IRENA
International Renewable Energy Agency

REmap 2030

A Renewable Energy Roadmap

Report

June 2014

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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FOREWORD

In 2011, the United Nations Secretary-General launched the Sustainable Energy for All (SE4ALL) initiative with three interlinked objectives to be achieved by 2030: ensure universal access to modern energy services; double the global rate of improvement in energy efficiency; and double the share of renewable energy in the global energy mix. IRENA joined this global effort and took the lead as the SE4ALL Hub for Renewable Energy. REmap 2030 is IRENA's solution for how we can work together to double the share of renewable energy in the global energy mix. This report is a summary of the first-ever global roadmap to meet this challenge.

REmap 2030 is both a call to action and a remarkable piece of good news. The good news is that the technology already exists to achieve that aspirational goal by 2030, and even to surpass it. Strikingly, taking external costs into account, the transition to renewables can be cost-neutral.

The call to action is this: unless countries take the necessary measures now, we will miss the goal by a considerable margin. If we continue with business as usual, under the policies currently in place, the world will increase the share of renewable energy from 18 percent today to only 21 percent, instead of a potential 36 percent or more.

REmap 2030 represents an unprecedented international effort that brings together the work of 82 national experts from 42 countries, who collaborated through a year-long programme of global webinars, regional meetings, and national workshops involving technology experts, industry bodies and policy makers. Its findings are clear. Compared to energy systems based on fossil fuel, renewable energy offers broader participation, is better for our health, creates more jobs and provides an effective route to reducing carbon emission – a goal that becomes increasingly urgent by the day. Many renewable energy technologies already provide the most cost-effective option for delivery of energy services, with innovation and increasing deployment continuing to drive costs down.

But amid these advances, there are still misconceptions on the positive impact that renewable energy has to offer in a global drive for a sustainable and inclusive growth. Policy makers are insufficiently aware of the challenges and opportunities that lie before them, and national electorates cannot easily obtain objective and transparent information. REmap 2030 aims to contribute to remedying these shortfalls.

Of course, there is no-one-size-fits-all solution. Every country is different, and each will need to take a different path. REmap 2030 is an invitation to countries to forge the renewable energy future most appropriate to their circumstances, informed by the most comprehensive and transparent data available. It is also a living document. This report is supplemented by a shorter summary, an expanding series of country and issue-specific studies, and the continually updated REmap web pages. The whole REmap initiative will continue to evolve and expand over time.

But at its heart, REmap 2030 offers a simple choice. Take the necessary action now and build a healthy, prosperous and environmentally sustainable future through renewable energy, or carry on as usual and see our hopes for a future built on a sustainable energy system recede a long way into the future. To me, this is no choice at all. Renewable energy is not an option. It is a necessity. REmap offers a pathway to make it happen.

Adnan Z. Amin
Director-General
International Renewable Energy Agency

MESSAGE FROM SUSTAINABLE ENERGY FOR ALL

When the United Nations Secretary-General launched the Sustainable Energy for All initiative in 2011, he sent a message to the world: to achieve sustainable, equitable progress, we have to change the way we power our societies. Along with ensuring universal access to modern energy services and improving energy efficiency, we need to double the share of renewable energy in the global energy mix by 2030.

Achieving sustainable energy for all requires an investment in our collective future, which must be fully integrated in the post-2015 development agenda.

In 2014, the Intergovernmental Panel on Climate Change has added new urgency to the Secretary-General's call. As the panel's report clearly shows, a global shift to clean energy, with energy efficiency and renewable energy at the center, offers us the best option for the protection of the world's climate.

The launch of REmap 2030, therefore, could not be more timely. The first global roadmap of its kind, based on an unprecedented analysis of the 26 most important energy markets, it shows not only what we must do, but how we can do it.

At its heart lies a remarkable finding: not only is it possible to double the global share of renewable energy by 2030, but it is possible to do so more cheaply than the alternatives. In other words, one of the key solutions to the greatest challenge of our era – climate change – is also the most cost-effective option.

REmap 2030 also shows how the other major objectives of Sustainable Energy for All – ensuring universal access to modern energy services and doubling the global rate of improvement in energy efficiency – are furthered by this push toward renewable energy.

It provides a pathway for hundreds of millions of people currently left off the grid to benefit from clean, healthful, locally produced power, and it demonstrates the powerful symbiotic relationship between renewable energy and energy efficiency, in which progress in one fosters progress in the other.

Our challenge is to ensure that these messages find the widest possible audience. REmap 2030 needs to be seen not only by international policy makers and climate scientists, but also by financiers and entrepreneurs, industry leaders and venture capitalists.

Its message is clear: the world stands poised at the dawn of a new industrial revolution – one that can be powered by clean, healthful energy sources that will never run out. Let us grasp this opportunity with enthusiasm to build a better world.

Kandeh Yumkella
Special Representative of the Secretary-General of the United Nations and CEO, Sustainable Energy for All

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Australia: Helen Bennett, Shari Lapthorne, Arif Sayed, Tim Sill, Veronica Westacott; Belgium: Reinhilde Bouckaert, Els van de Velde; Canada: Michael Paunescu, Nadja Schauer; China: Dong Ming Ren, Liu Xiaobing, Xu Jigang, Kaare Sandholt; Denmark: Therese Kofoed Jensen, Hans Jørgen Koch, Jakob Stenby Lundsager, Trine Tougaard; Ecuador: Jorge Burbano, Daniel Ortega, Alfredo Samaniego, Luis Villafuerte; European Commission: Thierry Bertouille, Tom Howes, Oyvind Vessia; France: Cécile Gracy, Remy Lauranson; Germany: Alexander Haack, Rainer Hinrichs-Rahlwes, David Jacobs, Niklas Martin, Tobias Nagler, Thomas Pregger, Martin Schoepe, Gerhard Stryi-Hipp, Sven Teske, Jochen Weilepp, Ellen von Zitzewitz; India: D.K. Khare, P.C. Maithani, Alok Srivastava; Indonesia: Herman Darnel Ibrahim; Italy: Maria Gaeta, Luca Miraglia, Estella Pancaldi, Riccardo Toxiri, Jan Okko Ziegler; Japan: Junichi Fujino, Mirei Isaka, Yoshihiro Kaga, Kenji Kimura, Yuki Kudoh, Daisuke Kunii, Hiranao Matsubara, Toshiaki Nagata, Mika Ohbayashi, Tetsuro Oi, Yoshiaki Shibata, Manabu Utagawa, Tatsuya Wakeyama, Yoh Yasuda; Malaysia: Wei-nee Chen, Gladys Mak, Lim Shean Pin; Mexico: Margott Galvan, Eduardo Iglesias Rodríguez, Ricardo Saldana; Morocco: Karim Choukri; The Netherlands: Rick Bosman, Marc Londo, Karina Veum; Nigeria: Eli Jidere Bala; Russia: Evgeniy Nadezhdin; Saudi Arabia: Thamer AlMahoudi, Ibrahim Babelli, Ahmed Al Sadhan, Otman Al Saleh, Hussain Shibli, Maqbool Moos; South Africa: Andre Otto; South Korea: Jiwoon Ahn, Yong-Kyung Chung, Sangjun Lee, Yungsoo Shin, Jin Yong Soh, S.K.Gavin Yu; Tonga: 'Inoke F. Vala; Turkey: Selahattin Çimen, Mustafa Erkeç, Sebahattin Öz, Yusuf Yazar; Ukraine: Oleksandr Grytsyk, Igor Kovalov, Mykola Pashkevych; United Arab Emirates: Ayu Abdullah, Steve Griffiths, Dane McQueen, Sgouris Sgouridis; United Kingdom: AbuBakr S Bahaj, Nick Clements, Jonathan Radcliffe, Rachel Solomon Williams; United States: Doug Arent, Carla Frisch, Michael Mills, Timothy Williamson; Uruguay: Pablo Caldeiro, Magdalena Preve.

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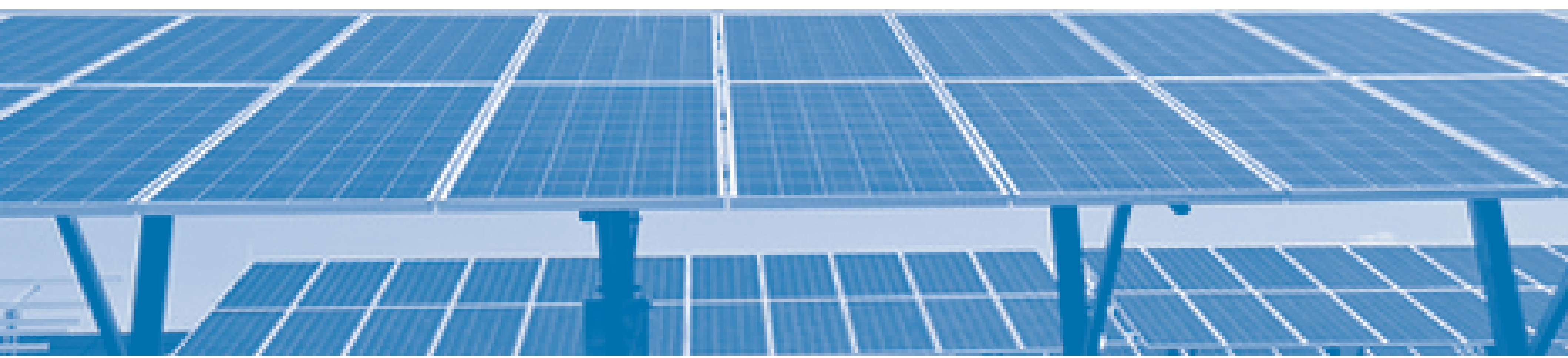
- IRENA REmap workshop, Malta, 5 September 2012
- IRENA REmap workshop, Abu Dhabi, 14 November 2012
- Singapore International Energy Week, 31 October 2013
- IRENA REmap workshop, Abu Dhabi, 12/13 November 2013
- United Nations Framework Convention on Climate Change, 19th Conference of Parties (COP-19) side event, Warsaw, 22 November 2013

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



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The global share of renewable energy can reach as high as 36% by 2030 with technologies that are already available today as well as with improved energy efficiency and energy access. Going further than this will require thinking "outside the box", with early retirement of conventional energy facilities, technology breakthroughs and consumer-driven societal change. The report summarised here, prepared by the International Renewable Energy Agency (IRENA) through broad consultations and engagement around the world, provides a global roadmap for doubling the share of renewables in the energy mix. This full report of REmap 2030 provides insights into five specific areas:

1. Pathways for doubling the share of renewable energy in the global energy mix based on the national plans of 26 REmap countries and the additional REmap Options, and how to go beyond doubling based on different strategies represented by the RE+ Options;
2. Socio-economic impacts related to doubling the global share of renewable energy;
3. Current situation of renewable energy markets in the power, district heat and end-use (industry, buildings, transport) sectors as well as developments between 2010 and 2030 if all REmap Options are implemented;
4. National policy proposals to improve the existing policy framework; and
5. Opportunities for international co-operation of governments for doubling the global share of renewable energy.

This report has six chapters. **Chapter 1** is an introduction to REmap 2030. It explains the link between REmap 2030 and the Sustainable Energy for All (SE4ALL) initiative, as well as the knowledge gaps that this study closes in view of the requests from the IRENA Member States and the SE4ALL objectives of 1) modern energy access, 2) doubling the global share of renewable energy by 2030 and 3) doubling energy intensity improvements between today and 2030.

Chapter 2 explains the REmap methodology. **Chapter 3** presents the Reference Case and the REmap Options as well as the RE+ Options and innovation needs to go beyond a doubling of the renewable energy share. **Chapter 4** presents findings on the costs of the policies, externalities and socio-economic benefits for REmap 2030. **Chapter 5** focuses on specific actions that would be most productive in the four sectors of electricity, industry, buildings and transport. It ends with a short discussion of biomass, which is the largest source of renewable energy now and will continue to be in the future according to REmap 2030. Finally, **Chapter 6** discusses how REmap can be operationalised, what policies are needed and how can international co-operation help.

REmap 2030 indicates a pathway for doubling the share of sustainable renewable energy in the world's total final energy consumption (TFEC)[1].

- Based on a bottom-up analysis of 26 countries which participated in REmap 2030, the policies that are currently in place and under consideration – termed the Reference Case in this study – would take the

1 TFEC includes the total combustible and non-combustible energy use from all energy carriers as fuel (for the transport sector) and to generate heat (for industry and building sectors) as well as electricity and district heat. It excludes non-energy use, which is the use of energy carriers as feedstocks to produce chemicals and polymers, but includes the consumption in blast furnaces and coke ovens of the iron and steel sector. This report uses this indicator to measure the renewable energy share, consistent with the Global Tracking Framework report (World Bank, 2013a).

world only from the current 18% renewables share to a 21% share in 2030[2].

- This study identifies additional REmap Options on top of the Reference Case. The REmap Options together with doubling the rate of energy efficiency improvements and providing universal access to modern energy services via renewables would raise the renewable energy share to as much as 36%[3].
- To continue the transition beyond a doubling of the share of renewable energy, intensified research, development and deployment (RD&D) policies are needed, along with standards, quality control, technology co-operation and project development capacity. These technology options are presented under RE+ Options.
- Biomass currently makes up 75% of total renewable energy consumption today, with traditional use of biomass accounting for more than half of all renewables. Not all traditional use of biomass today is sustainable, however.
- As traditional use of biomass decreases, the share of modern renewables will more than triple. As energy demand continues to grow, this will require a quadrupling of modern renewables in absolute terms.
- Technology costs have fallen significantly and will continue to decline through technology innovation, competition and growing markets, and regulatory streamlining.
- On a country level, the Reference Case for renewable energy deployment in 2030 ranges from 1% to 43%, with a 21% weighted average for the 26 REmap countries (including traditional use of biomass). With REmap Options fully implemented, the range would be from 6% to 66%, with a 27% weighted average (excluding traditional use of biomass). The average increases to 30% for the world as a whole.

2 Renewable energy share in TFEC is estimated as the sum of all renewable energy use by all energy sources (*e.g.,* biomass, solar thermal) and the share of district heat and electricity consumption originating from renewable energy divided by the TFEC. It can be estimated for the total of all end-use sectors of a country or for each sector separately.

3 Using a different metric, such as primary energy, would yield more than a doubling for the same amount of renewables.

- The level of renewable energy ambition tends to correlate with the energy price level. The macroeconomic perspective and business economics diverge in many countries.

The economic case for the renewable energy transition is even stronger when socio-economic benefits, such as climate change mitigation, health impacts and job creation are included. A high renewable energy share based on a range of renewable technologies provides flexibility, increases independence and makes the overall energy supply more reliable and affordable.

- IRENA's analysis suggests that the average substitution cost for doubling the share of sustainable renewables is US Dollar (USD) 2.5 per gigajoule (GJ)[4] of final renewable energy use in 2030[5]. The average substitution cost by country ranges from USD -12 to USD 14 per GJ.
- Worldwide incremental energy system costs average USD 133 billion annually until 2030, while average incremental investment needs are around USD 265 billion annually to 2030. Renewable subsidy needs rise to USD 315 billion in 2030 with the REmap Options fully deployed, but in some countries, subsidies peak before 2030. In comparison, global subsidies for fossil fuels amounted to USD 544 billion in 2012.
- Average health benefits due to the mitigation of air pollution from fossil fuel use are in the range of USD 1.9-4.6 per GJ, while carbon dioxide (CO_2) mitigation benefits are in the range of USD 3-12 per GJ. The total of cost and benefits results in net savings of at least USD 120 billion, and as high as USD 740 billion by 2030.

4 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).

5 Substitution cost represents the difference between the annualised costs of the REmap Options and a conventional energy technology used to produce the same amount of energy divided by the total renewable energy use in final energy terms.

- Compared to the Reference Case, renewable energy can yield 8.6 gigatonnes (Gt) of CO_2 reductions in 2030, on par with the potential reduction due to energy efficiency. Renewable energy and energy efficiency offer, jointly, the prospect of significant CO_2 reductions, in line with a maximum global temperature rise of 2 degrees Celsius (°C).
- REmap Options will result in the creation of net 900 000 jobs in the energy sector on average to 2030, compared to the Reference Case, generated directly by core activities without taking into account the intermediate inputs necessary to manufacture renewable energy equipment or to construct and operate facilities.

Global electricity consumption will grow faster than TFEC, from nearly 20% to around 25% of TFEC in 2030. However, electrification[6] and deploying renewable electricity alone will not be sufficient to reach a doubling of the renewable energy share. Renewable electricity uptake needs to be complemented by direct replacement of fossil fuel use in the three end-use sectors of buildings, transport and industry.

If the REmap Options are deployed, the total share of modern renewable energy in 2030 would reach 44% in power, 38% in buildings, 26% in industry and 17% in transport (including renewable electricity and district heat in end-use sectors). Around 40% of the total modern renewable energy use in REmap 2030 is in power generation, with 60% in the other three end-use sectors.

- Governments underestimate the change that is coming. Solar photovoltaics (PV) is a good example: total governmental projections yield less than 500 gigawatt-electric (GW_e) of solar PV in 2030, whereas REmap 2030 demonstrates that a combination of current market trends coupled with enabling policies can result in 1 250 GW_e.
- If all REmap Options are deployed, coal use will be affected most, with a decline of up to 26%, and gas and oil use would decline by 15%, compared to the Reference Case. A higher share of renewable energy in the energy supply mix would change the balance and affect international trade flows. Total renewables consumption could exceed the consumption of each of the three fossil fuels if expressed based on either of the commonly applied primary energy accounting methods.
- Biomass dominates the renewable energy portfolio. Greater focus on ensuring sustainability is necessary to accelerate the use of biomass, especially in the three end-use sectors. In addition, innovative solutions for electrification should be explored.
- Markets and policy makers both play crucial roles. Markets provide affordable solutions, but a sustainable future requires policy guidance. Policies must enable investments and stimulate market growth and transformation, with a focus not only on short-term gains, but also on long-term impact. Effective policies must take into account system and infrastructure issues, such as biomass supply and demand, electricity generation capacity and the transformative value of smart grids. Market forces play a key role in finding efficient solutions and scaling up the best practices.
- This analysis identifies five key areas for national action where targeted policies are needed to accelerate progress.
- There is a need to focus on overall system design rather than on the cheapest source of renewable energy. Governments must ensure the development of enabling infrastructure, including power grids and storage, to support the integration of high shares of variable renewables.
- Pre-commercial research needs to be conducted in emerging technology areas. Notably, new renewable energy solutions are needed for the three end-use sectors.

Meeting the objective of doubling the share of renewable energy by 2030 requires action by both the public and private sectors. Numerous

6 Electrification means that services provided by end-use sectors which are currently based on fuel-based technologies (*e.g.*, gasoline-running passenger vehicles, coal-based industrial production processes) are being substituted with their electricity-based counterparts (*e.g.*, electric vehicles, electrolysis for chemical production processes). This raises the share of electricity use in the TFEC of the end-use sectors since less fuel is used whilst more electricity is consumed.

barriers exist today, and action is needed to overcome them. Based on the 26 REmap country analyses and dialogue, this report has identified five key areas for national action to improve the existing policy framework for doubling the renewable energy share in the global energy mix:

1. Planning realistic but ambitious transition pathways for renewable energy:

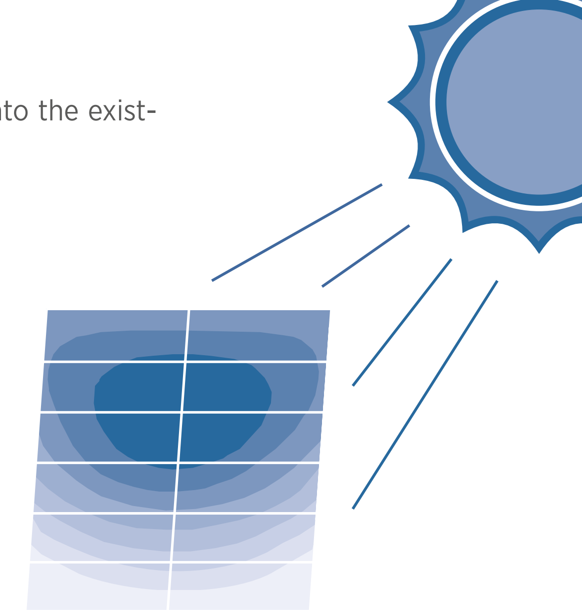
- Assess the base-year situation and Reference Case trends for renewable energy for 2030 on a country basis;
- Develop a national roadmap to meet renewable energy targets. Monitor progress and re-evaluate targets and framework effectiveness and efficiency regularly;
- Ensure human and institutional capacity to develop and sustain the transition;
- Streamline planning processes and ensure their consistency and inclusiveness on different levels, including municipal, national and regional planning.

2. Creating an enabling business environment:

- Invest in new capacity and develop risk-minimising measures to reduce the cost of capital and levelised cost of energy generation and use;
- Consider increased renewable energy deployment as an alternative to fossil fuel subsidies;
- Ensure fair market access and phase out negative price distortions;
- Account for external effects in the pricing of fossil fuel energy supply and use;
- Ensure quality of products through standards and regulations, and find the country balance for local content requirements in the light of market access for cost reductions and innovation;
- Through country-dialogue and community engagement establish a set of credible and predictable policy frameworks that can be maintained over longer periods. Ensuring smooth integration into the existing infrastructure;
- Reduce the duration of project implementation by improving the planning and regulatory framework.

3. Ensuring smooth integration into the existing infrastructure:

- Strengthen existing and build enabling infrastructure such as transmission grids, interconnectors and electric vehicle charging stations;
- Facilitate sustainable biomass supply and consider the nexus in the development of renewable energy strategies and policies, notably land, energy, water, agriculture, trade and infrastructure;
- Develop market for affordable and reliable equipment for modern energy access.



4. Creating and managing knowledge of technology options and their deployment:

- Build a strong, publicly accessible knowledge base on renewable energy technology costs, potential and options;
- Expand project development knowledge for bankable project proposals;
- Collect and report best-practice information on technology and policies;
- Establish and improve programmes to increase awareness and strengthen the capacity of manufacturers, installers and users;
- Design renewable energy technologies from the point of view of product and service life-cycle environmental and sustainability impacts.

