the additional costs associated with higher shares of renewable energy. Importantly IRENA's REmap programme is also emerging as global baseline for measuring progress on renewable energy, with the strength of its findings based on the collaborative nature that works closely with countries and their experts.

Since the release of the first edition of the REmap Global Roadmap in 2014, IRENA has expanded the REmap programme into a core activity of the agency. REmap has grown to encompass 40 countries representing 80% of today's global final energy demand and the programme is deepening the level of engagement with countries and regions through collaborative efforts focused on in-depth country reports, regional analyses, and workshops and events.

REmap also serves as the basis for IRENA's engagement in SE4All, as an important component of IRENA's activities within the SDG7 (similarly focused on averting catastrophic climate change) and with the G20.

REmap is an ongoing project and this is a living document. Country analyses are being continuously updated and improved and this will continue with countries as national plans are updated and as new technology cost and performance information is available. By doing so, REmap 2030 will continue to provide guidance to countries based on the most up-to-date information about the possible pathways, technology and policy options increasing the global renewable energy share.

Further work to promote renewables

Over the course of 2016/2017 IRENA will expand its programmatic activities relating to energy system transformation – detailing how technologies and sectors can change to increasing levels of renewable energy and how countries and regions and cooperate to enable this transformation.

These changes are taking place at the time when countries are looking for sustainable pathways to ensure economic prosperity and improved quality of living for all, with transformation of the current energy system as a key element. Accounting for some two-thirds of GHG emissions worldwide, the energy sector has become a primary arena for efforts to stabilise the climate system and as this roadmap demonstrates a doubling of the global renewable energy share, coupled with accelerated energy efficiency improvements, offers a compelling path to decarbonisation of the global energy system which is essential to keep temperature rise below 2 °C. This roadmap has stressed that a concerted global effort is needed to reach this objective. Averting the effect of climate change will require engagement of all stakeholders.

However much remains to be understood on how this transformation can occur. The aim of IRENA's REmap programme will be to provide a broadening range of findings to help counties assess various energy pathways.

In 2016/2017, the REmap programme will build on the existing work to monitor renewable energy sector progress and the global outlook until 2030. It will assess selected technology options for accelerated deployment, and act as a vehicle of identification and exchange of best practice. Comprehensive country and regional reports, sector-specific roadmaps and targeted socio-economic analysis will further inform decision-makers on the progress and priorities in accelerating renewables technology deployment. In addition to continuous collaboration with national experts, engagement with multilateral bodies and the financing community as well as the private sector will be further strengthened, including through the SE4All energy efficiency hub (C2E2), G20, UNFCCC's technical entities, IEA Technology Cooperation Programme, World Bank, regional banks, as well as the private sector. IRENA will also develop an information system for enabling easier access to REmap data and findings, allowing others to use the data to assess their own country's renewable energy potential.

IRENA's activities are expanding across a wide range of topics, and the REmap programme will work closely with the agency's leading work in grids, bioenergy, innovation, technology status, costs, and socio-economic analysis to create and share knowledge with the countries. A combination of expert analysis on leading trends combined with potential developments in the future can provide policy and decision makers with an important tool for assessing the potential for a clean, sustainable future based on renewable energy.