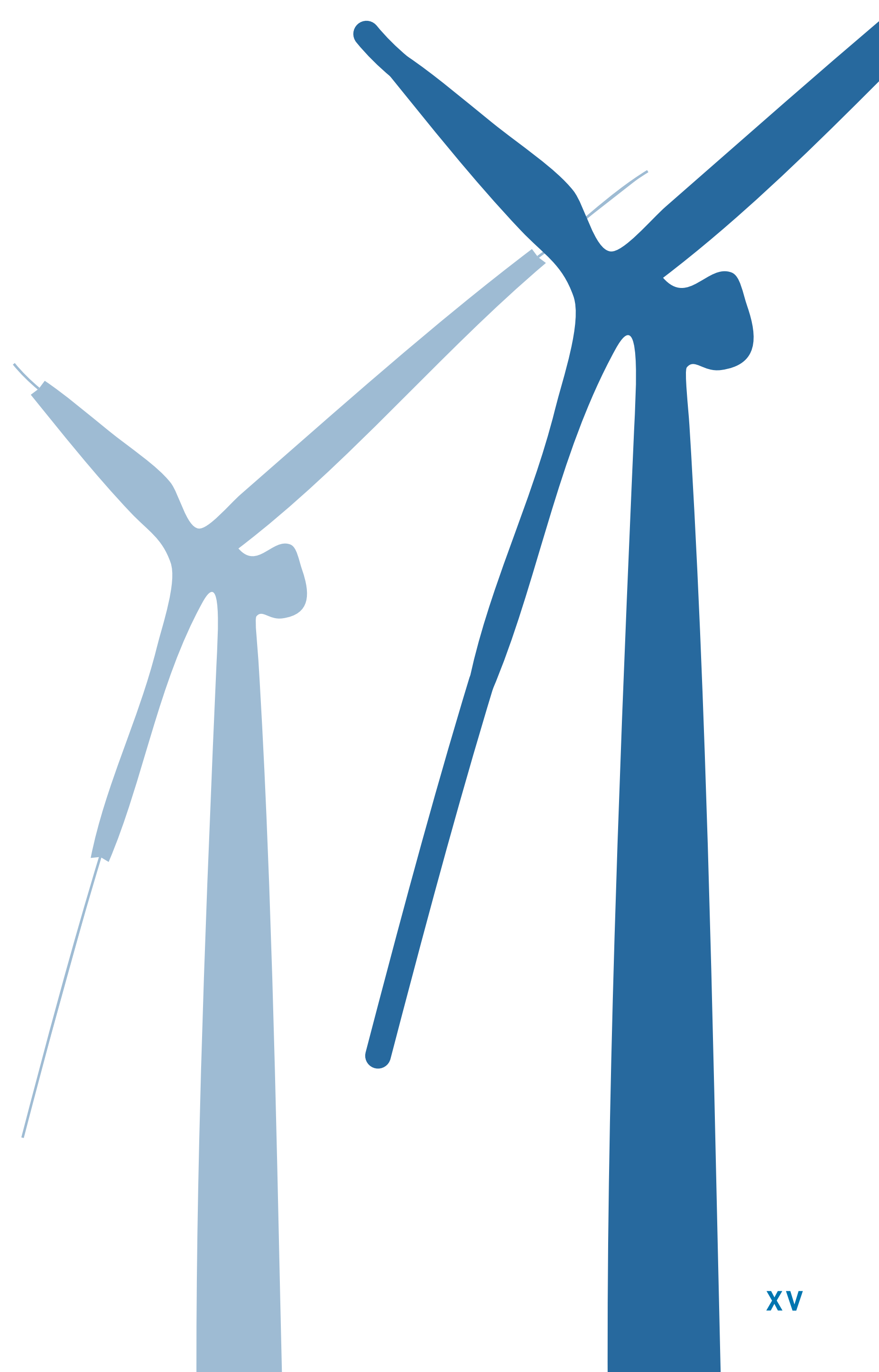
5. Unleashing innovation:

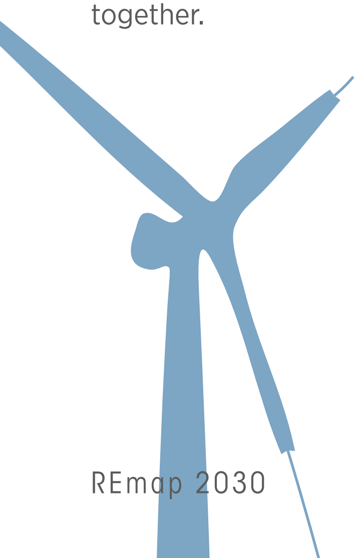
- Develop targeted policies that support the technology life cycle;
- Review energy applications of high relevance and low renewable energy potential and develop programmes to fill the gap with new technology.

The renewables potential varies by country, and therefore specific areas and groupings for co-operation need to be considered. Areas of focus include:

- Scaling up international markets, for economies of scale and accelerated technology learning;
- An enhanced knowledge base, including better data on biomass use, renewable energy resource potential and comparative technology costs;
- More-detailed assessment of the nexus between access, efficiency and renewable energy share, as well as energy, water and land use;
- Promotion of the role of sustainable biomass products and renewable electricity as internationally traded energy carriers;
- Intensified sharing of experiences and best policy and planning practice for renewable energy.

Most action will be national, but in many regions more international co-operation can help to accelerate an energy transition. Actions and policies will need to be tailored to account for the specific needs of regions, sectors and technologies and involve multiple stakeholders. International co-operation will enable a surge in the adoption and use of renewable energy worldwide. Interconnectors (trade and grid stability), harmonised standards, capacity building, exchange of best policy practices and precommercial research for innovation are all indispensable to go beyond a 36% renewables share – and are achievable only when countries work together.





1 INTRODUCTION

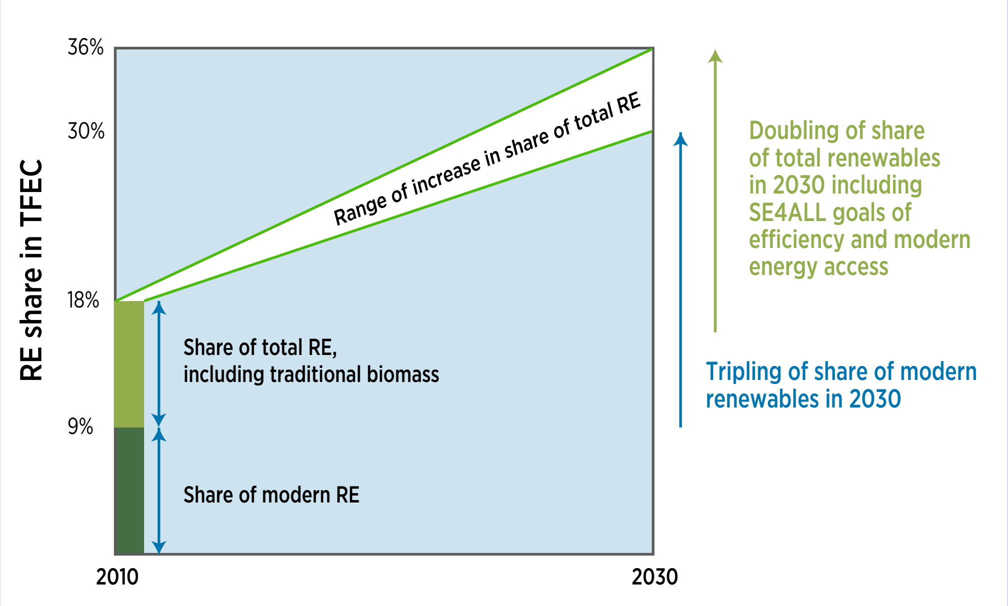
In 2012, the United Nations General Assembly declared 2014-2024 to be the Decade of Sustainable Energy for All, underscoring the importance of energy issues for sustainable development and for the elaboration of the post-2015 development agenda (UN GA, 2012). In the same year, the UN Secretary-General set up a High-Level Group on Sustainable Energy for All (SE4ALL) to develop a global action agenda based on three interconnected objectives: 1) ensuring universal access to modern energy services, 2) doubling the rate of improvement of energy efficiency and 3) doubling the share of renewable energy in the global energy mix (SE4ALL, 2012). The International Renewable Energy Agency (IRENA) is the renewable energy hub for SE4ALL.

IRENA was established in April 2011 as the inter-governmental agency for deployment of renewable energy. As of the end of April 2014, the Agency had 130 Members and 38 countries in the process of accession. The Members asked the Agency to explore how an aspirational target of doubling the global renewable energy share could be put into practice (IRENA, 2012a). IRENA developed REmap 2030 to explore in more detail the feasibility of the third objective, including the interconnectivity between renewable energy and energy efficiency strategies.

REmap 2030 is a roadmap to double the share of renewable energy by 2030. It is the first global study to provide renewable energy options based on a bottom-up analysis of official national sources. In investigating the doubling of the share of renewable energy in global total final energy consumption (TFEC), IRENA engaged its Members. The underlying data were provided largely by the 26 REmap countries, and the findings generally were co-ordinated with the country expert appointed by each country. The roadmap goes beyond the power sector to investigate the three end-use sectors of buildings, transport and industry, which are too often overlooked. Furthermore, the cost of this transition was calculated in-depth. The study not only investigates the additional technology potential to reach a doubling, but also identifies the innovation and technology development needs to go beyond a doubling, as well as the real-world barriers that could impede these developments – and proposes ways to overcome them.

In January 2013, IRENA published the working paper *Doubling the Global Share of Renewable Energy: A Roadmap to 2030* (IRENA, 2013a). This publication, based on an analysis of global energy scenarios for 2030, showed that a doubling of renewable energy is achievable and requires action in all regions. It also revealed a significant gap between the global

Figure 1.1 Doubling the share of renewables by 2030



Note: The world currently gets 18% of its energy from renewables, but only 9% is modern renewables, and the other 9% is traditional use of biomass, of which only part is sustainable. To achieve a doubling of sustainable renewable energy, modern renewables need to replace traditional use of biomass almost entirely. As a result, the share of modern renewables more than triples from 9% in 2010 to 30% or more by 2030.

renewable energy share in 2030 based on existing national renewable energy plans and the doubling objective of the SE4ALL initiative. Bridging this gap will require major progress in improving energy efficiency and achieving universal energy access.

Figure 1.1 shows the share of renewable energy in 2010 as a share of TFEC; 9% of TFEC is modern renewable energy, and up to another 9% is traditional use of biomass, resulting in a total renewable energy share of 18% in 2010. The International Energy Agency (IEA, 2012a) defines traditional use of biomass as: "the use of wood, charcoal, agricultural residues and animal dung for cooking and heating in the residential sector. It tends to have very low conversion efficiency (10% to 20%) and often relies on unsustainable biomass supply".

Although the IEA collects data on biomass use in the building sector and proposes a methodology for breaking down the reported data by modern and traditional forms, the total volumes reported are subject to great uncertainty for numerous reasons. The actual volumes used in some developing countries and economies in transition are often not measured but estimated based on simplified approaches, such as the extrapolation of historical data based on growth in gross domestic product (GDP). Furthermore, because the definition of traditional use of biomass is broad, the total volume changes depending on the definition and method of estimation, resulting in inconsistencies across years. Consequently, there is a great deal of uncertainty. It is clear, however, that to achieve sustainable energy for all, the efficiency of traditional use of biomass needs to be increased. As a result, the share of modern renewables more than triples from 9% in 2010 to 30% by 2030, as shown in Figure 1.1.

IRENA discussed the development of a more detailed IRENA roadmap for its Members at the third meeting of the IRENA Council in June 2012 (IRENA, 2012b) and organised two consultation workshops with IRENA Members in September and November 2012. Representatives from 18 countries attended. The main feedback was that an IRENA roadmap would help streamline IRENA's internal and external activities and should be based on a transparent process for country engagement and peer review so that country experts can learn from each other's inputs (IRENA, 2012c,d). REmap 2030 is an evolving document (IRENA, 2012e).

This full roadmap report provides detailed results of the analysis and additional information related to the objective of doubling the share of modern renewable energy, and is an extended version of the Summary published on 19 January 2014 (IRENA, 2014a). This report is based on the 26 REmap country analyses prepared by the IRENA Secretariat in dialogue with national experts. These country analyses will be made available in the coming months and are living documents that will be updated regularly.

The foundations for the REmap 2030 process – along with the results of the global analysis – were presented at the third meeting of the Assembly and in the REmap working paper in 2013. The proposed way forward was an iterative three-step process built around and reliant upon full Member engagement with three elements:

- Pathways for doubling the global renewable energy share;
- Additional renewable technology options to meet the objective; and
- Opportunities for international co-operation to realise this vision.

This report addresses each of these elements and is organised as follows: **Chapter 2** explains the REmap methodology. **Chapter 3** presents Reference Case developments at the country and global level as well as the extent to which the renewable energy share in the global energy mix can be raised if all identified REmap Options are implemented on top of the Reference Case. **Chapter 3** outlines the RE+ Options and innovation needs to go beyond a doubling of the renewable share. **Chapter 4** presents findings on the costs of the policies, externalities and the socio-economic benefits for the REmap 2030. **Chapter 5** focuses on specific actions that would be most productive in the sectors of electricity, industry, buildings and transport. It ends with a discussion of biomass, the largest source of renewable energy now as well as projected in the future. Finally, **Chapter 6** discusses how REmap can be operationalised, what policies are needed and how international co-operation can benefit individual countries as well as help to achieve the aspirational global objective.

This chapter presents a brief explanation of the general REmap approach and also provides details about the methodologies which are specific to different analyses covered in this report. An extended methodology can be found online.

2.1 REmap Options and REmap countries

REmap is an analytical approach based on an assessment of the gap between national renewable energy plans, additional renewable technology options in 2030 and the Sustainable Energy for All (SE4ALL) doubling objective. In addition, a large number of regional sector analyses were identified, evaluated and prioritised for region-specific and inter-regional actions within specific sectors. International Renewable Energy Agency (IRENA) worked with the World Bank, the International Energy Agency (IEA) and other parties to establish SE4ALL references for renewable energy. The Global Tracking Report was published in the second quarter of 2013 (World Bank, 2013a).

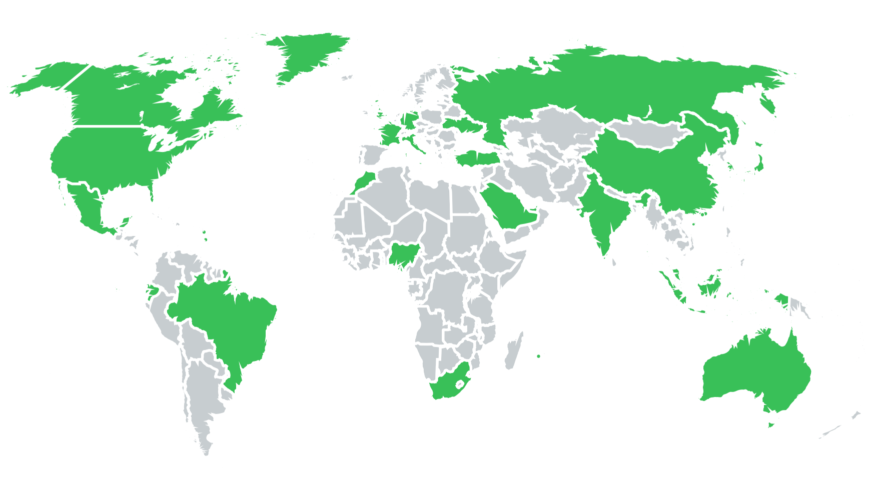
As a starting point, the analysis in 2013 focused on economic aspects and prerequisites for a renewable energy transition. To ensure a transparent, inclusive and open process, IRENA invited all of its Members to identify and nominate national REmap focal points and experts to support REmap 2030. The experts provided their overall energy supply and demand projections up to 2030, including renewable energy policies and targets that were in place or under consideration. Furthermore, the experts provided insights and expertise on the technical, economic and political feasibility of different pathways for renewable energy deployment in the electricity and end-use sectors in this period, and how these different sectors and renewable energy technologies interact. These submissions are not the official views of participating governments, but are based on national data sources and perspectives contributed by credible research institutes.

Experts provided insights and expertise on the technical, economic and political feasibility of different pathways for renewable energy deployment in the electricity and end-use sectors.

REmap analysis covers 75% of projected global total final energy consumption (TFEC) in 2030, with analysis of the following 26 countries: Australia, Brazil, Canada, China, Denmark, Ecuador, France, Germany, India, Indonesia, Italy, Japan, Malaysia, Mexico, Morocco, Nigeria, Russia, Saudi Arabia, South Africa, South Korea, Tonga, Turkey, Ukraine, the United Arab Emirates (UAE), the United Kingdom (UK) and the United States (see Figure 2.1).

Figure 2.2 shows the methodological steps of the REmap country analysis and how this roadmap was prepared. REmap 2030 is a bottom-up analysis of the 26 countries which participated in this study. The methodology is unique, as country dialogue between IRENA and the national experts is key.

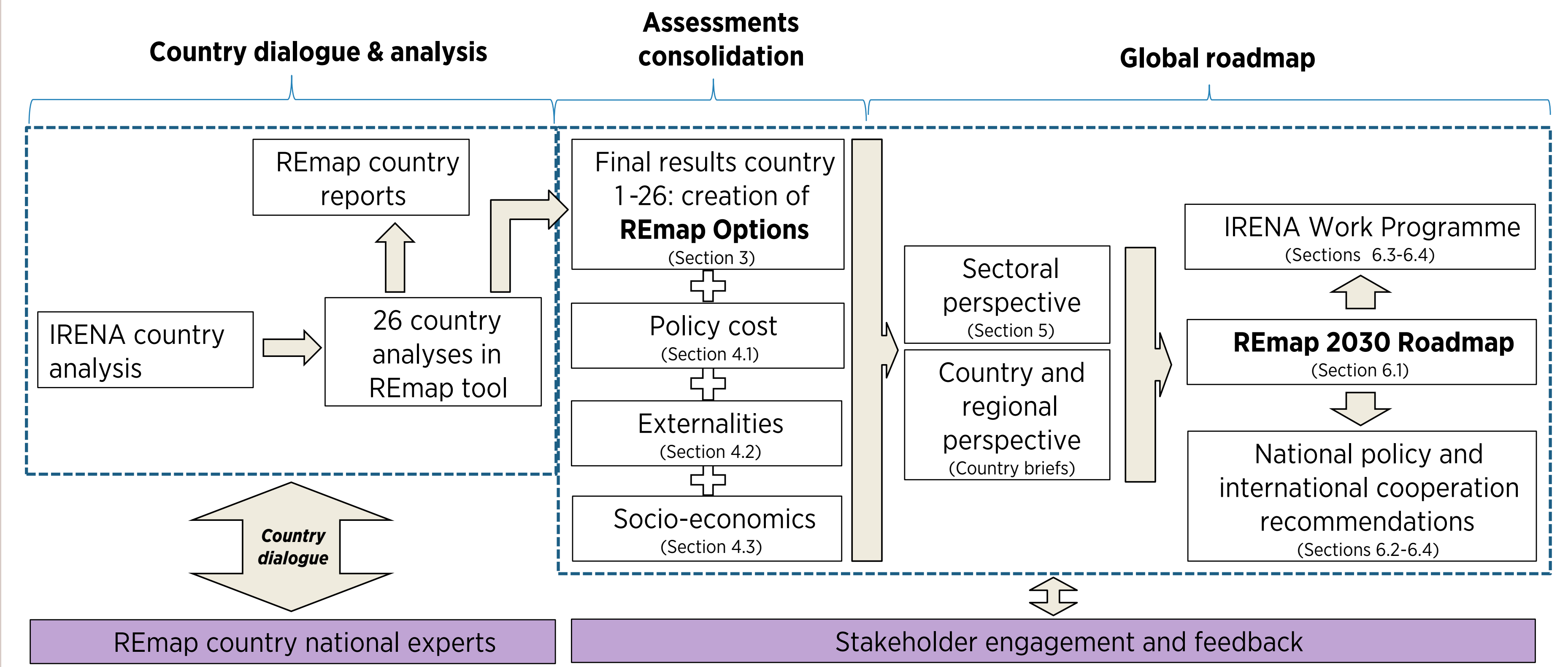
Figure 2.1 The 26 REmap countries analysed



REmap 2030 analysis starts with national-level data covering the analysis of both end-use and power and district heat sectors. The countries first provided their current national plans which start with year 2010, the base year of this analysis. These were collated to produce the business-as-usual Reference Cases, including their targets for renewables. The Reference Cases represent policies in place or under consideration, including energy efficiency improvements. The Reference Case includes the TFEC of each end-use sector and the total generation of power and district heat sectors, with a breakdown by energy carrier for the period 2010–2030. This rich data availability allows 26 REmap countries to be grouped by sector and individual energy carrier. An overview of the sources for the Reference Cases is provided online.

Then, the additional technology options were investigated. These additional technologies are defined as REmap Options – essentially illustrating what a doubling of the share of renewables would look like. The choice

Figure 2.2 Steps in country analysis and preparation of the REmap 2030 roadmap



for the Options approach instead of a scenarios approach is deliberate: REmap 2030 is an exploratory study, not a target-setting exercise, and countries can make informed choices as to how to use the identified options. The aim is to be practical and to co-operate directly with countries in order to analyse and discuss their specific cases in detail. Such an approach also creates an opportunity to discuss implementation of the options identified with the countries, and to improve the existing analysis continuously over the years.

The analysis shows that the REmap Options are not a technical limit; more renewable energy is possible. In addition to REmap Options, there are also RE+ Options, which are based on IRENA studies, technology databases and other literature. They investigate which flanking measures (in particular, efficiency and modal shifts) will take the share of renewable energy beyond a doubling. It is important for policy makers to pave the way for further progress and new technologies in the long term.

The country analyses were complemented by other IRENA analyses carried out at the sector level, in particular for the buildings and industry sectors where potential estimates were available for the same time frame (IRENA, 2014b,c). Potential estimated at the sector level by IRENA was an important part of the discussion on the REmap Options with the national experts. For each country, a detailed analysis was carried out and then translated into a short report for discussion with the country (zero-order draft). Based on the country inputs, both the country analysis and the zero-order draft were revised, and the final country results were estimated. Summaries of the zero-order drafts, as country briefs, will be made available online in the first half of 2014. There are no limits to country inputs and to the number of rounds of review with a country; the analysis is living, and to the extent possible the aim is to incorporate the latest developments and policies. Once the final results are agreed with the countries, they are aggregated to prepare the REmap 2030 roadmap.

As Figure 2.2 shows, the REmap Options are the central part of the analysis, as they define the potential for additional renewable energy technologies. They do not represent a theoretical or technical potential, but a "realistic" potential estimates of opportunities in each country, including:

- what can realistically be planned by 2030 in view of planning procedures (*e.g.*, years required to implement a project) and environmental considerations;
- resource availability;
- what can be funded with the available financial resources;
- what can be built starting with current skills;
- the capacity for renewables manufacturing capacity;
- what is politically possible;
- what is the age of existing capital stock, and how much of total capital it will account for in 2030.

In collecting data from 26 countries, IRENA had to harmonise the Reference Case projections to ensure consistency across countries (*e.g.*, the system boundaries of end-use sectors, time horizon of national plans, etc.), since this study is the first attempt to collect such data. For REmap 2030, IRENA's experts therefore first cross-checked the zero-order drafts of country analyses to improve comparability, as different country plans are based on different assumptions and system boundaries.

Other inconsistencies were found when identifying the REmap Options. A few countries provided projections or data; for most of them, IRENA worked with the country experts to collect data. The variables required for this assessment included such country-specific parameters as the capital stock age profile, resource availability, and the local capital cost and availability of technologies. Finally, some energy price data were taken from countries, while other price data came from third-party sources.

IRENA developed a REmap tool to include the data in an energy balance sheet, which contains a list of key technology options expected to be deployed by 2030. A detailed list of these technologies and the related background data are provided online. The costing data from IRENA's costing publications and IRENA/IEA-ETSAP technology briefs were used to populate the tool for validation by the national experts, and update if necessary

(IRENA, 2013b-d). The tool includes the cost (capital, operation and maintenance) and technical performance (reference capacity of installation, capacity factor and conversion efficiency) of renewable and conventional (fossil fuel, nuclear and traditional use of biomass) technologies for each sector analysed: industry, buildings, transport, power and district heat. The tool also includes the international and national energy prices and discount rates.

The information collected was crucial to validate and improve estimates from the existing literature and also served as a useful resource for countries developing, reviewing or updating their own renewable energy plans. Separate guidelines on the methodology (IRENA, 2013e) and the costing calculations (IRENA, 2013f) were prepared along with a detailed manual for the tool (IRENA, 2013g).

Although the analysis is based on the 26 REmap countries, the results are presented and the conclusions are drawn for the world as a whole. The total of the Reference Case and the REmap Options for the 26 REmap countries is defined as REmap 2030; if results refer to the global situation, this is indicated.

The 26 REmap countries account for about three-quarters of TFEC worldwide today and a similar share of the estimated TFEC in 2030 (see Table 2.1). The 26 REmap countries make up 79% of global power consumption but represent only 66% of total renewable energy use. The selection of countries is found to be representative to project global developments in sufficient detail, although the analysis of developing countries and economies in transition should be extended. The low coverage of renewable energy use in these regions is explained mainly by traditional use of biomass use in Africa, which is underrepresented in the analysis.

To be able to draw conclusions for the global situation, the coverage values provided in Table 2.1 are used to scale the findings of the 26 countries. While this is workable for the total of all energy carriers, *i.e.*, TFEC, for some specific fuels or energy sources, the results are scaled to the global level by adjusted coverage values. Solar, wind, geothermal and liquid biofuels are all overrepresented in the 26 REmap countries, which includes most industrialised and large developing countries, where the technologies mainly have been deployed. They are therefore scaled up with values ranging between 80% and 90% from the 26 countries to the global level. For traditional use of biomass, a coverage value of 50% is applied.

REmap analysis covers 75% of projected global total final energy consumption in 2030.

Otherwise, the 26 countries represent the developments for future TFEC because of the mix of countries, geography and the large proportion of gross domestic product (GDP) and population.

Box 2.1 The REmap tool

IRENA has developed a spreadsheet tool that allows national experts to evaluate and create their country's cost-supply curve. The tool provides a simplified but dynamic accounting framework to evaluate and verify the Reference Case developments and the REmap Options within the countries. It comes with its own manual.

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 conventional technologies assumed to be in place in 2020 and 2030 with REmap Options based on the Reference Case. For ease of use, the experts have a range of technology options to choose from in the transport, building, industry, and power and district heat sectors.

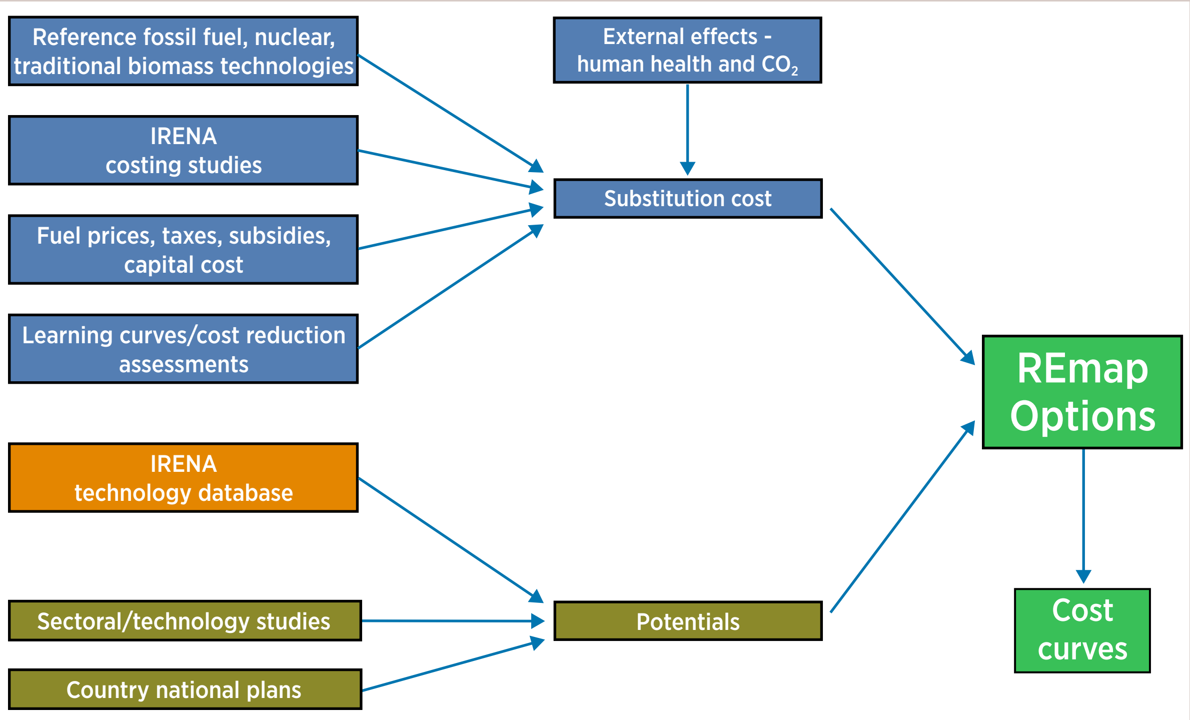
The tool allows experts to choose REmap Options, assess their impacts on the country's renewable energy share and evaluate their position within the country's cost-supply curve. At any time, the experts can increase or decrease the size of REmap Options and choose a different substitute. When a single button is clicked, the tool automatically adjusts the cost-supply curve. Furthermore, the tool allows for a consistent analysis and comparison of results among countries.

Further details can be found in the REmap methodology document, available online.

2.2 Cost supply curves and substitution costs

Each REmap Option is also characterised by its costs (see Figure 2.3). The cost of each REmap Option is 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% 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 including taxes, subsidies and the cost of capital for individual countries[1]. This approach shows the cost of the transition as businesses would calculate it. Assessment of all additional costs related to complementary infrastructure are excluded from this study (*e.g.*, grid reinforcements).

Figure 2.3 Characterisation of the REmap Options



The cost curves presented in this roadmap start with the renewable energy share in TFEC in 2010 and subsequently incorporate the increase according to the Reference Case. The costs of the Reference Case are not indicated, as the technologies are assumed to be deployed anyway. Then, each REmap Option is added to the renewable energy share (x-axis) along with its associated substitution cost (y-axis). The substitution costs of REmap Options are plotted as cumulative frequency curves in descending order of substitution costs, starting with the cheapest and ending with the most expensive one. The shape of the cost curve related to REmap Options is determined by the distribution of the substitution costs and the potential (in %) of the renewable energy technology. Substitution costs are the difference between the annualised cost of the REmap Option and of a conventional technology used to produce the same amount of energy, divided by the total renewable energy use in final energy terms (in US Dollar (USD) per gigajoule (GJ) of final renewable energy). The substitution costs depend on the conventional technology substituted and the characteristics of the REmap Option. The cost can be positive or negative (saving), as some renewable energy technologies are already or will be cost effective compared to conventional technologies.

1 To the extent that data availability allows, 2030 electricity prices account for the developments in the power sector fuel and technology mix changes.

Table 2.1 REmap coverage of global economic activity and energy use

Coverage of 26 REmap countries	2010	2030	References
TFEC	75%	75%	IEA (2012b) and IRENA estimate based on IEA (2012b)
Renewable energy use	66%	–	
Electricity consumption	79%	79%	
Population	65%	62%	World Bank (2013)
GDP based on PPP[1]	76%	64%	PwC (2013)
CO_2 emissions	73%	72%	IRENA estimate

1 *According to the World Bank (2013c), GDP based on purchasing power parity (PPP) is "...gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as the U.S. dollar has in the United States. GDP at purchasers' prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources."*

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 75 renewable energy technologies which is also used for the analysis. The technology details can be found online. In addition, country experts may add at any point their own technologies that they deem important for the country analysis.

All costs are measured in real 2010 USD unless otherwise stated. Localised cost data provides an estimate of the costs of renewables from the business perspective, including the cost of capital, carbon prices and/or fossil fuel subsidies. The government perspective provides a means to compare the REmap Options among different countries. The analysis uses an identical set of technical performance data for the technologies for both the business and government perspectives. For any country, the major difference between the analysis of its substitution costs based on the business and government perspectives originates from national and international energy prices. An overview of the detailed energy price data and discount rates used for this analysis is provided online.

Substitution costs are the key 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. However, substitution costs are not a limiting factor in this analysis for the implementation of REmap Options.

Incorporating the effect of externalities related to climate change mitigation and improved health effects, both originating from the reduced consumption of traditional use of biomass and fossil fuels, would reduce substitution costs. The effects of monetising these externalities on substitution costs are estimated in a separate analysis. In addition to substitution costs, the finance needs related to the implementation of all REmap Options are estimated, namely total subsidy needs and total incremental system costs and investment needs (see Chapter 2.4).

2.3 Definition of renewable energy share indicators

Throughout this study, renewable energy share is estimated related to TFEC. TFEC includes the total combustible and non-combustible energy use from all energy carriers as fuel (for the transport sector) and to generate heat (for the industry and building sectors) as well as electricity and district heat. It excludes non-energy use, or the use of energy carriers as feedstocks to produce chemicals and polymers. This report uses this indicator to measure the renewable energy share, consistent with the Global Tracking Framework report (World Bank, 2013a). Using a different metric, such as primary energy, may yield different results. The effect of changing the accounting approach on the results has been analysed separately.

Renewable energy share in TFEC is estimated as the sum of all renewable energy use from all renewable sources and the share of district heat and electricity consumption originating from renewable energy divided by TFEC. It can be estimated for the total of all end-use sectors of a country or for each sector separately.

There are different ways to estimate the renewable energy share for end-use sectors (industry, buildings and transport) and energy transformation sectors (electricity and district heat). In this study, three indicators are developed to measure the renewable energy share in TFEC (all expressed in %). For the three end-use sectors, the following indicators were estimated:

1. **Total renewable energy use, including renewable electricity and district heat use:** The total renewable energy use by all energy carriers) and the share of electricity and district heat consumption originating from renewable energy (see how the renewable energy share for energy transformation sectors is estimated below) are added up to estimate each sector's total renewable energy use, then divided by TFEC. All results presented in Chapter 5 refer to this indicator.
2. **Total renewable energy use, excluding renewable electricity and district heat use:** The total renewable energy use by all energy carriers is added up to estimate each sector's total renewable energy use, then divided by the sector's TFEC. The denominator is the same as the first indicator.
3. **Total renewable energy use, excluding all heat and electricity use:** The total renewable energy use by all energy carriers is added up to estimate each sector's total renewable energy use, then divided by the sector's TFEC, excluding total district heat and electricity consumption. The denominator is lower than the denominator of the first and second indicators.

For the energy transformation sectors, a single indicator was used to estimate the renewable energy share based on generation from renewable energy sources only. For these sectors, total electricity and district heat generation from renewable energy sources are divided by the total electricity and district heat generation, respectively, in order to estimate their total renewable energy share.

2.4 Policy costs and benefits

2.4.1 Calculation of the policy cost

Three indicators are developed to estimate the financial implications of the implementation of REmap Options. These three indicators are: 1) net incremental system costs, 2) net incremental investment needs and 3) subsidy needs. The methodologies to estimate each of these indicators are described below:

1. *Net incremental 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 the period 2010-2030 for each year. This indicator is calculated in two steps. In a first step, the substitution costs (in USD/GJ) of each REmap Option in 2030 is back calculated for each year in the period 2010-2030. The substitution cost in each year is then multiplied with the annual deployment of REmap Option for that year (total additional potential in 2030 is distributed over the 2010-2030 period). In a second step, all years are summed to arrive at a total incremental cost for the period 2010-2030 and from this total an annual average for the period is calculated. This takes into account the so-called "learning effects", which are the cost reductions of renewable energy technologies as the total installed capacity increases over time[2].
2. *Net incremental investment needs.* The total investment costs 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 costs than the conventional equivalents[3].

2 The resulting average incremental system cost for the period 2010-2030 (in bln USD/year) is higher compared to the calculations provided in other sections of this report which only refer to a snapshot of the incremental cost in 2030 after the cost reductions from learning effects. The calculation for 2030 alone provides a perspective only for the year 2030 with the results of learning investments occurring over time. The average incremental system cost for the period 2010-2030 provide a better metric taking into account total system cost over the entire REmap period.

3 This is on average; many renewable energy technologies in specific markets now have, or will have by 2030 with increased deployment, lower investment costs than the conventional options, particularly in the OECD region.

The capital investment cost (in USD per kilowatt (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 conventional, 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.

Incremental investment needs are important as they indicate the additional financing that is needed for the energy sector. They do not, however, indicate what the cheapest case is – this is estimated with the net incremental system costs.

3. *Subsidy needs*[4]. Total subsidy requirements for renewables in all sectors are estimated as the difference in the delivered energy service cost (*e.g.*, in USD per kilowatt-hour (kWh) or USD/GJ based on a government perspective) for the renewable option against the dominant incumbent one (*i.e.*, for the option of solar hot water heating in the UK, the comparison is against gas-fired hot water heating, and for power generation it may be any fossil fuel-fired electricity generation) in a given year.

This difference is multiplied by the deployment for that option in that year to arrive at a subsidy total for that technology. The differences for all REmap Options are summed to provide an annual subsidy requirement for renewables. The subsidy calculations are for 2010-2030 and are spread over the economic life of the investment, which tends to be longer than real-life subsidy programmes. 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 subsidy" is not subtracted from the total. The subsidy totals in this report are only for the deployment of renewables between 2010 and 2030.

4 A subsidy can differ greatly depending on how it is calculated and what is considered a form of financial or in kind support. The International Monetary Fund (IMF) considers two kinds of subsidy (IMF, 2013): (i) pre-tax, when energy consumers pay prices that are below the cost incurred to supply them with the energy, and (ii) post-tax, which include both the pre-tax total and a tax subsidy, *e.g.* external costs that results from the supply of the energy, but not paid by the energy provider.

2.4.2 Externalities

External effects related to greenhouse gas emission reductions as well as improvements in outdoor and indoor air pollution from the decreased use of fossil fuels are estimated. The analysis of greenhouse gas emissions considers both carbon dioxide (CO_2) and methane (CH_4). To evaluate external costs, a carbon price range of USD 20-80 per tonne of CO_2 is assumed (applied only to CO_2 emissions) (IPCC, 2007a).

The external costs related to outdoor and indoor air pollution are evaluated from the following sources: 1) outdoor emission of sulphur dioxide (SO_2), mono-nitrogen oxides (NO_x) and particulate matter of less than 2.5 micrometres (PM2.5) from fossil fuel-based power plant operation, 2) outdoor emissions of NO_x, and PM2.5 from road vehicles and 3) indoor emissions of particulates from biomass and coal combustion in the residential sector.

To evaluate the external costs related to outdoor emission of SO_2, NO_x and PM2.5 from fossil power plant operation, the following parameters for respective pollutants were used: (a) emission factor (*i.e.*, tonne per kWh for 2010 and 2030 taken from the IIASA GAINS database (ECRIPSE scenario (IIASA, 2014), and (b) unit external costs (*i.e.*, Euro per tonne average for the European Union (EU), taken from the EU CAFE project (AEA, 2005). The parameter (a) is available for individual countries concerned. It corresponds only to emissions from the operation phase of the power plants and does not include the emissions during the whole life cycle (*e.g.*, construction, transportation, dismantling)[5]. The parameter (b) is adjusted by

5 The omission of other phases of the life cycle results in significant underestimation of the extent of external costs.

the ratio of GDP per capita relative to the average GDP per capita for the EU, following the methodology proposed by Markandya (1998). The fixed ratio for 2010 was used for 2030.

The parameters (a) and (b) were applied to the power generation for 2010 and 2030 for the respective countries derived from the REmap 2030 country analyses. Unit external cost covers human health impacts (mortality and morbidity) as well as crop damages. Damages to materials, ecosystems, cultural heritage, etc. were not included in the unit external cost calculation. Impacts related to CO_2 emissions are dealt with in a separate analysis. The unit costs have ranges, corresponding to the variation in the method used to value mortality (use of the value of a life year versus value of statistical life; median versus mean estimates).

To evaluate the external costs related to human health impacts from outdoor emission of NO_x and PM2.5, the same methodology as for the fossil power plant operation case was used. The emission factors correspond to those from light-duty vehicles only, and gasoline and diesel vehicles are distinguished. The unit external cost values are the same as for the emissions from power plant operation. Such external effects as accident and noise are not considered.

For the evaluation of health-related externalities related to indoor air pollution caused by biomass and coal combustion in the residential sector, the total number of deaths due to indoor air pollution from the World Health Organization (WHO) (2014), available for respective countries, was used to compute death according to the residential consumption of biomass (cases/exajoules (EJ)). In the case of China only, coal consumption in the residential sector was added to biomass consumption. The number of expected deaths in 2030 was computed using biomass and coal consumption in the residential sector in 2030, derived from REmap 2030 country analyses. The value of prevented fatalities, taken from the above-mentioned CAFE study, was applied to the total expected death figure to estimate the external costs related to this category. The value used for the prevented fatalities is in the range of Euros 1-2 million per case. The value was adjusted for the respective countries according to their ratio of GDP per capita relative to the EU average.

2.4.3 Socio-economic benefits

The analysis of the socio-economic effects of REmap 2030 focuses on the employment effects. The method used for the employment analysis is the employment factor approach – similar to the one used for the 2012 version of Greenpeace's *Energy [R]evolution* report (Rutovitz and Harris, 2012). Estimations are limited to the jobs originating from energy supply; demand-related jobs are excluded (activities in energy efficiency, etc.). For example, changes in total jobs due to the substitution of gas boilers with biomass furnaces in buildings or the replacement of conventional vehicles by electric vehicles are excluded from the analysis.

Key points

- Policies in place and under consideration will take the global renewable energy share to 21% of total final energy consumption (TFEC) by 2030.

- If all REmap Options are implemented, the share of modern renewables in the global energy mix triples to 27%. Access to modern energy based on renewable technology solutions and further improvements in energy efficiency can increase the renewable energy share to as much as 36%.

- Global traditional use biomass is projected to decline from 9% in 2010 to 7% in 2030 according to the Reference Case, and down to 3% in REmap 2030. Modern biomass use for cooking increases by 300% in the same time period.

- In the Reference Case, the largest growth of renewable energy use in absolute terms in the 26 REmap countries is projected in the transport and power sectors, with an increase of approximately 150% between 2010 and 2030. The renewable energy uptake varies greatly between countries, depending mainly on resource endowment and policy frameworks.

- Total final renewable energy use in the Reference Case is around 93 exajoules (EJ) per year worldwide. The REmap Options increase total use to 132 EJ, quadrupling modern renewable energy use compared to 2010 levels of around 30 EJ. Biomass is critical, as it accounts for 61% of total renewable energy use in REmap 2030.

- The average substitution cost of doubling the global renewable energy share in REmap 2030 is US Dollars (USD) 2.5 per gigajoule (GJ), without consideration of national taxation or subsidies and externalities (government perspective). Including existing taxes and subsidies and country-specific discount rates, the average cost changes into a savings of USD 0.7 per GJ (business perspective).

- The REmap Options are a package. All Options are needed to meet the doubling objective. Deployment of options should be based on a holistic energy system view and factor in assessments of resource availability and supply, energy diversification, security of supply and system operation.

- Non-electric energy use in the end-use sectors (buildings, industry and transport) accounts for 69% of all REmap Options and 60% of global renewable energy use in REmap 2030. More attention is needed for renewable energy deployment in these three sectors.

- The potential and costs of the REmap Options vary by country. Denmark and Brazil can reach renewable energy shares of over 50%, and France and Germany can reach renewable energy shares of at least a 40%, in REmap 2030. The substitution cost by country ranges from USD -12 to USD 14 per GJ from a government perspective.

- Six countries – Brazil, Canada, China, India, Indonesia and the United States – account for half of the global renewable energy use in REmap 2030.

- A higher share of renewable energy is possible but requires greater efforts through modal shifts and early retirement and more innovation in breakthrough technologies. Going from research and development (R&D) to significant deployment can take some decades, so action must be taken now.

- There is a need for a comprehensive innovation approach including aspects such as intellectual property rights, research, development and deployment (RD&D), technology transfer, standards and quality assurance and project development and finance. A technology lifecycle approach is needed for successful innovation.

This chapter is divided into four sub-chapters. **Chapter 3.1** describes the pathway for doubling the global renewable energy share based on REmap 2030 findings. **Chapter 3.2** presents the Reference Case findings in detail. **Chapter 3.3** describes the REmap Options by sector, source and substitution costs; it also elaborates on the challenges in doubling the global renewable energy share by 2030. **Chapter 3.4** describes the RE+ Options and the innovation needs to go beyond a doubling of the global renewable energy share. More country-specific results can be found on-line in the 26 REmap country briefs.

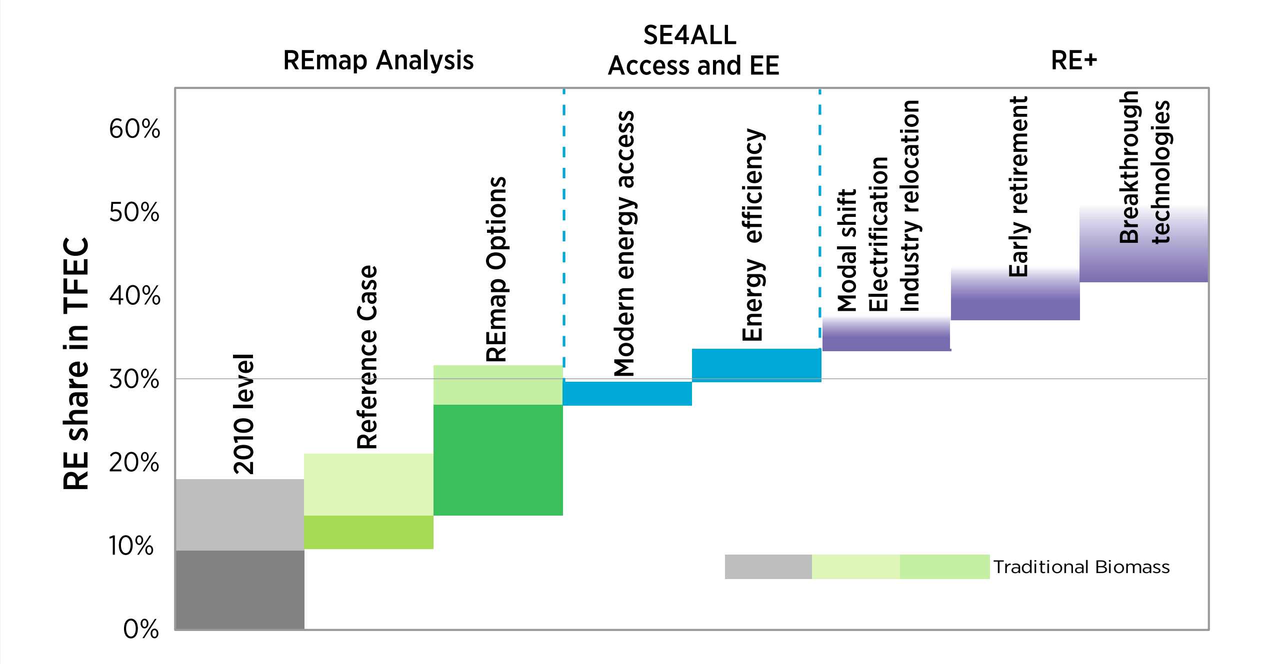
harvested and used in unsustainable, unsafe ways. It is mostly traded informally and non-commercially.

Figure 3.1 shows the status quo in 2010 (far left, grey bars), where the light grey-shaded area of the bars represents the share of traditional use of biomass. Under the Reference Case (light green bar), renewable energy use grows slowly, increasing its share from 18% of TFEC in 2010 to only 21% in 2030. However, International Renewable Energy Agency's (IRENA) analysis found that markets are already growing faster than gov-

3.1 Pathways for doubling the global renewable energy share

Figure 3.1 illustrates the pathways for doubling the global share of renewable energy and presents results for the REmap Options, the Sustainable Energy for All (SE4ALL) objective and RE+ Options. At present, renewables make up 18% of global TFEC, of which half of this share (9% of TFEC) is contributed by modern renewables. A large share of modern renewable energy comprises modern forms of bioenergy and hydropower. Other modern renewable energy sources are wind, solar, geothermal, waste and marine, which together contribute to less than 1% of TFEC. The second 9% of TFEC which is provided by current renewables comprises traditional use of biomass, whose global use is hard to quantify. In developing countries, traditional use of biomass is still widely

Figure 3.1 The stepping stones towards a doubling of renewable energy



The world can double its share of renewable energy in total final energy consumption by 2030.

Note: The lightly shaded areas indicate traditional use of biomass. The Reference Case represents the renewable energy share by 2030 based on the policies in place in the 26 REmap countries. The REmap Options show the additional growth by 2030 based almost entirely on modern renewables, with traditional use of biomass being reduced to less than 2% of TFEC. The blue bars represent the SE4ALL objectives of modern energy access and energy efficiency, which bring the share of renewables to around 34% by 2030. The purple bars, RE+ Options, represent other fields of action that can be pursued to take the share of renewables even further.

ernments anticipate and that more can be achieved at a lower cost than governments have estimated.