REmap

A Renewable Energy Roadmap

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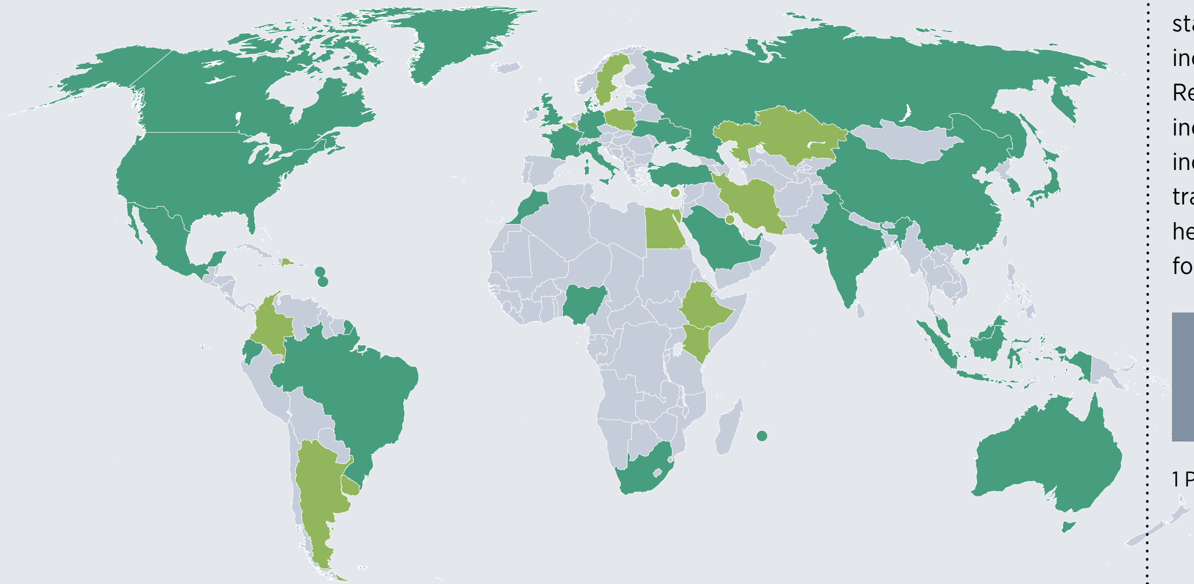
ROADMAP FOR A RENEWABLE ENERGY FUTURE

APPENDIX: REMAP METHODOLOGY AND DATA

This chapter presents a brief explanation of the general REmap approach, its terminology, and details about the methodologies for some of the different analyses covered in this report. More in-depth information on specific aspects of the REmap methodology is available online, including the REmap methods for costing and externality assessment, and sourcing for commodity prices, technology cost and performance, and country level renewable energy targets and sources.

*Please visit **www.irena.org/remap** for more information.*



A1: General approach and options assessment

REmap 2030 is a roadmap of technology options to increase the global share of renewables. It is a bottom-up, iterative analysis approach based on 40 countries, which account for 80% of total global energy demand. REmap identified the 'realistic potential' of accelerating renewable energy deployment – one that can be accomplished with existing technologies, is economically practical, and achievable by 2030.

The REmap analysis starts with national-level data covering power and district heating sectors and buildings, industry and transport for the base year 2010. Countries then provided their latest national plans starting were collated to produce business-as-usual **Reference Cases,** including each country's targets for renewables and fossil fuels. The Reference Cases represent policies in place or under consideration, including energy efficiency improvements. The Reference Case includes the final energy consumption for building, industry and transport separately and distinguishes between power, district heating and direct uses of energy with a breakdown by energy carrier for the period 2010–2030.

REmap Option
PJ/year in 2030

=

Potential of certain RE technology beyond Reference Case
PJ/year in 2030

1 PJ equals 1 000 000 GJ

The potential of renewable energy technology options beyond the Reference Case is subsequently investigated with the country. The potential of these technologies are described as **REmap Options,** and the resulting case when all Options are deployed is called **REmap.** For each REmap Option, the analysis also considers the costs to substitute a non-renewable energy technology to deliver the same amount of heat, electricity or energy service.

A table overviewing the sources for the Reference Cases and REmap Options is available online. In addition shortly after the release of the report detailed country tables will be provided online detailing additional sourcing for the Reference Case and REmap Options for each country.

A2: REmap Tool

IRENA has developed a spread-sheet tool that allows national experts to evaluate and create their country's REmap 2030 analysis and assess the potential, cost and benefits of REmap Options. The tool provides a simplified but dynamic accounting framework to evaluate and verify Reference Case developments and REmap Options within each country.

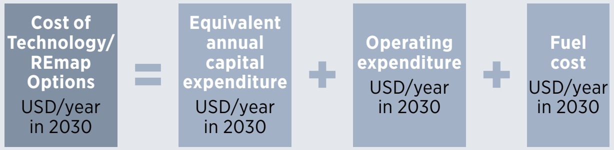
The tool consists of two parts. In the first part, national experts can evaluate and adjust the country's Reference Case for REmap Options between 2010 and 2030. In the second part, they can substitute non-renewable energy technologies assumed to be in place in 2020 and 2030 with REmap Options based on the Reference Case. For ease of use, the tool offers a range of technology options to choose from in the power and district heat sectors and in buildings, industry and transport. The tool allows the national expert to choose REmap Options, assess the options' impacts on the country's renewable energy share and evaluate their position within the country's cost-supply curve, as well as see the result of the Options for a range of costs and benefit co-analyses. At any time, the user can increase or decrease the size of REmap Options and choose a different substitute. Furthermore, the tool allows for a consistent analysis and comparison of results among countries.