9% of total final energy consumption in 2010 was traditional use of biomass, and 9% was modern renewables. Only 3.6% was renewable electricity, dominated by hydropower.

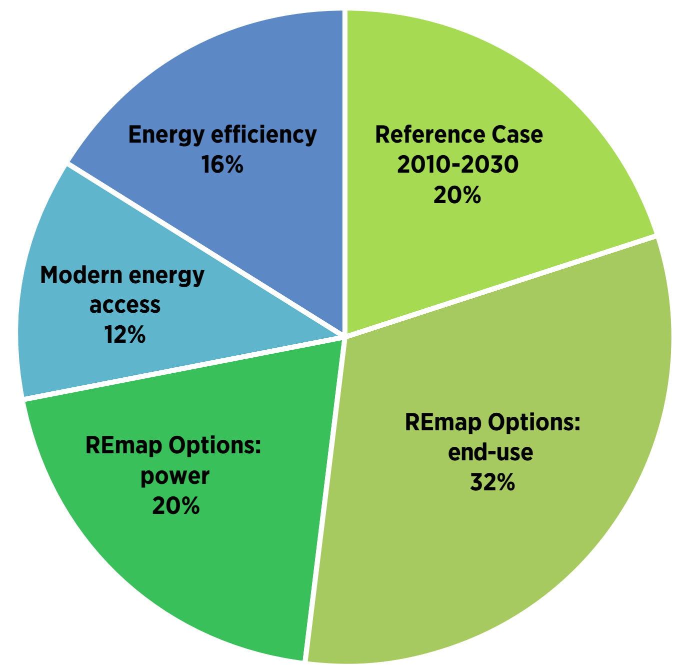
With policy action to ensure the uptake of the REmap Options (dark green bar), the renewable energy share could increase much further – to around 27% of TFEC in the 26 REmap countries. The REmap Options also entail a shift from traditional use of biomass to more sustainable modern biomass, almost tripling the share of modern renewable energy from 9% in 2010 to nearly 27% in REmap 2030. This tripling comes at a cost of USD 2.5 per GJ in 2030. Moreover, this transition saves money once the external costs of fossil fuels, which are not priced today, are taken into account.

The REmap Options do not assume that all traditional use of biomass is phased out. Achieving the SE4ALL objective of modern energy access (first blue bar in Figure 3.1) will require additional policy efforts. At present, more than a third of the world's population still relies on wood and animal waste as a source of energy, especially for cooking. The resulting indoor air pollution (smoke) poses considerable health risks. A shift to clean cook stoves fired with modern biomass would provide a better cooking service, reduce energy consumption and drastically reduce negative health impacts. Likewise, a billion people may still lack access to electricity in 2030; closing that gap, partly in the form of small, distributed generators of renewable power (such as mini-grids and solar home systems), would push the share of renewables in TFEC to 30%[1].

The second blue bar is the impact of SE4ALL's energy efficiency objective on the renewable energy share in 2030. This is additional energy efficiency improvements beyond what has been achieved in the Reference Case, which incorporates the energy efficiency of the 26 REmap countries. With greater energy efficiency, the same amount of renewable energy covers a larger share of demand and would raise the share of renewables. Efficiency gains and the first bar of RE+ Options could bring the share of renewables up to 36%.

Figure 3.2 shows the contribution of each technology development. Reference Case, representing the growth in renewable energy based on

Figure 3.2 Contribution to doubling the global renewable energy share in TFEC: from 2010 to REmap 2030



Important synergies exist between energy access, efficiency and turning to renewables.

1 Substituting modern biomass for traditional biomass reduces biomass consumption by around a factor of two for the same energy service, thereby reducing the share of renewables in energy consumption, while also increasing its share of energy services provided.

current policies between today and 2030, contributes only 20% towards the global doubling (from 9% to 14% modern renewable energy in TFEC, a 5 percentage point increase). With policy action, more renewable energy technologies can be deployed beyond Reference Case, represented by the REmap Options. The REmap Options can get us another 52% of the way towards a doubling of the renewable energy share (from 14% to 27% share in TFEC, a 13 percentage point increase). More than half of the REmap Options are located in the end-use sectors, and the remainder in the power sector. A combination of Reference Case and the REmap Options would result in around 70% of the action needed to achieve the doubling.

To achieve the doubling, deployment of renewable energy technologies need to be complemented by modern energy access and improving energy efficiency. Modern energy access represents 12% of the increase (from 27% to 30% of TFEC, a 3 percentage point increase) and energy efficiency

Box 3.1 Renewables and energy access

Nearly 1.3 billion people remain without access to electricity, and 2.6 billion do not have access to clean cooking facilities. In the Reference Case, 1 billion people will still be without electricity access and 2.6 billion without clean cooking facilities in 2030. Seven out of ten people without electricity access will live in Africa. One-third of the people using traditional use of biomass will live in Africa and India.

Half of renewable energy use in 2010 was traditional use of biomass, representing nearly 9% of TFEC worldwide. Renewable energy can help to improve the access situation. Renewable resources have characteristics that make them the best solution for access to electricity in rural areas. Solar photovoltaics (PV), wind, small hydropower and biomass power are the main solutions for off-grid and mini-grid electricity access.

Renewable solutions tend to be significantly cheaper than diesel- or kerosene-based energy supply systems. They are also cheaper than grid extension in situations with low population density and low per capita demand.

The cost for solar lighting systems have come down dramatically, and uptake of privately owned systems and solar lantern electricity supply is rising rapidly. In Bangladesh, for example, more than 60 000 systems are sold every month, and 2.4 million systems have been installed. In recent decades, China has successfully provided electricity access to more than 50 000 villages through small hydropower mini-grids.

Solar- and wind-based hybrid mini-grids are making inroads on islands and in rural areas of Africa and Asia, and diesel-based supply systems are increasingly being retrofitted with renewables. Thousands of systems have been installed to date. A recent trend is the rapid decline in battery cost, which allows for solar PV to capture a greater share of daily demand.

IRENA analysis for the Pacific has shown that retrofit of diesel mini-grids with renewables is technically and economically feasible in all cases. IRENA analysis suggests that full access would raise global electricity demand by only 1%. More than half of this demand would be met with renewables through decentralised solutions.

Full access through a switch from traditional to modern cook stoves could halve traditional use of biomass and change it into modern biomass use. Uptake rates for modern cook stoves are still below 10% in Africa. Full access to modern cook stoves could save 1 million lives a year due to reduced indoor air pollution. It will also save the equivalent of 3% of today's energy use. This biomass can be used elsewhere.

The majority of charcoal is still produced in an unsustainable way. Technical solutions such as efficient charcoal making and briquettes exist but are not practiced widely. Sustainability standards and their enforcement are critical, as well as development of economically viable and reliable alternative solutions for urban areas.

Liquefied petroleum gas (LPG) cooking fuel is an oil refinery and gas processing by-product, and its supply prospects are uncertain in the long term. Instead, modern renewable energy can replace traditional use of biomass for cooking. Worldwide, there are about 50 million biogas installations for cooking, notably in China and India. Bioethanol is also gaining ground as a cooking fuel. Electric cooking is expanding worldwide and opens up the option of increased use of renewable electricity.

16% (from 30% to 34%, a 4 percentage point increase). Together these two can contribute 28% to the doubling of the global renewable energy share and ensure that the objective is met.

Therefore reaching a doubling of the renewable energy share in the global energy mix requires a combined approach. Action will be required to ensure the development of different technologies, not only renewables, but technologies also related to modern energy access and energy efficiency.

RE+ Options (the three purple bars, see Figure 3.1) represents technologies and steps that can take the share of renewables even further; the REmap Options, in combination with SE4ALL's other two aspirational objectives, are not the limit to renewables development. RE+ Options include modal shifts in transport, electrification, industry relocation and technologies not yet ready for the market today ("breakthrough"), but also other actions that are hard to monetise.

A "modal shift" means a switching of energy consumption methods, such as when people switch from cars to, say, busses, trains and (electric) bicycles. "Electrification" generally covers the modal transition towards the use of electricity-based technologies in all sectors, with prominent examples including electric stoves and heat generation from electricity using heat pumps. Note that these actions often take place because of convenience and are irrespective of cost: for example, North Americans are already talking about how electric vehicles (EVs) will help solve local pollution problems; China is by far the world's largest market for electric bicycles; and Europe continues to expand its already well-developed public transport networks.

Finally, "industry relocation" means that new industrial facilities will be built where renewable energy is abundant and inexpensive, just as old industry was placed where conventional energy was readily available. As industry increasingly follows sources of renewable energy, renewables can be integrated more easily into the overall energy supply. Until now, industry has relocated mainly to countries with considerable inexpensive hydropower, with a prominent recent example being new aluminium production facilities in Iceland. But increasingly, firms may relocate to follow inexpensive wind and solar power.

The second purple RE+ Options bar indicates the potential impact of "early retirement" on the renewable energy share. Renewables growth is normally limited by energy demand growth and capital stock replacement rates. Early retirement of conventional energy equipment in industry, buildings and the power sector could open up additional opportunities for renewables growth. This process is already materialising in some European countries (*e.g.*, Germany, Spain and Italy), where the recent rapid growth of wind and solar PV power is resulting in a certain level of over-capacity, which reduces the annual operating time of gas and coal plants.

New industrial facilities will be built where renewable energy is abundant and inexpensive, just as old industry was placed where conventional energy was readily available.

Lower operating time or early closure affects the companies that operate the existing plants and comes at an additional cost. Conventional facilities are generally designed for a service life of 40 years or longer, and they become increasingly profitable the longer they stay in operation without having to be modernised. The challenge for policy makers is to encourage the early retirement of conventional facilities that inhibit the further growth of renewables, since once a conventional plant has repaid its financing, it could remain profitable even though it is inefficient and polluting.

Finally, the third purple RE+ Options bar represents the impact of a wide range of fledgling, promising technologies that may not be competitive on a grand scale by 2030. In ocean power, for example, technology options which are currently being pursued include wave energy collectors and underwater turbines. Here, it is important for policy makers to remember that although 2030 is the time frame for this discussion, it does not mark an endpoint for renewables. If we are to continue the transition to renewable energy after 2030, we need to not only ramp up wind power, solar, biomass and geothermal today, but also pave the way for additional options to become competitive further into the future.

3.2 Reference Case

This chapter presents detailed results of the Reference Case, a picture of our energy use in 2030 if current and planned government policies and targets are achieved.

3.2.1 TFEC growth between 2010 and 2030

The Reference Case represents business as usual in the 26 REmap countries – *i.e.*, where these countries aim to be by 2030 under current and planned government policies.

Worldwide, the TFEC of the three end-use sectors (industry, transport and buildings) increased by 41% from 232 EJ in 1990 to 335 EJ in 2010 (including electricity) (IEA, 2012b). TFEC growth is projected to continue between 2010 and 2030 according to the Reference Case and would reach a total of 471 EJ (equivalent to an increase of 41% in the same period). This is a doubling of global TFEC between 1990 and 2030.

Developing countries and economies in transition will account for at least 60% of projected world's total final energy consumption in 2030.

In the Reference Case, the developing countries and economies in transition will account for 60% of the TFEC of the 26 REmap countries by 2030, compared to 50% in 2010. This share of TFEC could be higher for developing countries and transition economies if global TFEC (rather than the TFEC of the 26 REmap countries) is assessed, since the growth in these countries is high and they are underrepresented in the REmap analysis.

Only minor changes are projected in the global TFEC breakdown by sector between 1990 and 2030. Industry's share increases from 36% in 1990 to 39% in 2010 and 42% in 2030 in REmap 2030, almost entirely at the expense of the building sector, which sees its share decrease from 36% to 30% in the same period. The share of the transport sector practically remains identical at about 28%.

The end-use sectors used more electricity in 2010 (18% of TFEC) than in 1990 (14% of TFEC), and this share is projected to rise to 23% in 2030. The share of electricity use in the building and industry sectors increased between 1990 and 2010 and is projected to continue increasing up to 2030 in the Reference Case.

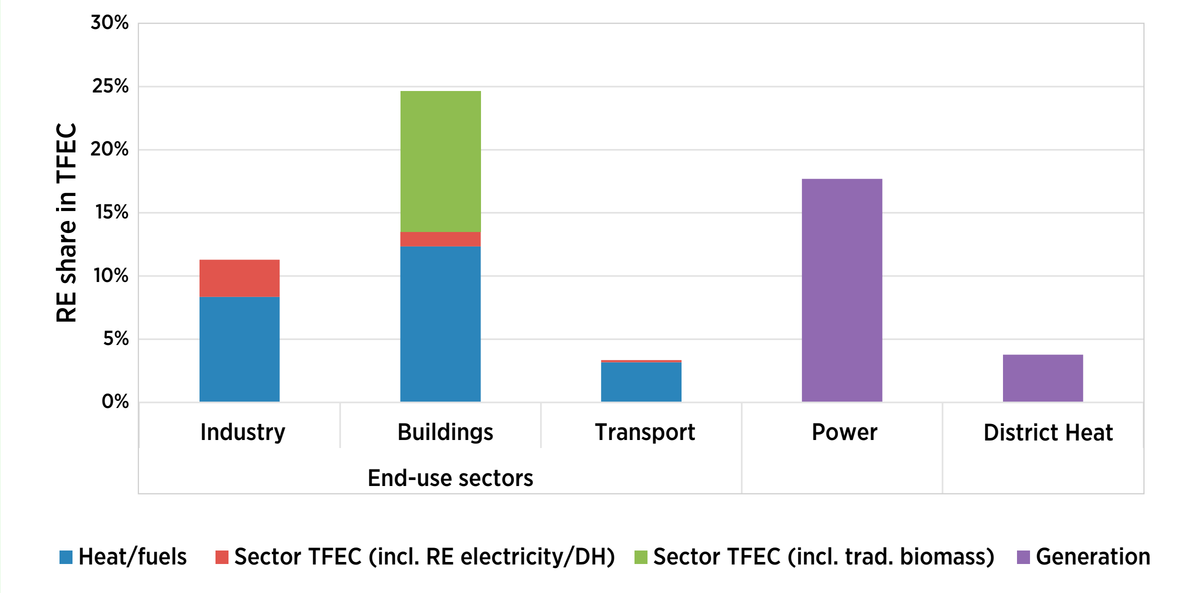
3.2.2 Developments in renewable energy use

Figure 3.3 shows the modern renewable energy shares of the end-use sectors in 2010, which are between 3% for the transport sector and 12% for the building sector, excluding the consumption of renewable power and district heat. Industrial process heat generation is mainly from fossil fuel-fired boilers and combined heat and power (CHP) plants. Gasoline and diesel using road vehicles, ships and airplanes dominate the transport sector, and a mix of fossil fuels and traditional use of biomass is used for cooking and space heating in buildings.

In addition to modern renewable energy use in buildings, there is also the traditional use of biomass in developing countries. The contribution of this to the sector's renewable energy use is shown by the light shaded bar on top of the modern renewable energy share bar. When this is accounted for, the building sector's renewable energy share in 2010 increases to nearly 47%.

In contrast to end-use sectors, the power sector today has a much higher renewable energy share of 18%. When this is accounted for, the renewable energy shares in the industry and building sectors increase by about 2-3 percentage points given that electricity use is an important share of the sectors' TFEC in applications such as industrial motor systems or appliance use in households and offices. The effect of accounting for electricity use in the transport sector is negligible as the electric vehicle

Figure 3.3 Renewable energy shares of the analysed sectors, 2010



The Reference Case increases the renewable energy share only minimally in TFEC and in each of the end-use sectors in the period 2010-2030 (for the sector TFEC values, including electricity and district heat). The share of modern renewable energy increases only 5 percentage points, from 9% to 14%. The renewable energy share in the transport sector rises by 3 percentage points; and for buildings, 6 percentage points. These developments are insufficient to double the global renewable energy share. The only exception is the transport sector, whose renewable energy share doubles from 3% in 2010 to 6% in 2030 (including electricity use).

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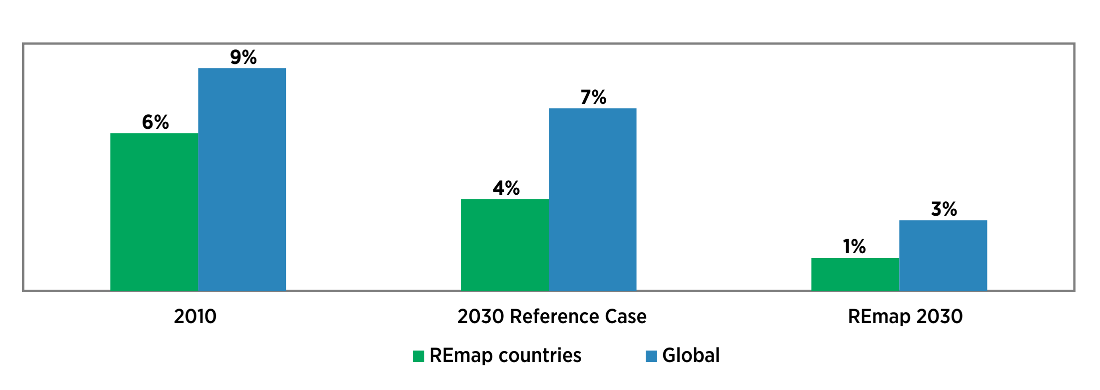
In the building sectors of the selected developing countries, biomass is still used traditionally for cooking and heating and makes up 6% of TFEC today (see Figure 3.4). In the Reference passenger car stock is small, and the contribution of electrified public transport and rail systems in the sector's overall TFEC is low.

When all end-use sectors are aggregated, the renewable energy share in the global energy mix is estimated at 18% in 2010. Scaling the national plans of the 26 REmap countries to the global situation raises the global renewable energy share in TFEC from 18% in 2010 to only 21% in 2030 (including traditional use of biomass). The projected renewable energy uptake varies widely between countries. While Brazil and Germany are projected to reach 50%, United Arab Emirates (UAE) and Saudi Arabia are projected to reach less than 5%. Resource endowment and policy frameworks make the difference.

Figure 3.4 Traditional use of biomass in the 26 REmap countries and the world, 2010-2030



Current policies envisage limited substitution of traditional use of biomass.

Case, some of this biomass is already projected to be substituted, reducing the traditional use of biomass share to 4% by 2030. The developments are limited to countries with modern cook stove or rural electrification programmes which target traditional use of biomass substitution.

Table 3.1 shows the growth of renewables in the Reference Case of the 26 REmap countries for heating, cooling, transport and power applications. Total renewable energy use increases by 50% from 40 EJ to 59 EJ. Thermal applications account for about two-thirds of the total by 2030, and power generation makes up the remaining one-third. Biomass dominates thermal applications.

The capacity growth of modern renewable heating/cooling technologies in the building and industry sectors (10% increase) in the Reference Case is lower than the growth of renewable energy technologies in the power sector (145%) between 2010 and 2030. Total biomass use in stand-alone boilers and CHP in the industry, building and district heat sectors is projected to grow from 12 EJ in the REmap countries in 2010 to a total of 16 EJ by 2030 (excluding traditional use of biomass of 13 EJ in buildings). Total consumption of modern biomass will be more or less equally shared between

Table 3.1 Renewable energy use projections in the Reference Case of the 26 REmap countries, by technology, 2010-2030

		2010 (EJ/yr)	2030 (EJ/yr)	Increase
REmap 26	**Renewable Heat**	**29**	**32**	**10%**
	Biomass heat industry (modern biomass)	5.7	9.3	65%
	Biomass heat buildings (modern biomass)	5.6	5.2	-5%
	Traditional biomass (buildings)	16	13	-20%
	Biogas industry/buildings	0.3	1.2	300%
	Solar thermal heat	1	3	200%
	Geothermal industry	0.01	0.02	100%
	Geothermal buildings	0.15	0.48	220%
	Liquid Biofuels	**2**	**5**	**150%**
	Renewable Electricity	**9**	**22**	**145%**
	Hydroelectricity	7	12	70%
	Wind	1	5	500%
	Solar PV	0.1	1.4	1 300%
	Biomass power	0.6	2.6	300%
	Geothermal power	0.1	0.4	300%
	Concentrated solar power (CSP)	0.01	0.3	3 000%
	Biogas power	0.1	0.2	100%
	Total	**40**	**59**	**50%**
	Total – Global	**63**	**93**	**50%**
	Renewable Energy (RE) Shares			
	RE share in TFEC (incl. traditional biomass)	18%	21%	7%
	Traditional biomass share	6%	4%	-33%
	RE share in TFEC (excl. traditional biomass)	9%	14%	45%
	RE share in heat (industry and buildings)	10%	12%	20%
	RE share in transport	3%	5%	70%
	RE share in power	18%	27%	90%

Under current policies, total renewable energy use in the 26 REmap countries increases by 50% by 2030, with the largest growth in the transport and power sectors.

3

buildings/district heat and manufacturing industry plants over the entire period. Total estimated biomass space and water heating capacity in the building sector of the REmap countries is approximately 480 gigawatt-thermal (GW_{th}), while process heating capacity in the industry sector is approximately 465 GW_{th} in 2030.

The use of biofuels in the transport sector will increase by 150%, from 2 EJ in 2010 to around 5 EJ in the 26 REmap countries, equivalent to 290 billion litres of liquid biofuel by 2030 worldwide compared to today's biofuel demand of 116 billion litres (99 billion litres of bioethanol and 17 billion litres of biodiesel).

Total renewable energy use increases by 50% between 2010 and 2030, increasing the global renewable energy share minimally, to 21%, if current policies continue.

Solar thermal use in the 26 REmap countries is expected to triple between 2010 and 2030 from about 1 EJ to 3 EJ, almost exclusively in the building sector, where it will reach 36% of the sector's total modern renewable energy use (excluding electricity and district heat). Total installed capacity will rise to around 790 GW_{th}. There is also a 25 GW_{th} projection for the industry sector. The largest growth for both biomass and geothermal technologies, in the Reference Case, is projected to occur in the district heat sector.

In 2010, 20% of all the electricity generated worldwide already came from renewable sources. Hydropower makes up the greatest share of this by far, accounting for 16% of total power generation, or roughly four-fifths of the 20% share of renewables. Given that wind turbines and solar PV, two technologies which are currently growing rapidly, also generate electricity directly, a much larger share of renewable electricity by 2030 seems likely.

Renewable electricity generation will increase by 145% between 2010 and 2030 in the 26 REmap countries, bringing the global renewable energy share from 18% in 2010 to 26% in 2030 – similar to the growth projected in transport and higher than that for heating applications. Hydro and wind are projected to dominate total power generation in the 26 REmap countries (>80%). Between the beginning of 2010 and end of 2013, global wind capacity doubled. A fivefold increase was achieved between end of 2005 and mid-2013, less than eight years. Another fivefold increase in wind power generation capacity is environed between 2010 and REmap 2030, though this increase starts from a much higher installed capacity in 2010 than in 2005. Nonetheless, this increase could be modest given recent trends.

3.3 REmap Options

This Chapter presents detailed results of the REmap Options, such as country results and sensitivity analysis.

3.3.1 Overall results, and details by sector and source

If all REmap Options are implemented, the global modern renewable energy share would triple from 9% in 2010 to 27% in 2030 worldwide (excluding traditional use of biomass) (see Table 3.2). The renewable energy share increases at a similar magnitude in buildings and even more (by a factor of five at least) in the transport sector. The renewable energy share reaches 38% in buildings compared to 14% in 2010, and 17% in the transport sector compared to 3% in 2010. The increase is lower in the industry and power sectors. Compared to the 2010 situation, the ranking of the renewable energy share by sector does not change, but the transport sector comes closer to the level of the industry sector in REmap 2030.

Bioenergy accounts for nearly 90% of total renewable energy use for heat generation in 2030, and hydropower for 55% of renewable electricity generation, based on current policies.

The share of traditional biomass used globally would decline from 9% in 2010 to 3% in REmap 2030 if all REmap Options are implemented.

Figure 3.5 shows the TFEC of end-use sectors in REmap 2030, with a breakdown by fuels, electricity and district heat. Each of these are

Table 3.2 Breakdown of global total and sector-specific renewable energy shares

	Renewable Share of:	as % of:	2010	2030 Reference	REmap 2030	RE use REmap 2030 (EJ/yr)
Industry	Heat[1]	Heat consumption	8%	9%	19%	25
	Heat & Electricity & DH[2]	Sector TFEC	11%	15%	26%	51
Buildings (excluding traditional biomass)	Heat[1]	Heat consumption	12%	16%	35%	25
	Heat & Electricity & DH[2]	Sector TFEC	14%	20%	38%	50
Transport	Fuels[1]	Fuel TFEC	3%	5%	15%	16
	Fuels & Electricity[2]	Sector TFEC	3%	6%	17%	18
Power[3]		Generation	18%	26%	44%	62
District heat (DH)[3]		Generation	4%	14%	27%	5
Total (as % of TFEC)	Modern RE (excl. traditional biomass)[4]		9%	14%	27%	119
	Modern + Access		18%	21%	30%	132
	Modern + Access + EE (assumes the implementation of all the 3 SE4ALL objectives)				34%	
	Modern + Access + EE + "RE+"				>36%	

Most renewable uptake will happen by substituting conventional technologies in the power and building sectors.

1 Represents total combustible and non-combustible renewable energy use from all energy carriers to generate heat (for industry and building sectors) divided by the sector's TFEC, excluding electricity and district heat. For the transport sector, it represents total renewable energy fuel use divided by the sector's TFEC, excluding electricity

2 Represents total combustible and non-combustible renewable energy use from all energy carriers to generate heat (for industry and building sectors), and total electricity and district heat consumption generated from renewable energy divided by the sector's TFEC. For the transport sector, it represents total renewable energy fuel use and total electricity consumption generated from renewable energy divided by the sector's TFEC.

3 Represents total electricity generated from renewable energy sources divided by total electricity production, or total district heat generated from renewable energy sources divided by total district heat production. The absolute values (in EJ) for the power and district heat sectors refer to the total generation, but not to consumption. Therefore they should not be added on top of the total renewable heat and fuel use in the end-use sectors to estimate the total renewable energy share in TFEC.

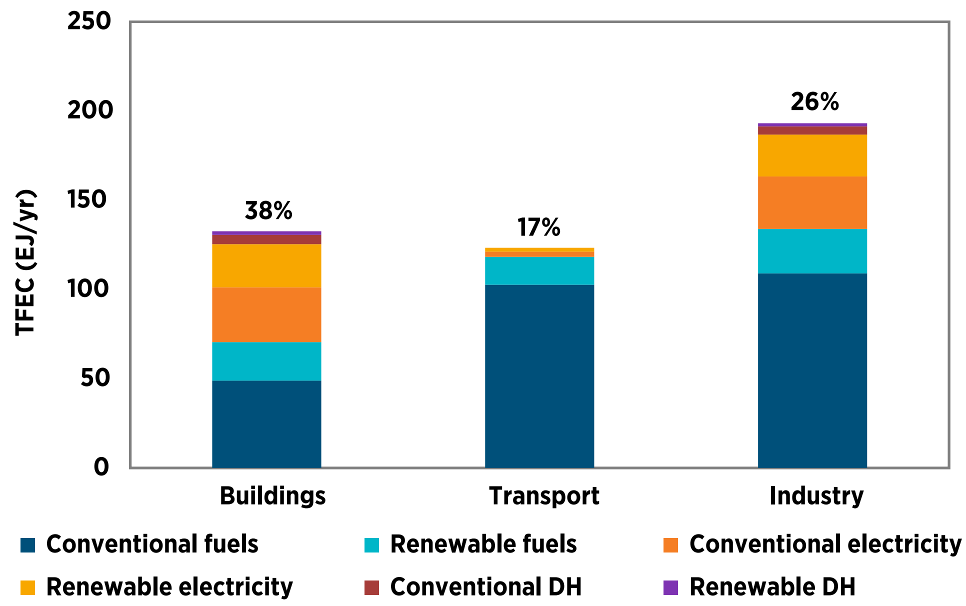
4 See Figure 3.7 for the cost-supply curve which plots the development of the modern renewable energy share.

further broken down to conventional (blue shaded bars) and renewable (green shaded bars) sources. The contribution of the three sectors to global TFEC are more or less the same (in EJ/yr). In absolute terms, a similar market size of renewable fuels exists across the end-use sectors of between 25 and 31 EJ[2]. For the building and industry sectors, renewable electricity and to a small extent renewable district heat add another 25 EJ of renewable energy use each. As a result, total renewable energy use in the industry and building sectors amounts to 101 EJ. This is approximately three-quarters of

3

2 Table 3.2 and Figure 3.5 show a global liquid biofuel consumption of 16 EJ for the transport sector. This is based on final energy terms. Here, final energy is converted to primary energy based on a primary biomass-to-liquid biofuel conversion efficiency of 50%.

Figure 3.5 Global TFEC breakdown of the end-use sectors by fuels, electricity and district heat (DH) in REmap 2030



The building and industry sectors combined account for three-quarters of total global renewable energy use, as forseen in REmap 2030.

the global renewable energy use of 132 EJ, according to REmap 2030 including modern energy access.[3]

Figure 3.6 shows the share of different renewable energy sources in global TFEC for 2010, as well as for 2030 with additional growth from the REmap Options included. In 2010, traditional use of biomass accounts for half of the global renewable energy use of 63 EJ. Among the renewable energy sources other than biomass, hydropower is the most important.

REmap Options add 39 EJ of additional renewable energy use in the 26 REmap countries. This translates to a total of 53 EJ worldwide. The largest source, modern biomass, accounts for about 56% of the REmap Options identified, *i.e.* 30 EJ of the total 53 EJ. Biomass will continue to be the largest source of renewable energy to generate both power and heat and to be used as motor fuels. In total, the various forms of solid, liquid and gaseous biomass make up 61% of renewable energy use in the REmap 2030. In the end-use sectors, the biomass share in total renewable energy use reaches 80%.

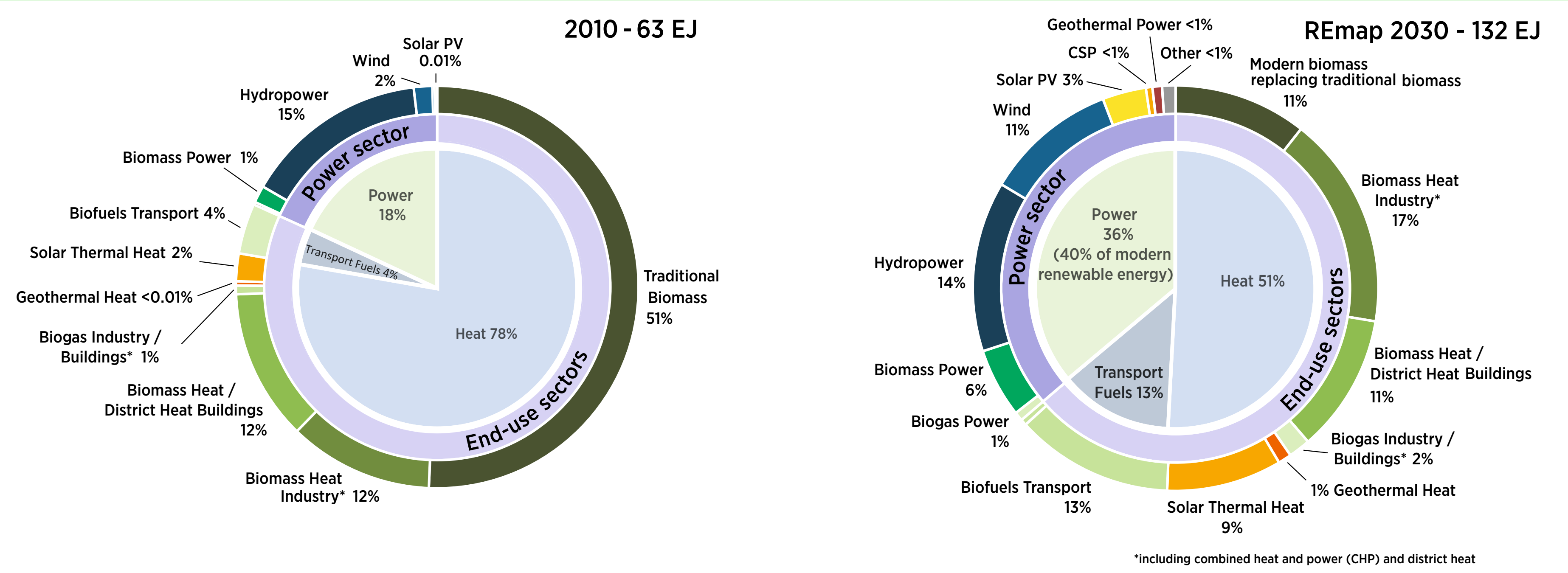
As mentioned earlier, however, the main shift within biomass will be from its traditional uses to modern technologies and fuels. The reason why REmap 2030 is largely dominated by biomass is that the analysis covers all end-use sectors, and is not limited only to the power sector. Biomass easily finds a large potential area of application in all end-use sectors compared to other renewables. In contrast, renewable energy technologies other than biomass have equally large potential in the power sector.

Scaling up renewable energy involves not only the power sector, but also end-use sectors where biomass can easily find applications.

Biomass potential in the 26 REmap countries is followed by solar thermal for heating and cooling (5 EJ) and solar PV for electricity generation (2.2 EJ). In total, solar accounts for 19% of the total REmap Options in

3 In the Reference Case, total global renewable energy use is 93 EJ, of which 65 EJ is modern and 28 EJ is traditional. Worldwide, REmap Options add 53 EJ of modern renewable energy use to the Reference Case; as a result, modern renewable energy use reaches 118 EJ. The remaining 14 EJ to arrive at 132 EJ is related to the substitution of traditional use of biomass. About 7 EJ of the total traditional biomass use of 28 EJ is substituted already in REmap Options. In order to realise SE4ALL's modern access objective, all traditional biomass use should be substituted. Of the remaining 21 EJ of traditional biomass use, 17 EJ is substituted further with total modern renewable energy use of 10 EJ, and 4 EJ is regarded as modern. As a result, additional modern renewable energy use of 14 EJ takes total use from 118 EJ to 132 EJ.

Figure 3.6 Global renewable energy use by technology and sector, 2010 and in REmap 2030



Global renewable energy use will grow by 110% in absolute term by 2030.

Note: REmap 2030 estimates a total renewable energy use share of 36% for power and 64% for the end-use sectors, including traditional use of biomass. When traditional use of biomass is excluded, the shares of power and the end-use sectors are 40% and 60%, respectively.

the 26 REmap countries (7.2 EJ in total). In addition to the Reference Case use, total solar is expected to reach 12.6 EJ in the REmap 2030, including CSP for power generation and solar thermal use in the district heat sector.

Wind power is the third largest renewable energy source, with a total additional estimated potential of 6.3 EJ in the REmap Options (*i.e.*, 17% of the total). Its total use by 2030 is estimated to reach 11 EJ. Biomass, solar and wind account for more than 90% of the total REmap Options and 84% of total renewable energy use by 2030 in the REmap countries (including the remaining quantities of traditional use of biomass).

Other REmap Options (10%, or 2.8 EJ) are a mix of hydropower (2%), geothermal (2%), electrification technologies (1.5%) and other sources such as ocean or waste energy (4.5%). Today, hydro makes up the largest share of renewable electricity, but by 2030, REmap Options will increase significantly both the absolute amount and share of wind power consumption, as wind power deployment exceeds that of hydropower by 2030. The additional potential for hydro in the 26 REmap countries is small (0.5 EJ only) because its use is already high in the Reference Case (12.5 EJ).

Although REmap 2030 indicates that EV use can increase substantially, its contribution to global renewable energy use is modest, about half

Box 3.2 Electrification

The portfolio of renewable energy technologies in REmap 2030 relies heavily on biomass. If biomass does not take off as projected, doubling the global renewable energy share could be challenging. The RE+ Options propose alternative strategies to overcome such challenges. Electrification is one of them, substituting fuel use for space and process heating in the building and industry sectors and for internal combustion engines in the transport sector.

In the IEA's *Energy Technology Perspectives* (ETP) *2012* (IEA, 2012c) the electricity share of end-use sectors could increase from its current level of approximately 20% to as high as 24% by 2030 and 30% by 2050, according to the most ambitious climate policy scenario. The electricity shares of end-use sectors are projected to increase in transport to 4% and 13% (from 1%), in industry to 29% and 31% (from 23%) and in buildings to 34% and 39% (from 28%) by 2030 and 2050, respectively. The REmap 2030 electricity use shares in 2030 are comparable: for transport 5%, industry 27% and buildings 43%. As more renewable power is generated, end-use sectors would gain a higher renewable energy share through these changes in the fuel mix.

Electrification is technically possible in many applications. Heat pumps can provide heat in buildings as well as low-temperature heat in several industry sectors, such as in food and beverages. Air conditioning for space heating is also gaining a higher market share, for example in Japan, Sweden and Turkey. With increasing prosperity, cooling demand will be met by air conditioning more, a market which has only been partially met by electrical devices such as fans. Alternatives to thermal industrial processes are also being slowly commercialised, such as microwave drying. Research is also focused on the development of alternatives for processes that account for a large share of industrial energy use. An example is electricity-based iron production (electrowinning), similar to what has so far been applied typically in the production of non-ferrous metals. Plug-in hybrids and battery-electric vehicles are options in the transport sector.

However, electricity is more expensive than fossil fuels and is only successful if it substantially improves efficiency and productivity or provides other benefits, such as less air pollution or greater safety and convenience (such as electric cooking). With efficiency twice as high as petroleum-based passenger vehicles, electric vehicles create a large efficiency gain. Heat pumps meet this criterion as well, with conversion efficiencies of at least 300% (coefficient of performance of 3) compared to 90-107% efficient boilers.

But electrification does not always make a great difference. For example, the maximum efficiency that an electric heater could reach is 100%, on par with modern fossil fuel boilers. Heat pumps, electric resistance heating, electricity and carbon dioxide (CO_2) as a feedstock for chemicals production (*e.g.*, methanol, synthetic methane) are all technically feasible, but economics constitutes a major barrier. Given the costs and maturity of the related technologies today, it is not realistic to expect a substantial contribution of electrification by 2030, and the share in TFEC of the limited number of applications will be somewhat limited because of the high efficiency gains. A planning horizon to 2050 therefore seems more feasible since significant time and efforts is required.

Part of this trend in planning is already included in REmap 2030. More developments are needed for the development of cost-effective solutions, and electrification alone is not a solution unless the power is renewable. New policies to accelerate technology innovation should acknowledge the importance of electrification now as a renewable energy and energy efficiency strategy and work towards the development and commercialisation of related technologies in the next few years, especially since a single portfolio of technologies may not be sufficient to go beyond a doubling of the global renewable energy share.

of the total contribution of electrification technologies (less than 1%). The high efficiency of these vehicles compared to internal combustion engines is the main reason. In addition, only the consumption of power (approximately 80% of the total generated) is displayed in Figure 3.6, and the share of electricity originating from renewables only (44% of the total power consumed by EVs).

Each end-use sector has a different portfolio of REmap Options. If all REmap Options are deployed, the industry sector of the 26 REmap countries will use 18.7 EJ of renewable energy for process heat generation (or 25 EJ worldwide), of which 16.1 EJ will be from biomass and 2.6 EJ from solar thermal. The building sector will use 9.5 EJ of modern biomass and 6.2 EJ of solar thermal (or 25 EJ of modern renewables worldwide). The transport sector will use 13 EJ biofuels (or 16 EJ worldwide). Among the end-use sectors, buildings will account for the largest renewable energy use in REmap 2030, followed by the industry and the transport sectors. If all REmap Options are deployed, renewable electricity generation will reach approximately 12 500 terawatt-hours (TWh) per year (or 45 EJ) in the 26 REmap countries.

It is worth noting that the power sector makes up only just over a third of the share of renewables in TFEC, with the other nearly two-thirds coming from heat and fuel use in the three end-use sectors. If a doubling of the global renewable energy share is to be reached, more attention should be focused on renewables in the building, industry and transport sectors. Biomass is the main renewable energy which can be directly deployed in these sectors, apart from solar and geothermal heat. Hence, its role is especially important.

3.3.2 Substitution costs of the REmap Options

Figure 3.7 shows the global cost curve for the 26 REmap countries, calculated from the perspective of governments. This approach produces a better cost estimate for society than the business perspective, which includes national taxes and subsidies that amount to redistributions of national output. The options are aggregated and shown individually based on the average cost of substitution. Three main categories of possible technology deployment, as envisaged in REmap 2030 analysis:

1. The horizontal bar to the far left shows the growth of modern renewables in the Reference Case, which rises from around 9% in 2010 to around 14% in 2030. The cost impact was not determined for the Reference Case, as this growth is assumed to take place in any case. Some traditional use of biomass is already substituted in the Reference Case, which results in a lower TFEC, thereby increasing the renewable energy share. The green areas in the Reference Case indicate biomass, which accounts for about half of the uptake. The other half consists of power sector options: hydro and wind, followed by solar. Solar heating applications complete the renewables uptake.
2. The REmap Options raise the share of modern renewable energy from around 14% to around 27% (upper x-axis) and range from negative cost options (savings) to more costly options. The trends visible in the figure would produce savings of as much as USD 10 per GJ, while the most costly options reach USD 25 per GJ. These estimates are based on substitution costs for renewable technologies, rather than the final cost of energy services, which can also be influenced by other factors. Consequently, savings occur wherever a renewable alternative is less expensive than the existing conventional one. Likewise, a positive cost figure indicates additional costs because of substitution, not just the cost of that particular renewable energy source.
3. The figure also shows the contribution of the other two SE4ALL objectives to the renewable energy share in TFEC. Subsequently, with implementation of the modern energy access objective, the renewable energy share reaches 30% (the blue arrow on far right). Implementing the energy efficiency objective takes the renewable energy share to 34% (the lower x-axis).

The area between the curve and x-axis is a measure of the total annualised cost in 2030. Cost savings offset most of the cost increases. Net annualised costs divided by total final renewable energy use yields an average cost of substitution for the total of REmap Options of approximately USD 2.5 per GJ. This outcome suggests that the share of renewables can be doubled with only limited additional costs.

Biomass offers the greatest potential for accelerating the scale-up of renewables, followed by solar energy options.

This curve displays the aggregated potential of selected REmap Options. REmap Options are the realistic potential of renewable energy technologies beyond national plans of the countries, taking into account resource availability, capital age of stock, planning procedures, etc. It is one portfolio of technologies, according to REmap 2030 based on the bottom-up analysis of the 26 REmap countries. These technologies represent the additional potential estimated based on dialogue between IRENA and the countries. This portfolio is not an allocation of the global additional potential based on the gross domestic product (GDP) of countries, and does not represent a static growth rate of technology deployment nor extrapolations. Further technology portfolios can be generated based on the different understanding of the parameters that constitute REmap Options.

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. 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. For instance, some options produce savings or improvements in efficiency that help reduce the costs of more expensive options below those that would exist otherwise.

The position on the cost curve can also change, depending on taxes, subsidies and external effects. Macroeconomic effects can change the ranking as well. The focus on the cheapest individual options will not result in the least expensive overall transition; achieving that requires a holistic approach, and only when all of these options are pursed simultaneously can the share of renewables in TFEC be doubled by 2030 at the costs presented.

Furthermore, current plans need to take account of the effect of technological learning; what seems costly now may not be by mid-century, particularly if already-emerging technologies are promoted. Another reason to consider costlier options is to accelerate technology learning. Governments may want to invest in technologies that are costly now in order to "buy down" the unit investment cost through technology improvements and economies of scale.

Each country's portfolio of renewable energy technologies should be as broad as possible.

To the right of the cost curve, some technology options have higher costs. This does not, however, mean that the potential for low-cost REmap options is exhausted, or that only the potential of technologies with high costs remains for implementation. Rather, it points to two important findings about the ambition level across countries:

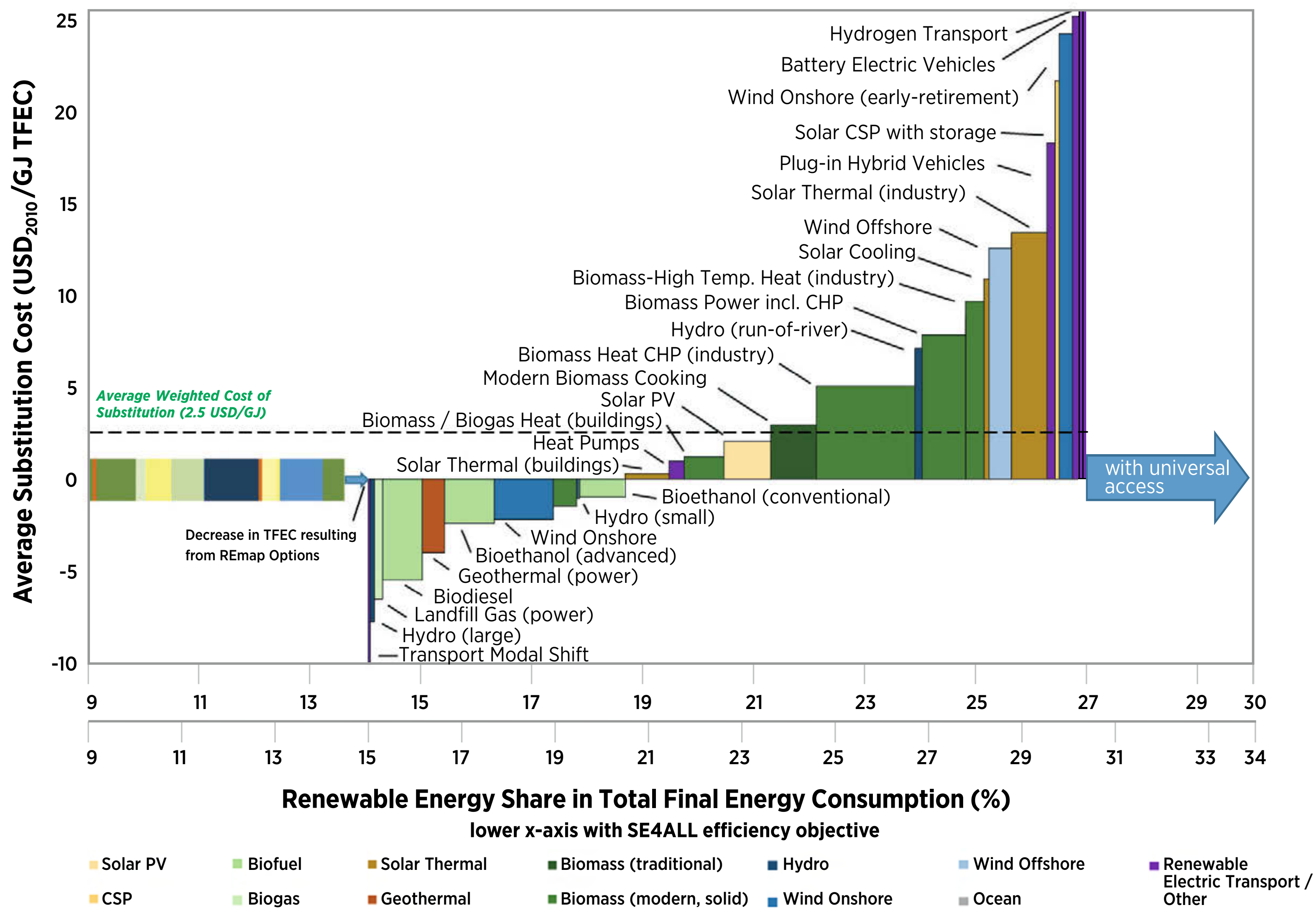
1. Certain countries with very high renewable resource potential either have few policies in place to utilise that potential at low cost, or leave deployment to the market only (*e.g.*, Russia);
2. Other countries that already have a high renewable energy share appear content with it and see less need to proceed further (*e.g.*, Brazil).