The tool provides standard values for **commodity prices and technology costs and performance** for both renewable and non-renewable energy technologies. For each country these costs and performance are then localised for the technologies that are used in the analysis, i.e. adjusted based on national sources, projections, expert feedback, or IRENA's own cost and technology briefs. An overview of these basic commodity price and technology performance assumptions are available online at **www.irena.org/remap.**

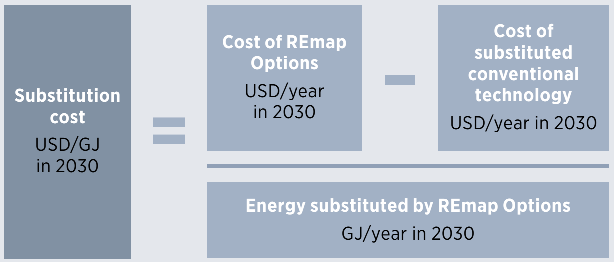
A3: Metrics for assessing Options

IRENA has developed a spread-sheet tool that allows national experts to evaluate and create their country's REmap 2030 analysis and asses

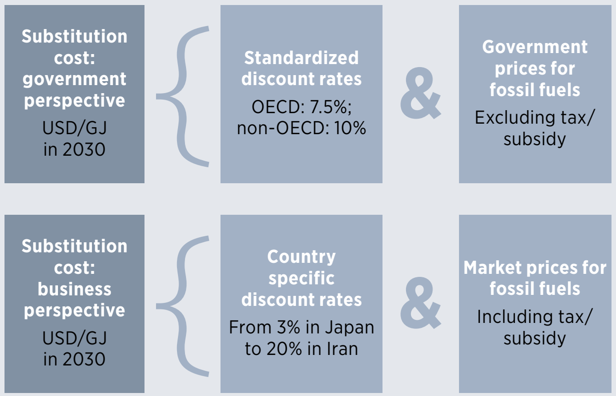
A3.1: Cost assessment



Each REmap Option is characterised by its costs, with the main metric represented by its substitution cost. Based on the substitution cost of each REmap Option, country cost curves were developed and then combined in global cost curves to provide two perspectives: government and business.



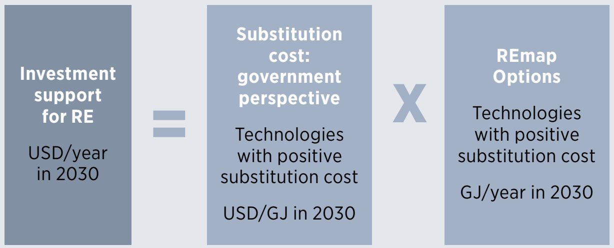
In **the government perspective,** international costs exclude energy taxes and subsidies, and a standard 10% (for non-OECD) or 7.5% (for OECD) discount rate was used. This approach allows for a comparison across countries and for a country cost-benefit analysis; it shows the cost of the transition as governments would calculate it. For the **business perspective,** the process was repeated to include national prices (including, for example, energy taxes, subsidies and the cost of capital) in order to generate a localised cost curve. This approach shows the cost of the transition as businesses or investors would calculate it. Assessment of all additional costs related to complementary infrastructure are excluded from this report (*e.g.*, grid reinforcements).



The cost of identical technology options can vary from country to country as well, depending on resource quality, cost of capital and other factors. The REmap tool includes a standard set of about 80 renewable energy technologies which is also used for the analysis. Substitution costs are one of the indicators for assessing the economic viability of REmap Options and therefore are also aggregated to estimate the average substitution costs of individual technologies, countries and sectors.