Higher deployment for all renewable energy technologies is technical possible, but it requires more ambitious policies in countries.

Technical potential is much higher than the deployment indicated by the width of individual technologies according to Figure 3.7. This is valid for all technologies, and more renewable energy can be deployed than the REmap Options shown. With further utilisation of the technical potential, the global share of renewable energy can be expanded, and the contribution of individual technologies to global renewable energy use can change. Further deployment will depend on the political will of countries and on innovation in existing and mature technologies.

Figure 3.7 considers renewable electricity for vehicles and heat pumps as well, but this is not enough to reach substantially higher renewable energy shares in the end-use sectors. The scope must be broadened, for example through thermal storage and hydrogen as a storage medium. In a situation of resource scarcity, the optimal use of resources may change as progress is made. Initially, biomass may be co-fired in coal plants, but eventually it may be better to use scarce biomass for biofuels. Biogas can be incinerated directly to generate power, but it is also well suited to be upgraded and stored for use during periods of scarcity – especially if a high share of variable renewable power is aimed for.

Figure 3.7 Technology cost curve for the 26 REmap countries based on the perspective of governments in 2030



The cost of doubling modern renewable energy in the energy mix is negligible, at USD 2.5 per GJ on average.

Note: The horizontal bar from 9% to 14% represents the Reference Case developments. The cost-supply curve shows the REmap Options in the 26 REmap countries reaching 27% as represented by the green bars in Figure 3.1 (upper x-axis). SE4ALL's energy efficiency objective takes the share of renewable energy further (lower x-axis).

The power sector is especially complex. At all times, supply must meet demand, lest blackouts occur. Although a variable renewable technology like solar and wind may be introduced up to 20% with limited considerations for the grid, high shares may require significant grid upgrades. Furthermore, costs rise considerably if storage is needed for variable renewables. It generally enhances grid stability if a range of technology options is considered, so investing in a number of different technologies, not only the cheapest ones, makes sense. Figure 3.7 is a simplification of the REmap tool as each option is itself represented by a cost curve, and costs differ by country.

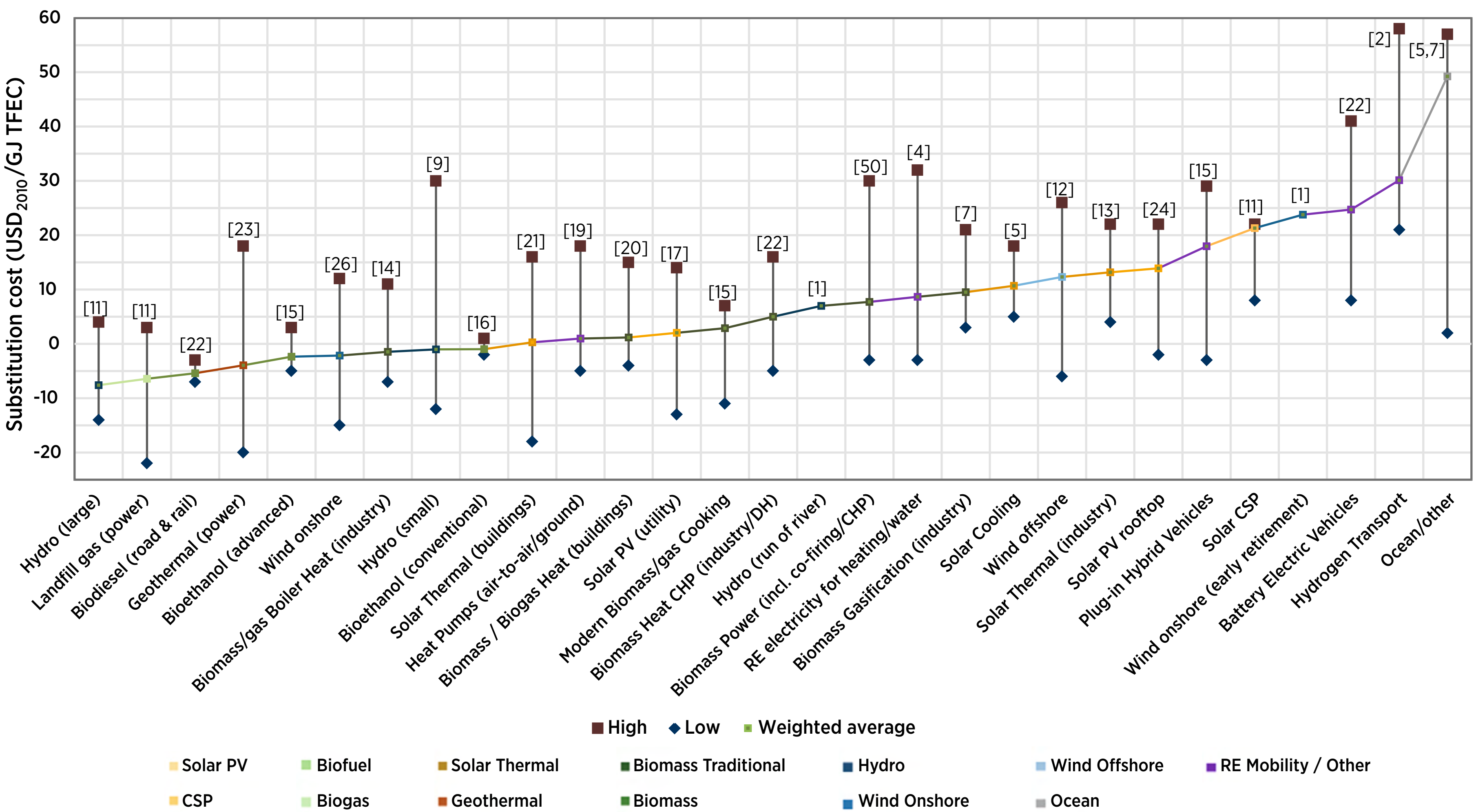
Figure 3.8 shows the range in the average substitution cost of each REmap Option based on the variation across individual countries. Some technologies have potential in one country only (*e.g.*, run-of-river hydro), and others have additional potential in all 26 countries (*e.g.*, onshore wind). This shows that the REmap 2030 technology portfolios differ across individual countries. In some countries, mainly power sector-related REmap Options may exist, while in others, additional options in all sectors are estimated.

For individual countries, the shape of the cost curves and the rankings of the technologies differ depending on resource endowment, capacity factors and the type of conventional technology substituted (*e.g.*, solar PV substituting coal in one country and oil in another). The same holds true for the cost curves of individual technologies where different countries are ranked. The position of countries would change for each technology. The costs of individual technologies range +/- USD 10 per GJ around the average value. The figure shows that although the weighted average substitution costs of some technologies are positive, attractive market options exist in certain countries (*e.g.*, offshore wind, solar thermal for industry). Countries should develop targets in their national plans to deploy these opportunities. Country briefs which can be found online provide further country details.

Table 3.3 Weighted average substitution costs of selected REmap Options based on the perspective of governments and businesses in 2030

	Business Perspective	Government Perspective	Difference
		(USD/GJ)	
Hydro (large)	-12.3	-7.6	4.7
Landfill gas (power)	-2.2	-6.4	4.2
Geothermal (power)	-5.5	-3.9	1.5
Bioethanol (advanced)	-8.4	-2.4	6
Wind (onshore)	-2.6	-2.2	0.5
Hydro (small)	0.4	-1	1.5
Bioethanol (conventional)	-12.7	-1	11.8
Solar thermal (buildings)	-1.9	0.3	2.2
Heat pumps (air-to-air/ground)	-3.7	1	4.6
Biomass/ biogas heat/cooking (buildings)	-2.1	1.2	3.3
Solar PV (utility)	1.1	2	0.9
Biomass/gas heat (incl. CHP)	3.8	4.5	0.7
Hydro (run-of-river)	1.1	7	5.9
Biomass power (incl. co-firing/CHP)	5.9	7.7	1.8
Solar cooling	8.3	10.7	2.4
Wind (offshore)	8.7	12.3	3.6
Solar thermal (industry)	13.4	13.2	0.2
Solar PV (rooftop)	10.8	13.9	3.1
Electric mobility	-34.3	21.3	55.6
CSP	14.7	21.3	6.6
Wind (onshore, early retirement)	25.4	23.8	1.6
Hydrogen transport	14.9	30.1	15.3

Figure 3.8 Ranges of substitution costs of REmap Options in the 26 REmap countries based on the perspective of governments in 2030



Note: Dots indicate the weighted average of all countries where different technologies are assumed to be implemented (all indicated with a separate color). The substitution costs of technologies are consistent with the bars shown in Figure 3.7. Values in brackets show the number of countries which implement that REmap Option. Since some technologies are grouped together (e.g., biomass power from co-firing, CHP, etc.), the value provided in brackets is higher than the number of countries analysed.

3

The shape of the cost curve, and hence the best technology portfolio, differs from one country to another.

Table 3.3 shows the comparison of substitution costs of individual technologies based on the perspective of governments and businesses. The largest differences between the business and government perspective estimates exist in the transport sector technologies, namely conventional and advanced bioethanol, electric mobility and hydrogen transport, from between USD 6 and USD 55 per GJ. Transport sector technologies based on the business perspective are clearly cheaper than under the government perspective, as including taxes on fossil fuels at the national level makes a large difference compared to the international prices.

The differences between the two estimates for power and heating applications are lower. This is because the difference between the national and international fuel prices (fossil fuels and biomass) is lower than that of motor fuels. There is also the effect of local and international discount rates on heating and power technologies, in particular for renewable technologies which do not use any fuels. Developing countries often have higher local discount rates compared to the standard 10% international discount rate, making the business perspective of, for example, wind or solar more expensive than under the government perspective.

3.3.3 Substitution costs by sector

Table 3.4 shows the average substitution costs with a breakdown by sector. These costs are the aggregated substitution cost of all technologies assumed to be implemented in that sector. The average cost of the portfolio of REmap Options in the industry sector is USD 5 per GJ based on a government perspective. The business perspective estimates average costs of USD 4.3 per GJ. The average cost of the REmap Options in the building sector is estimated at USD -2.3 and USD 1.6 per GJ in the business and government perspectives, respectively.

The average cost of substituting fossil fuel use in the transport sector comes at high savings of USD -12.7 per GJ based on the business perspective. The substitution costs are moderate when based on the government perspective, estimated at USD -4.1 per GJ. The considerable difference between the two estimates is the result of high excise and value-added taxes applied to gasoline and diesel fuels in most countries. The transport sector has the lowest cost of substitution.

Table 3.4 Global average substitution costs in REmap 2030, from government and business perspectives

	Government	Business
	(USD/GJ)	
Industry	5	4.3
Buildings	1.6	-2.3
Transport	-4.1	-12.7
Electricity	5.7	4.1
District heat	5.3	5.7
Total	2.5	-0.7

The energy transition appears less costly from a business perspective than it looks to governments.

Note: Costs related to autoproducer power plants and the power generation part of CHP plants owned by the industry, building and district heat sectors are allocated under the electricity sector. Partitioning of fuel input to CHP plants for the co-generation of power and heat is based on the energy content of the output.

In the electricity and district heat sectors, the substitution costs are estimated to be between USD 4 and USD 6 per GJ. Among all sectors, increasing the share of renewable energy in the industry, power and district heat sectors is the most expensive, at least USD 5 per GJ.

Globally, the same relationship is found consistently for each sector, assuming that taxes and subsidies remain the same as today by 2030; the substitution costs based on the business perspective are lower. Although the business perspective is more cost effective compared to the government perspective for all sectors, only the buildings and transport sectors have a business case by 2030, *i.e.*, savings. For other sectors, the REmap

Options have positive substitution costs. New policies are needed that provide proper incentives for these sectors to change the business economics.

3.3.4 Comparison of REmap results with integrated energy models

This roadmap investigates the potentials achievable through additional options by country, sector and technology, based on a bottom-up analysis of the 26 REmap countries. Country engagement is one of the main principles of REmap 2030 in identifying renewable energy options between now and 2030. IRENA has facilitated the collection and analysis of country data through the REmap tool, a spreadsheet that allows easy comparison of existing plans and future renewable energy options in each of the 26 countries. The tool displays what a country's energy system looks like in 2020 and 2030 based on existing plans, and then asks the national REmap experts to identify – sector by sector – what conventional technologies may be substituted with renewable energy technologies. To the extent possible, the Reference Case and the REmap Options were estimated in dialogue with the 26 countries. The potential and costs of these options are displayed on a cost-supply curve. This approach has both advantages and disadvantages.

National energy plans and scenarios currently differ substantially in terms their scope, assumptions and level of detail. The REmap approach facilitates an open and easily comparable way of aggregating countries at a global level. Furthermore, it creates a common framework to include widely dispersed countries and their national plans and/or scenarios. The cost-supply curves in this study provide a one-to-one comparison of individual renewable energy technologies with their conventional technology equivalents based on country analyses. It also provides a fair level of detail about different renewable energy technologies and covers all sectors of the economy. It is therefore a useful, transparent summary of the costs and potential of more than 450 technology choices.

The roadmap is not a scenario analysis, and the findings are not prescriptive. The roadmap instead follows a practical approach, and the aim is to communicate with a diverse group of audience: from policy makers to technology developers, academia and the general public. The approach also allows IRENA and countries to work together, next to other practical benefits; for example, national experts can easily review assumptions and easily provide data in the REmap tool. The cost and potential of each technology can be easily calculated back to the raw technology performance and cost data, which allow results to be re-estimated by varying the default parameter values (*e.g.*, energy prices, discount rates). This flexibility is important because each country has its own characteristics, and countries not covered in this analysis may want to analyse their potential and compare themselves with others on a comparable metric.

On the other hand, a number of issues are not entirely covered in the cost-supply curves and in general in the simplified approach applied in this study. The analysis represents a point in time. The developments and dynamics between 2010 and 2030 were not estimated in detail; rather, all additional options are implemented in a single step in 2030. The interactions across different technologies or the developments and feedbacks in energy prices due to demand and supply changes (*e.g.*, rebound effects) were not taken into account.

Most variables in the model are exogenous; for example, fossil fuel prices in 2030 were taken from the IEA's *World Energy Outlook* (WEO) without taking into account the potential effect in demand reduction due to the implementation of the REmap Options. While the cost-supply curve is static, the energy system in general – and, for instance, the process of meeting electricity or heat demand – is dynamic. Some externalities were taken into account in separate analyses, but not all benefits and costs are incorporated. For example, there are institutional barriers, or transaction costs along with technology costs. Incorporating these could change the ranking of technologies.

All of these issues which are excluded from this analysis, as well as their effects, can be assessed in detail with sophisticated and integrated energy models. The main drawbacks of such models are, however, the lack of transparency in how results are estimated and generally the limited level of detail in the outcome. Therefore, such models may not always help policy makers in developing roadmaps for individual sectors, countries and technologies. In view of the practical aims of this roadmap and its primary focus – to identify the global technology options based on the independent, bottom-up analysis of the 26 REmap countries and their data – cost-supply curves are regarded as a suitable approach.

In order to see the potential differences in outcome between this analysis and integrated energy models, IRENA co-operated with the Energy Technology Systems Analysis Programme of the IEA (IEA-ETSAP). In June 2013, IRENA co-organised a REmap 2030 session together with the IEA-ETSAP (IRENA/IEA-ETSAP, 2013a), which is one of the longest-running international co-operation activities on energy issues in the world and consists of individual national teams in nearly 70 countries. Each team employs comparable, combinable technical-economic models to explore long-term energy scenarios in their respective country or region.

National energy plans and scenarios currently differ substantially in terms their scope, assumptions and level of detail.

The models employed by the IEA-ETSAP teams are so-called least-cost optimisation models. In other words, the models decide – based on a library of energy technology options – what sequence and combination of technologies can most cheaply satisfy energy demand. Similarly, these models can be used to identify the most economic combination of energy options to achieve a particular share of renewables in the energy system. These models account for a number of features that cannot be explored in the REmap tool, such as trade-offs between renewable energy and energy efficiency activities. They account for system planning issues like investments in the grid infrastructure and reflect competition for scarce resources (*e.g.*, biomass) in commodity prices and for dynamic cost structures as technologies get deployed over time. However, the models require expert knowledge to handle the associated software and to interpret the results.

The aim of the IRENA/IEA-ETSAP session was to see whether the results of the REmap tool could be compared with the IEA-ETSAP models. The premise of this comparative analysis was that the sequence of technology options in REmap's cost-supply curves should be similar to the technology options selected by the ETSAP models as they increase the required share of renewables in their energy system. As a result, a collaborative project was established whereby the ETSAP teams model showed how renewable energy and energy efficiency activities evolve as countries increase their renewable energy share.

The comparative analysis – which is still ongoing – suggests that for a number of countries and regions, the results are directly comparable to the REmap country results. Furthermore, the impact of higher renewable energy shares on commodity prices was compared, as were the impacts of higher renewable energy shares on investment needs for transmission and distribution networks. The results suggest that investments in transmission and distribution networks are in the range of 10% of total system investment costs, and that energy efficiency activities are becoming an important factor to achieve very high shares of renewables in the system. A joint paper between IRENA and IEA-ETSAP with detailed findings is in preparation.

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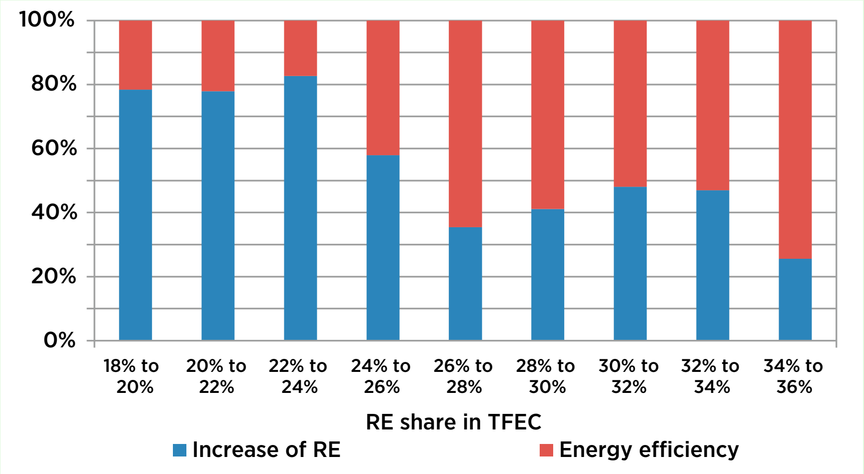
Figure 3.9 Contribution of renewable energy supply options and energy efficiency to the doubling of the global renewable energy share in 2030



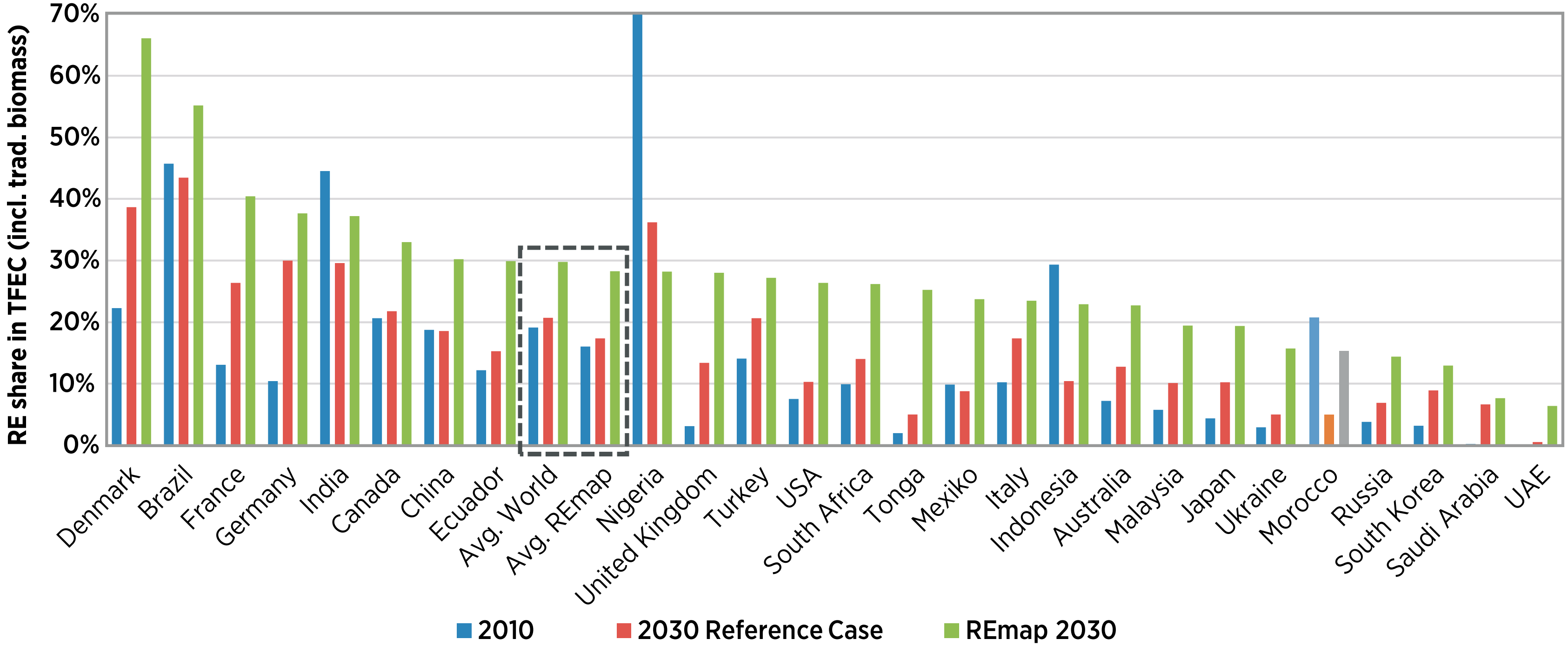
Source: IRENA/IEA-ETSAP (2014)

Figure 3.9 shows the results of a global IEA-ETSAP model to double the share of renewable energy from 18% to around 36% in 2030 in two-percentage-point steps. For each increase in the renewable energy share, a new simulation is run. Figure 3.9 shows the ratio between additional renewable energy activities and additional energy efficiency activities to achieve a higher share of renewable energy. For a global renewable energy share of around 26%, more renewable energy than energy efficiency activities are deployed to increase the renewable energy share. Between 26% and 34%, the ratio between renewable energy and energy efficiency activities is more-or-less equal. Beyond 34%, energy efficiency activities become the dominant driver for high shares of renewables.

3.3.5 Results by country

If all REmap Options are implemented, the share of modern renewable energy in the TFEC of the 26 REmap countries would increase from 9%

Figure 3.10 Current and projected share of renewable energy in the 26 REmap countries, 2010-2030



Doubling of the share of renewables worldwide does not mean doubling it in every country.

Note: The renewable energy shares for the 2030 Reference Case for France and the United Kingdom (UK) were assessed based on their 2020 renewable energy commitments according to their NREAP. No further deployment of renewable energy was included in their analysis of the Reference Case between 2020 and 2030; however, any improvements in energy efficiency were taken into account.

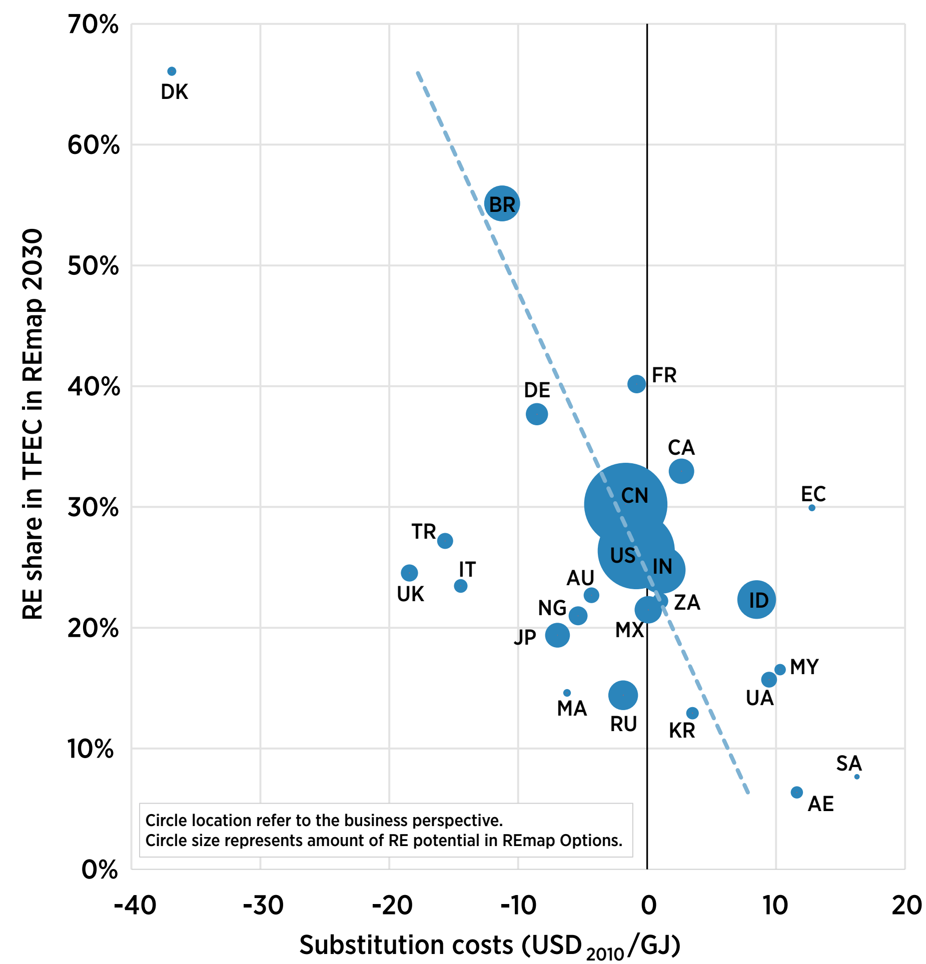
in 2010 to 27% in 2030. Details by country are provided in Figure 3.10. In 2010, the 26 REmap countries start off at different levels – ranging from 0% in Saudi Arabia and the UAE, to more than 20% in Denmark, Canada and Nigeria, to more than 40% in Brazil.

Most countries display an upwards progression in their renewable energy share from 2010 to the Reference Case in 2030. European Union (EU) countries show strong growth in both the Reference Case and REmap 2030. EU Member States all have renewable energy targets for 2020, as defined by their national renewable energy action plans (NREAP), and were discussing targets for 2030 at the end of 2013. Some, such as Denmark and Germany, have targets for 2030 to take their renewable energy share higher than in 2020, as indicated by the Reference Case. The renewable energy share of economies in transition and in the Middle East and North Africa (MENA) is projected to be below 20% in the Reference Case. Developing Asian countries, which will account for the largest share of TFEC worldwide, are estimated to have a renewable energy shares of between 16% and 30% if all REmap Options are deployed. The global doubling of the share of modern renewable energy does not mean a doubling in every country.

Brazil, Canada, China, Denmark, Ecuador, France and Germany could reach renewable energy shares of 30% or more.

The renewable energy share in countries with traditional use of biomass develops differently between 2010 and 2030 than in countries with no traditional use of biomass. Clearly, Nigeria, and to an extent Brazil and India, show different trends. Because Nigeria currently uses so much biomass (including solid biomass in industry), the country expects its share of renewables to shrink dramatically as industry switches mainly to natural gas, and as the use of traditional use of biomass in households for cooking is replaced by the more efficient use of modern biomass. Except for Nigeria, as bars for the average show in Figure 3.10, the share of

Figure 3.11 Country renewable energys potential and substitution costs from a business perspective



Countries are abbreviated as follows: Australia (AU), Brazil (BR), Canada (CA), China (CN), Denmark (DK), Ecuador (EC), France (FR), Germany (DE), India (IN), Indonesia (ID), Italy (IT), Japan (JP), Malaysia (MY), Mexico (MX), Morocco (MA), Nigeria (NG), Russia (RU), Saudi Arabia (SA), South Africa (ZA), South Korea (KR), Turkey (TR), Ukraine (UA), United Arab Emirates (AE), United Kingdom (UK) and United States (US).

renewables is much greater in 2030 under REmap 2030 than it would be in the Reference Case.

Of the different regions that the 26 REmap countries cover, Africa and Latin America are the least represented. Since both regions are developing and many developments are required on the infrastructure side, a greater representation of these regions by including more countries will be favourable in order to draw conclusions for those regions.

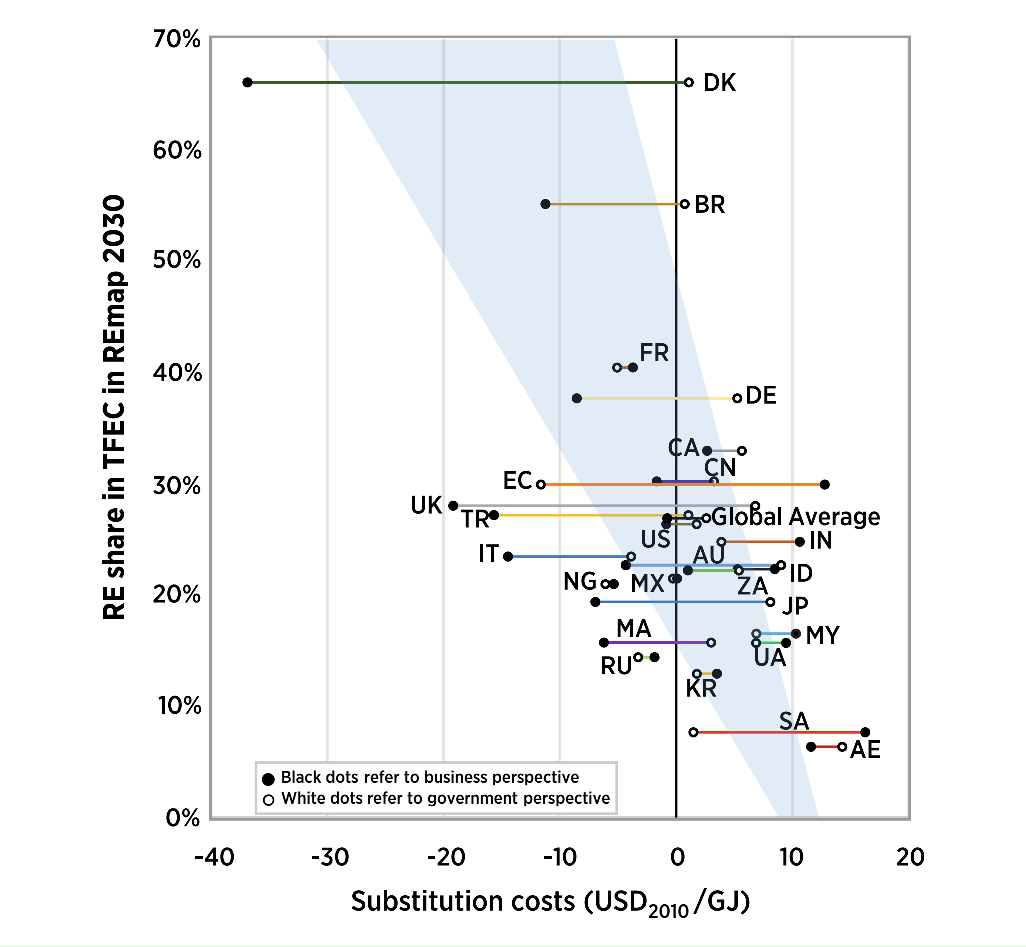
3.3.6 Substitution costs by country

Figure 3.11 shows the substitution costs for each of the 26 REmap countries under the REmap Options by 2030 from a government perspective. Note that the x-axis starts on the left at low costs and moves into high substitution costs to the right. Each country is indicated with a circle; the size of the circle shows the volume of the REmap Options. The larger the circle, the larger the additional potential of renewable energy technologies in that country. Countries with the largest circles and the lowest substitution costs are important to double the share of renewables in the global energy mix cost effectively.

According to Figure 3.11, the potential is greatest in Brazil, China and the United States (US), and these countries all have negative substitution costs from a government perspective. Other countries with large potentials and negative substitution costs are France, Germany, Japan and Russia. India, Indonesia and Canada also have large additional technology potentials, but their substitution costs are much higher.

The main driver for renewable energy deployment is found to be its costs. If costs allow it and there are sufficient resources in a country, there is no reason why one should not expect renewable energy use. Costs are determined based

Figure 3.12 Relation between country renewables potentials and substitution costs from the government and business perspectives



As the target share of renewables in the energy mix increases, the cost of the transition per unit of energy diminishes.

Note: Economic incentives increase to the left and decrease to the right. The global average refers to the total of the 26 REmap countries, and the other bars show the breakdown of this total by country. Countries are abbreviated as follows: Australia (AU), Brazil (BR), Canada (CA), China (CN), Denmark (DK), Ecuador (EC), France (FR), Germany (DE), India (IN), Indonesia (ID), Italy (IT), Japan (JP), Malaysia (MY), Mexico (MX), Morocco (MA), Nigeria (NG), Russia (RU), Saudi Arabia (SA), South Africa (ZA), South Korea (KR), Turkey (TR), Ukraine (UA), United Arab Emirates (AE), United Kingdom (UK) and United States (US).

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on energy prices and discount rates (both the government and business perspective), technical performance of the renewable energy alternatives and the conventional technologies they are compared to. These aspects are measured by substitution costs in REmap 2030.

Figure 3.12 shows the substitution costs for each of the 26 REmap countries under the REmap Options by 2030, both from a government perspective (white dots), and from a business perspective (black dots). In Figure 3.7, the cost curves for different types of technologies were presented; here, the overall cost curve for individual countries is shown. National taxation and subsidies have been removed in the government perspective (white dots) but are included in the business perspective (black dots). Each country line represents the difference in the substitution cost from the government and business perspectives with the REmap Options.

In Figure 3.12, the x-axis starts on the left at low costs and moves into high substitution costs to the right. The positions of the countries show a general relationship:

- Countries with weak economic incentives (positive substitution costs) tend to have low renewable energy shares,
- Countries with strong economic incentives (negative substitution costs) tend to have high renewable energy shares, and
- Countries on the left can raise their renewable energy share at negative costs (*i.e.*, higher savings) of substitution.

It is possible to break down the curve further. The *bottom left* of the curve (countries with renewable energy shares below 30% at negative costs of substitution) are promising countries, which start with a low renewable energy share in the Reference Case (generally less than 10%) but reach approximately 20% when all REmap Options are deployed. The doubling of the global renewable energy share by 2030 could be expected to start mainly in these countries, with substitution costs ranging from USD 0 (Mexico) to USD -19 (United Kingdom) per GJ based on a business perspective (when Ecuador is included, from USD +13 per GJ).

The *top left* shows some of the mature countries, which already have reached a high renewable energy share of at least 25% and could raise this share further at a negative substitution cost. Denmark and Brazil fall under this category entirely, as does Germany partly. Brazil already has a high renewable energy share, with a mix of hydro in the power sector and biofuels in the transport sector. Mainly, additional biofuels in the transport sector and other low-cost biomass uses in the end-use sectors can raise the renewable energy share further without any additional costs. The renewable energy share can be increased further in Germany with already cost-effective solar PV and wind technologies in the power sector. The substitution costs of these countries based on the business perspective range from USD -4 (France) to USD -36 per GJ (Denmark).

The *bottom right* of the curve shows the countries that subsidise fossil fuels and/or electricity; most of them also produce fossil fuels today and are expected to do so in 2030. They raise their renewable energy share from a low level, but only to a limited extent – and often at positive substitution costs. The substitution costs based on the business perspective range from USD 1 (South Africa) to USD 16.5 (Saudi Arabia) per GJ. In many cases (Malaysia, Saudi Arabia, Indonesia, etc.), these countries have higher substitution costs from the business perspective than from the government's view – a reversal of the situation in Denmark, Brazil, Germany or Japan. Here, energy pricing policies create a market which could favour the further deployment of renewable energy. In comparison, in countries with high energy subsidies, the national prices of fossil fuels are lower than the international market price. Although Russia heavily subsidises its natural gas, the price difference is minor because a mix of expensive nuclear and diesel generators is being substituted, resulting in negative substitution costs in both cases. South Korea subsidises its electricity retail prices and is therefore positioned next to energy-subsidising countries.

The comparison shows that there is a general trend between substitution costs and a country's role as a net exporter/importer of fossil fuels. Countries that export tend to have higher substitution costs; those that import, lower. However, the fuels substituted also crucially affect substitution costs. Where oil exporters use oil for power generation, costs seem low, but opportunity costs (not represented here) are high; the additional profits from the sale of oil exports would outweigh the slightly higher cost of power from renewables.

3.3.7 Renewable energy use

Figure 3.13 provides the contribution of countries to the total renewable energy use of the 26 REmap countries in REmap 2030. Six countries account for 55% of the total global renewable energy use (China, the US, Brazil, India, Indonesia and Canada) in REmap 2030. Detailed findings for these countries can be found in their respective analyses.

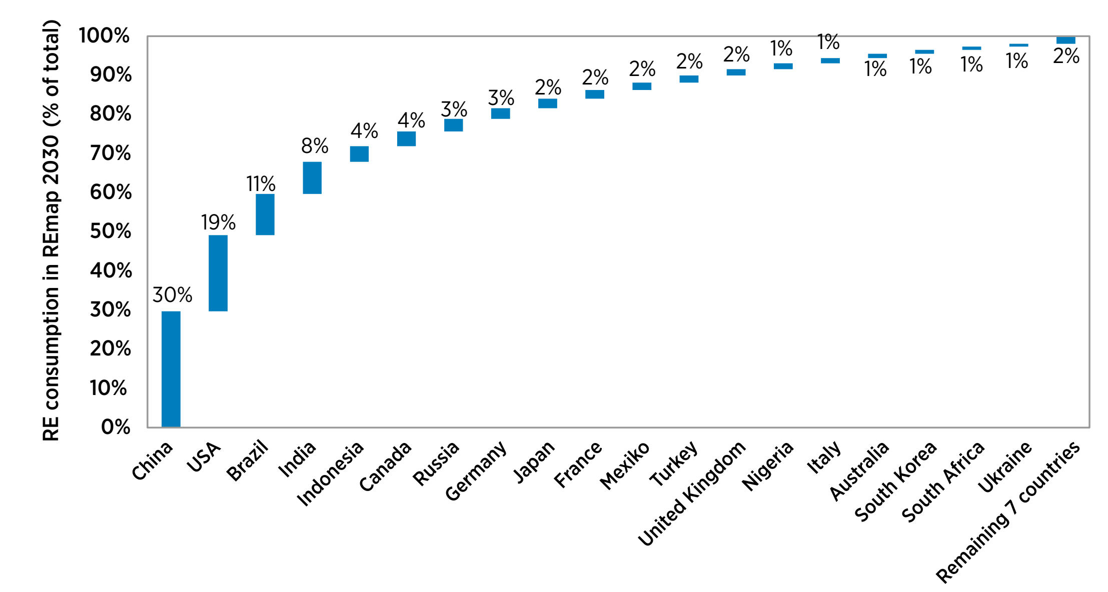
A quarter of the total REmap Options in the 26 REmap countries will be deployed in the US and another quarter in China. Indonesia, India, Brazil and Russia will together account for another quarter of the total REmap Options. These six countries originate from different regions and all show considerable differences in their existing policy frameworks, economic development, renewable energy share and fuel mix, indicating that opportunities for renewable energy exist in different resource, political and economic environments.

The US, the only high-income country among the six, has a moderate increase in its Reference Case between 2010 and 2030 for its end-use sectors, but the power sector is an exception; here, the renewable energy share increases from 11% in 2010 to 29% in 2030. The REmap analysis shows that the US total renewable energy share in TFEC could be increased from 7.5% to 26% by 2030 if all REmap Options are deployed. China could also double its renewable energy share to 30%. The results show that engagement of China and the US is essential if a global doubling goal is to be reached.

The third country in terms of potential is Brazil, mostly in the transport sector, where the renewable energy share increases from 42% in 2010 to more than 55% by 2030. Because the country already has so much hydropower, Brazil's REmap Options for the power sector are limited, consisting mainly of small amounts of a mix of biomass, solar and wind.

India and Indonesia deploy different technologies in both their end-use and power sectors. The largest REmap Options are in the power sectors, where the renewable energy share more than doubles and most traditional use of biomass in the building sector is substituted with modern forms of renewable energy.

Figure 3.13 Contribution of individual countries to total renewable energy use of the 26 REmap countries in REmap 2030



Six countries account for more than half of total global renewable energy use and three-quarters of the estimated renewable energy scale-up by 2030.

Note: All countries with a total share below 1% are grouped together as "remaining 7 countries"

Box 3.3 Traditional use of biomass

Traditional use of biomass accounted for about half of total global renewable energy use in 2010. Its sustainability, however, is questionable. The problems range from health issues (smoke from fires) to social issues (children collecting wood instead of going to school) and environmental impacts.

Because biomass used traditionally is often collected and traded informally, there is no clear definition of the term, and quantities are not known accurately. Whether biomass is categorised as sustainable depends on various factors, such as harvesting impacts on biodiversity, the carbon cycle, erosion, health impacts and the social consequences of biomass collection and use.

The United Nations Food and Agriculture Organization (FAO) defines traditional use of biomass as "woodfuels, agricultural by-products, and dung burned for cooking and heating purposes." The IEA considers modern bioenergy as all biomass consumed in Organisation for Economic Co-operation and Development (OECD) countries, while all bioenergy in the residential sectors of the non-OECD countries is labelled as traditional use of biomass. IRENA will work to improve these definitions and statistical data.

Traditional use of biomass can be transformed into modern biomass. Some sources say it is sufficient to replace a traditional use of biomass stove with a modern one. While this change does not affect the sustainability of the biomass supply per se, it reduces health impacts. Conversion efficiency gains reduce the need for biomass, which in turn improves sustainability. However, traditional use of biomass can also be substituted with other renewable energy technologies: anaerobic digesters can produce biogas from food and agricultural waste and animal dung, and the biogas can then be stored for use in cooking or heating; solar cookers can be used by families, or community solar cooking facilities can assist in food preparation for an entire village; and biofuels can also provide a source of fuel for cooking and heating on demand.

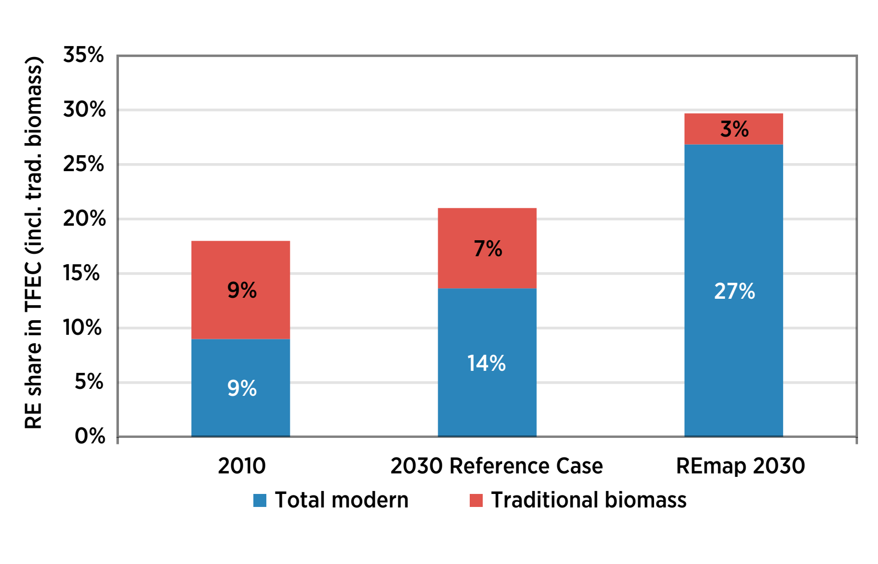
The global share of traditional use of biomass in TFEC is projected to decline from around 9% in 2010 to 6% in the Reference Case (see Figure 3.14). Based on IEA projections and country plans, IRENA estimates that Africa, Asia and Latin America will consume around 28 EJ of traditional use of biomass in 2030. The Reference Cases for the REmap countries make up 13 EJ of that total, leaving a remainder of 15 EJ.

Nine REmap countries use large quantities of traditional use of biomass: Brazil, Mexico, Nigeria, South Africa, Morocco, India, China, Indonesia and Malaysia. China, India, Nigeria and Indonesia alone make up 90% of this traditional use of biomass. For the REmap Options, 8 EJ is substituted with modern renewables, leaving 5 EJ of traditional use biomass, equivalent to around 3% of global TFEC. Because of the uncertainties around classifying traditional use of biomass and based on IRENA's analyses and input from the countries themselves, it was determined that this 5 EJ of traditional use of biomass should be considered modern, so it was not substituted.

The remaining 15 EJ of traditional use of biomass consumed outside of the REmap countries could be reduced to 7.7 EJ by 2030 if the efficiency of cook stoves is doubled, resulting in an additional 1.7 percent of renewable energy from these systems alone, assuming that global TFEC will reach nearly 440 EJ.

In total, the REmap Options combined with more efficient cook stoves results in almost complete substitution of traditional use of biomass with modern renewable variants. The result is around a 3% share in TFEC of modern biomass cooking/heating; down from 9% in 2010 – a two-thirds reduction in traditional use of biomass to deliver that same amount of useful energy.

Figure 3.14 Traditional and modern renewable energy use shares of biomass, 2010-2030



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While these six countries make up a large share of the total global renewable energy use, all other countries need to remain engaged for the world to progress. Although the absolute potential of the other 20 countries is small, some of them – such as Denmark and Germany – have ambitious renewable energy plans which could take their renewable energy shares beyond 30%; these two countries have driven wind and solar PV over the past two decades. Other countries with lower renewable energy shares could benefit from such best practices and experience (see Chapter 6).

3.3.8 Renewable energy share and accounting of primary and final energy

Different countries use different accounting methods to estimate the renewable energy share in their total energy mix. For example, EU countries and Ukraine estimate their shares based on gross final consumption (GFC). In comparison, Indonesia and the US use total primary energy supply (TPES).