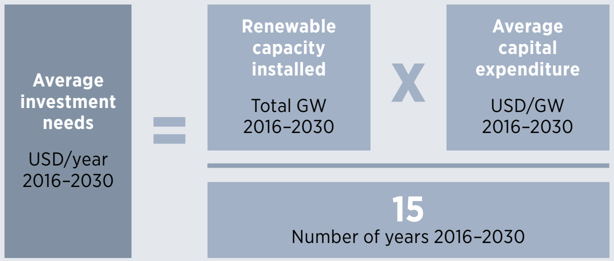
Based on the substitution cost inference can be made as to the effect on **system costs.** This indicator is the sum of the differences between the total capital and operating expenditures of all energy technologies based on their deployment in REmap 2030 and the Reference Case in 2030.

Renewable investment support needs can also be approximated based on the REmap tool. Total requirements for renewable investment support in all sectors are estimated as the difference in the delivered energy service cost (*e.g.*, in USD/kWh or USD/GJ based on a government perspective) for the renewable option against the dominant incumbent in 2030. This difference is multiplied by the deployment for that option in that year to arrive at an investment support total for that technology. The differences for all REmap Options are summed to provide an annual investment support requirement for renewables. It is important to note that where the renewable option has a lower delivered energy service cost than the incumbent option, which begins to occur increasingly by 2030, the "negative investment support requirement" is not subtracted from the total.



A more detailed cost methodology is available online at ***www.irena.org/remap***

Investments can also be assessed. The total **investment needs** of technologies in REmap 2030 are higher than in the Reference Case due to the increased share of renewables which, on average, have higher investment needs than the non-renewable energy technology equivalent. The capital investment cost (in USD/kW of installed capacity) in each year is multiplied with the deployment in that year to arrive at total annual investment costs. The capital investment costs of each year are then summed over the period 2010-2030. Net incremental investment needs are the sum of the differences between the total investment costs for all technologies, renewable and non-renewable energy, in power generation and stationary applications in REmap 2030 and the Reference Case in the period 2010-2030 for each year. This total was then turned into an annual average for the period.



In addition to GW in power and heat, the CAPEX required for biofuel plants is also taken into account

A3.2: Externality and CO_2 assessments

The **external cost accounting** in REmap has been significantly improved over the method in the REmap 2014 report. The costs from generation of energy arise from the emissions produced in the form of fine particulate matter ($PM_{2.5}$), mono nitrogen oxides (NO_x), sulfur dioxide (SO_2), volatile organic compounds (VOCs) and ammonia (NH_3). Additionally, the social costs of CO_2 are estimated. Emission effects covered are health effects arising from outdoor exposure, those arising from indoor exposure in the case of traditional use of bioenergy and effects on agriculture.

The basic approach for the external cost assessment included:

i. Estimate the emissions factors for the local pollutants by sector.

ii. Update estimates external costs in USD per tonne

iii. Apply the updated costs to the estimates of emissions from fuel use by sector and country for 2010 and for the two cases in 2030 to derive estimates of the total external costs of fossil fuel use by country.

REmap also assess **CO_2 emissions** that are emitted from the sectors covered within the bounds of the REmap analysis. For these sectors two assessments are made: CO_2 resulting from direct combustion of fossil fuels, and CO_2 resulting from direct combustion and lifecycle emissions from fossil fuels and renewable energy technologies.

A more detailed externality assessment methodology and CO_2 assessment method is available online at www.irena.org/remap.

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ROADMAP FOR A
RENEWABLE ENERGY FUTURE

2016 EDITION

Doubling renewables in the global energy mix by 2030 is not only feasible, but cheaper than not doing so. Economic savings would far exceed the costs. It would create more jobs, boost economic growth and save millions of lives annually through reduced air pollution. It would also, when coupled with greater energy efficiency, put the world on track to keep the rise of temperatures within 2°C, in line with the Paris Agreement.

But to meet that goal, renewable energy deployment must happen six times faster than today.

This second edition of IRENA's global roadmap provides an in-depth perspective on the energy transition in 40 economies, representing 80% of global energy use. It offers concrete technology options and outlines solutions to accelerate renewable energy growth.

The age of renewables is here. But without concerted action, they cannot reach their potential soon enough to meet international climate and development targets. For decision makers in the public and private sectors alike, this roadmap sends an alert — on the opportunities at hand and the costs of not taking them.

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