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 biomass), it is problematic when comparing these sources to wind and solar – which have no fuel, and hence no losses between primary and final energy. When calculating our consumption of finite resources, a focus on primary energy consumption makes sense; we count what we take from nature. It is not only a matter of choosing primary or final since there are different ways to estimate primary energy, and if the renewable energy share is based on final, it depends on the system boundaries. Different organisations use three ways to estimate primary energy:

- In the **Physical Energy Content** method used by the IEA and Statistical Office of the European Union (EUROSTAT), renewable electricity (*e.g.*, wind, solar PV and hydropower) and biofuels are counted in primary energy as they appear in the form of secondary energy (*i.e.*, using a 100% efficiency to convert them into primary energy equivalents), while geothermal, CSP electricity and nuclear electricity are counted using average process efficiencies (*e.g.*, 10-33%) to convert them into primary energy equivalents.
- In the **Direct Equivalent** method used by the Intergovernmental Panel on Climate Change (IPCC) or UN Statistics, all non-combustible energy sources (*e.g.*, renewables, nuclear) are converted into primary energy equivalents as they appear in TFEC (*i.e.*, using a 100% efficiency to convert them into primary energy equivalents).
- In the **Substitution** method used by the U.S. Energy Information Administration and BP, renewable electricity and heat are converted into

Table 3.5 Calculation of methods for total primary energy equivalents

<table>
<tr><th></th><th>Physical energy content (%)</th><th>Direct equivalent (%)</th><th>Substitution (%)</th></tr>
<tr><td>Power: Fossil fuel</td><td colspan="3">country specific (range 27-57)</td></tr>
<tr><td>Power: Nuclear</td><td>33</td><td>100</td><td rowspan="5">country specific (range 27-57)</td></tr>
<tr><td>Power: Solar PV, wind</td><td>100</td><td>100</td></tr>
<tr><td>Power: Hydro, wind, tide/wave/ocean, solar PV</td><td>100</td><td>100</td></tr>
<tr><td>Power: CSP</td><td>33</td><td>100</td></tr>
<tr><td>Power: Geothermal</td><td>10</td><td>100</td></tr>
<tr><td>Power: Biomass</td><td colspan="3">country specific (range 15-47)</td></tr>
<tr><td>Industry/buildings heat: Solar thermal</td><td>100</td><td>100</td><td>90</td></tr>
<tr><td>Industry/buildings heat: Geothermal</td><td>50</td><td>100</td><td>90</td></tr>
<tr><td>Industry/buildings heat: Biomass</td><td>100</td><td>100</td><td>100</td></tr>
<tr><td>Liquid biofuels</td><td>100</td><td>100</td><td>100</td></tr>
</table>

primary energy using the average efficiency of the fossil fuel power and heat plants otherwise required to produce these quantities.

Table 3.5 provides a comparison of the conversion efficiencies used when estimating the primary energy estimates. If one wants to compare the share of coal power to wind power, the conversion efficiency of a coal plant would need to be used to estimate the total amount of coal substituted to generate the same amount of power. So coal's primary energy equivalent (lumps of coal) is three times greater than its final energy value (electricity); a focus on primary energy then greatly overstates coal's contribution. In comparison, three times less wind energy would be required in primary energy terms according to physical energy content and direct equivalent methods since the conversion efficiency is 100%. According to the substitution method, the primary energy equivalent of wind would be higher compared to the other two methods because the conversion efficiency for wind is equivalent to the average efficiency of the conventional fossil fuel/nuclear system substituted.

Final energy can also be defined in different ways. GFC used by EU countries is defined as "the energy commodities delivered for energy purposes to industry, transport, households, services including public services, agriculture, forestry and fisheries, including the consumption of electricity and heat by the energy branch for electricity and heat production and including losses of electricity and heat in distribution and transmission", according to Renewable Energy Directive 2009/28/EC (EC, 2009). In comparison, total final consumption (TFC) excludes the losses of electricity and heat in distribution and transmission, and therefore its value is lower than GFC for the same country. TFEC has the same system boundaries as TFC, but it excludes non-energy use.

As suggested by the Global Tracking Framework, REmap 2030 uses the TFEC accounting methodology to estimate the renewable energy share in the global energy mix (World Bank, 2013a). The renewable energy share in 2030 could also be expressed in any of the other accounting methodologies but would yield different shares and country rankings.

Figure 3.15 compares the renewable energy shares in REmap 2030 based on TFEC and TPES separately for physical energy content and substitution methods (and including traditional use of biomass). The growth in renewable energy of the 26 REmap countries is 67% when the share is expressed based on TFEC. This growth is normalised to 100% in the figure. When the growth is expressed in terms of primary energy based on either of the commonly applied accounting methodologies (*i.e.*, physical energy content and the substitution methods), growth would be 20-30% higher.

Accounting method matters. It is easier to double the global renewable energy share when this is expressed in terms of primary energy.

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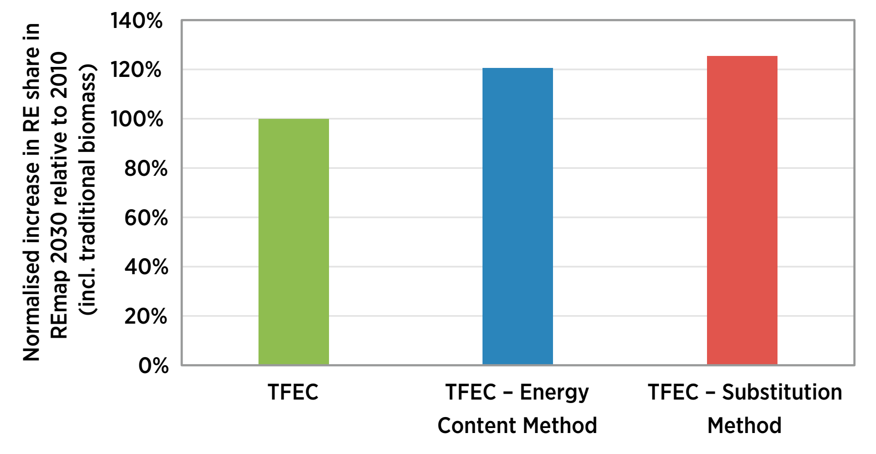
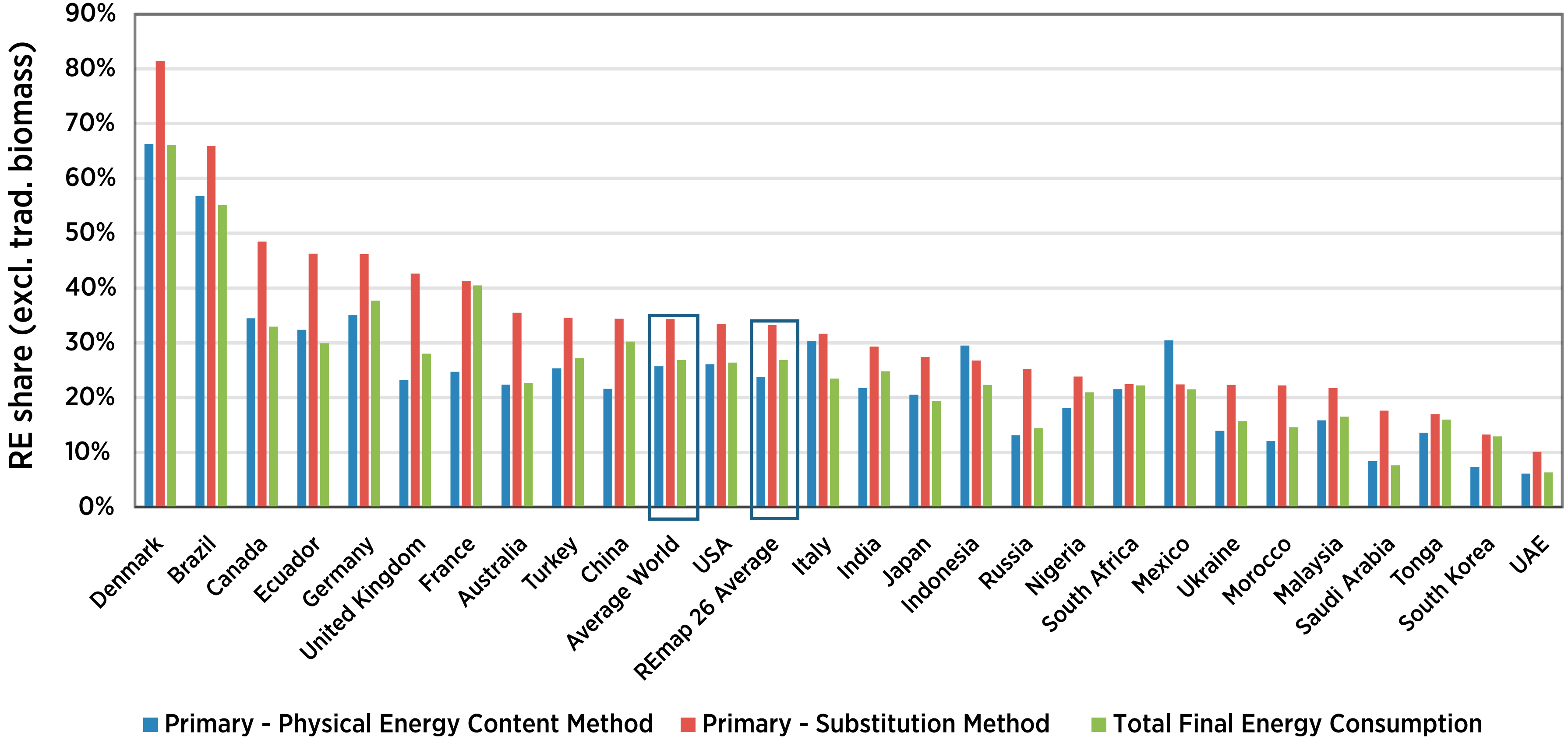
Figure 3.15 Growth in the renewable energy share of the 26 REmap countries based on different energy use accounting approaches



When expressed in terms of primary energy, growth in the renewable energy share works out between 20% and 30% higher.

Note: Excluding the energy efficiency objective, the growth in renewable energy share in TFEC is 67% (=30%/18%). This is normalised to 100%. The growth according to other methods is shown relative to this value.

Figure 3.16 Renewable energy share of REmap countries based on different energy use accounting approaches



Switching to a primary accounting method affects almost all countries the same and is generally positive for countries with a high electricity share.

The comparison of renewable energy share in REmap 2030 according to Figure 3.16 shows that the share differs depending on the accounting method. If the share is estimated based on the substitution method, it is always higher than if it is estimated based on TFEC. Large differences of as much as 15 percentage points exist, for example, in the case of Canada or Denmark. According to the TFEC, quantities of power consumed in the end-use sectors are regarded as final energy with a 100% efficiency (for solar, wind and hydro). Based on the substitution method, renewable power accounts for a larger share of the total energy mix as it is converted to primary energy based on the average conversion efficiency of the conventional system substituted (see Table 3.5). Therefore, countries with a high renewable energy share in the power sector also have a higher share in their TFEC, according to the substitution method.

When the renewable energy share is estimated based on the physical energy content method, the changes compared to the TFEC differ across countries. For example, in France, the renewable energy share estimated based on the physical energy content method is lower by 16 percentage points compared to when estimated based on TFEC. In the case of China, the difference is around 8 percentage points. This is mainly because in REmap 2030 in both countries, conventional power generation technologies (mostly nuclear in France and coal in China) continue to account for a considerable share of the power sectors' fuel mix, and conventional fuels are converted to primary with conversion efficiencies ranging from 27% to 57%.

In contrast, most renewable energy technologies have a conversion efficiency of 100%, hence their contribution to total primary energy is lower than the contribution of fossil fuels or nuclear. For countries with a high geothermal share, such as Italy, Mexico or Indonesia, the opposite relationship is found. Their renewable energy share increases by nearly 7 percentage points compared to when it is estimated based on TFEC. This is because geothermal power has a conversion efficiency of 10%, much lower than any of the conventional and renewable power generation technologies; therefore, it has a large contribution to the total primary energy of the country.

The estimation of the renewable energy share and its growth are highly dependent on the accounting method. Depending on the chosen method, the contribution of renewable energy to the total energy mix can easily be underestimated, and country comparison could yield misleading conclusions. For comparable monitoring of renewable energy use progress and for target setting, consistent definitions and internationally harmonised methods of energy accounting should be applied.

3.3.9 Uncertainties in REmap 2030 analysis and identifying the challenges to doubling the global renewable energy share

REmap Options represent an expert view of what could realistically be achieved with renewables, given today's decision-making environment, the status of a wide range of technologies, the age of current facilities in the energy sector, the availability of investment capital and an extrapolation of current market growth into the future. It assumes an evolutionary transition instead of a global revolution. All REmap Options together, in combination with access and efficiency objectives of the SE4ALL, could yield a renewable energy share of as much as 36% in the global energy mix by 2030. This would come at a cost of USD 2.5 per GJ of final renewable energy.

The result is subject to a range of uncertainties. Policy makers are well advised to allow for flexibility in their policy frameworks to accommodate such uncertainties. Various methods can be deployed to estimate uncertainties and risk. The following discussion combines formal sensitivity analysis and feedback received during various review meetings.

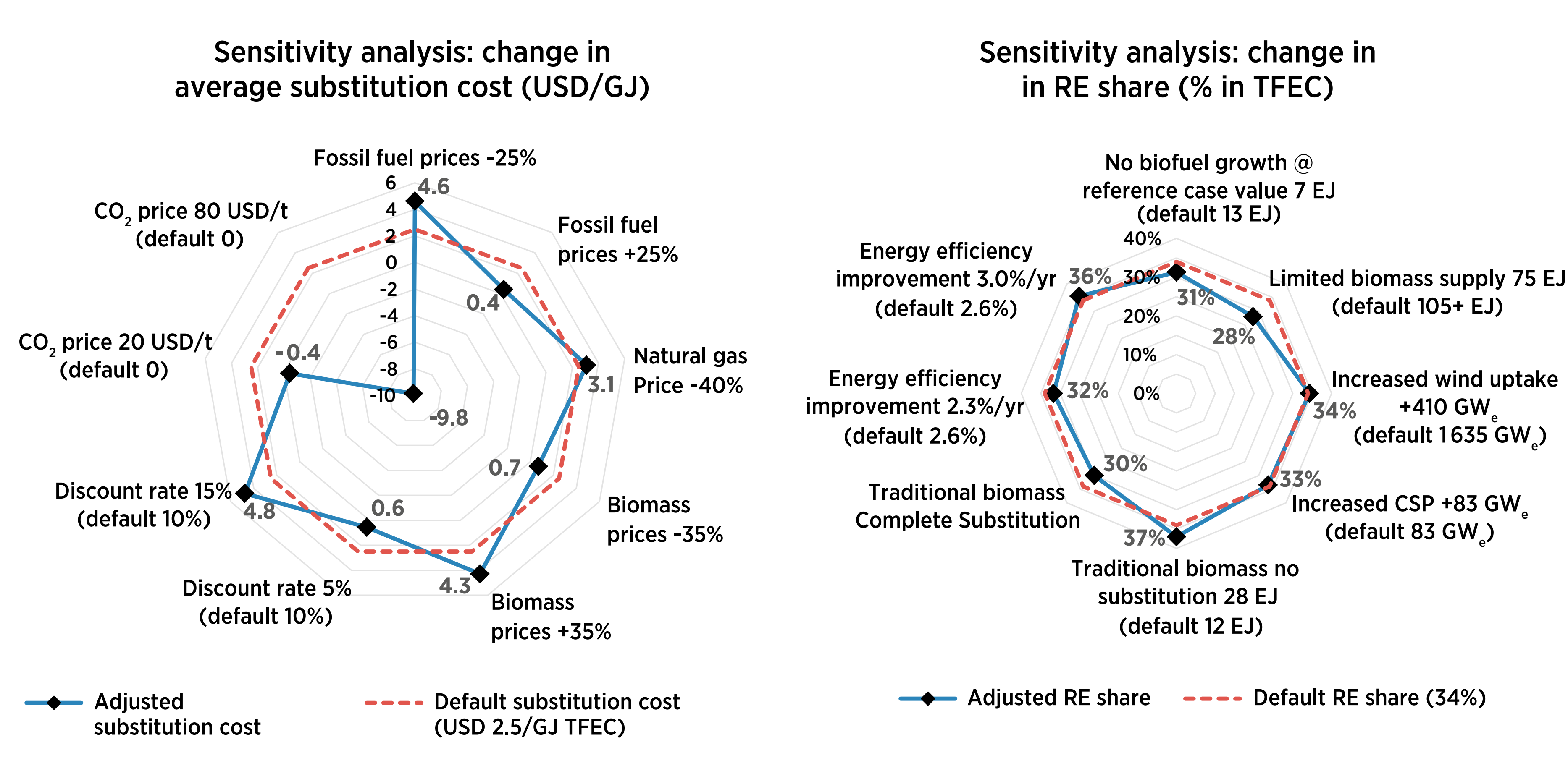
Energy efficiency plays an important role in determining the global renewable energy share

For sensitivity analysis, a set of key factors has been identified for the global energy mix and the costs of substitution. These factors have been varied from the default value within a range considered plausible. Figure 3.17 provides an overview of the variables which are considered to be key in determining the outcome of the REmap analysis, namely energy prices, discount rates, technology development and realising the other two objectives of SE4ALL. Either average cost of substitution or renewables share has been considered as an indicator for the sensitivity.

The key findings are discussed below:

- The sensitivity analysis results in an average substitution cost that ranges between USD 0.4 and USD 4.8 per GJ when the energy prices and discount rates were changed (equivalent to a cost reduction of USD 80 billion to a cost increase of nearly USD 90 billion in 2030). Average substitution costs increase when lower conventional fuel prices are used or when higher biomass prices or higher discount rates are applied. The change in conventional fuel prices has an effect on all REmap Options since renewable energy technologies always sub-

Figure 3.17 Results of the sensitivity analysis for substitution costs and renewable energy share



Note: Renewable energy share refers to REmap 2030 as well as to the implementation of the other two SE4ALL objectives: energy efficiency and modern energy access.

stitute a fossil fuel or nuclear counterpart. In comparison, the change in biomass prices relates only to 60% of the total REmap Options, but affects these options more significantly. Compared to today's fossil fuel supply cost of more than USD 3 trillion, the sensitivity is comparatively small. However, a combination of high discount rates, high biomass prices and low fossil fuel prices can raise the cost more than four-fold. Alternatively, positive deviations can turn the net cost into net savings.

- Energy efficiency plays an important role in determining the global renewable energy share. If the rate of energy-intensity improvements increases to 3% per year, the renewable energy share would increase to about 36% because demand for total final energy is lower. In contrast, the renewable energy share would be lower at 32% if energy intensity improvements reach 2.3% per year only. In comparison, the improvement rate in the 26 REmap countries was only 1.3% during the last two decades. If traditional biomass continues to be used as today without being substituted with modern renewable energy technologies, the renewable energy share drops to 30%.

- Biomass is a key resource within the REmap Options package. If biomass supply is limited to 75 EJ in 2030 (roughly equivalent to no energy crops, only residues), the renewable energy share would drop six percentage points. Some of this could be compensated by higher electrification of thermal end use, but probably not all. The default assumption is a six-fold growth of total liquid biofuels. By 2030, 37% of the total amount would be advanced liquid biofuels. If these advanced biofuels are not deployed, the renewable energy share would decrease by four percentage points. This result suggests that biomass is a key uncertainty. Promotion of sustainable and reliable biomass supply as well as further development and deployment of emerging conversion technologies is a priority.
- Increasing the uptake of wind and CSP technologies further raises the global renewable energy share only slightly by about 1 percentage point. So the growth assumption for wind and solar is a sensitivity of secondary importance on a global scale.

The sensitivity analysis helps to show how robust the REmap 2030 roadmap findings are. The analysis also provides the key challenges ahead and points to the main uncertainties in realising the findings of this roadmap. In order of priority, the following uncertainties can be discerned:

- Proper understanding of advantages of a transition and willingness of decision makers and the general public to make a transition.
- Pushback by established players to maintain the status quo.
- Pricing of external effects.
- Energy efficiency improvements significantly above historical rates.
- Prioritisation of modern renewable energy solutions for energy access.
- Simultaneous development of reliable and sustainable biomass supply systems and the creating of markets for this biomass. Energy, food, water and land use nexus issues complicate planning and are a source of investment risk. The price of biomass will depend on scarcity and ownership structures. This is a structural source of uncertainty where technology learning can only help to a limited extent.
- The cost-effectiveness of renewable energy technologies depends on technology learning, fossil fuel prices and cost of capital. Cost of capital is in turn a function of risk. This includes policy stability risk, country stability risk, exchange rate risk and various other factors. Risk guarantees, insurances and green bonds are some of the financial instruments that can be deployed to mitigate risk. However, it is up to policy makers to minimise risk by providing a stable and credible policy framework.
- Implementation of REmap Options results in at least a doubling of the renewable energy share in thermal applications of the industry sector and a tripling in the building sector. This is dominated mainly by modern biomass, and to some extent by solar thermal resources. Compared to today's limited deployment, the estimated growth will be a particular challenge.

The discussion above provides an overview of factors that are of particular importance for meeting the global doubling objective. On the level of individual countries and sectors, the key parameters can vary.

The cost-effectiveness of renewable energy technologies depends on technology learning, fossil fuel prices and cost of capital.

The analysis points to the importance of hedging strategies, a portfolio approach and the need for continuous innovation. It also points to the fact that there is a need for active policy engagement to make the transition happen. Key components require enabling infrastructure such as biomass supply and logistics, an enabling electricity grid and EV recharging infrastructure.

Also a consideration is that the doubling in 2030 implies still nearly two-thirds fossil and nuclear energy in the mix by 2030. An ongoing transition beyond 2030 will require further efforts. It is likely that energy carriers such as electricity and hydrogen will play an increasingly important role, while structural change must continue towards reduced energy intensity and increased efficiency. New technologies will be needed to broaden the field of renewable energy applications, especially in end-use sectors.

Through a number of strategies and technology breakthroughs, the portfolio of renewable energy technologies can be expanded. Next, the infrastructure and technology development strategies as well as the innovation needs in view of the challenges ahead are discussed. These are represented by RE+ Options, which show how doubling the renewable energy share can be ensured – and possibly exceeded with a wider portfolio of measures.

3.3.10 Alternative approaches: Electrification (REmap-E) and uniform targets (REmap-U)

According to the REmap 2030 renewable energy technology portfolio, biomass is the most important resource among all technologies due to its ability to be used for power generation, biofuels, and thermal applications in the end-use sectors. It accounts for more than half of the total renewable energy use in 2030. If all REmap Options are deployed, about two-thirds of the total biomass use in REmap 2030 global TFEC would be for heating. The remainder one-third would be shared between liquid biofuel use in transport and bioenergy for power generation.

The REmap 2030 analysis shows that biomass resources are large. However, affordable and sustainable sourcing of biomass remains as an important question. Given the large biomass growth need between 2010 and 2030, optimising its use by deploying the most cost-effective and sustainable (*e.g.* greenhouse gas (GHG) abatement) options is critical. The deployment of alternative resources can help to reduce the dependency on biomass.

For heating, alternatives are limited. As discussed earlier, this is especially the case for industrial process heat generation because high temperature process heat can only be generated by biomass. In the buildings and district heat sector, solar thermal, heat pumps and geothermal are alternatives. Although REmap shows that they offer large potential, on-site land availability, access of plants/buildings to resources and costs are constraints.

Alternatives to biomass for power generation are plenty. Solar PV, onshore/offshore wind, CSP, hydro, geothermal, ocean/tide/wave technologies all have further potential beyond what is estimated in REmap 2030. Power sector policies should first start with the deployment of non-biomass renewable technologies. Biomass use for power generation should be instead considered with the aim of increasing dispatchable renewable power generation and help integrating variable renewables to the grid. Another option is to convert coal power plants to biomass ones (*e.g.* Drax power plant in the UK), a strategy for countries where coal plants are retiring and for those with large and young coal power plant capacity.

In the transport sector, liquid biofuels play by far the most important role to raise the sector's renewable energy share. Next to the use of biofuels, the contribution of electric vehicles and modal shift are small. However, both electrification options are commercially viable and their deployment could be accelerated instead of liquid biofuel growth.

New technologies will be needed to broaden the field of renewable energy applications, especially in end-use sectors.

Electrification also offers the potential to reduce fuel use for heating. The case of electrification (including modal shift in transport, electric heating/cooling with heat pumps, and industry relocation) is represented by *REmap-E*. In the industry sector, electricity-based process for the production of ferrous and non-ferrous metals, or hydrogen can save large amounts of fuel. In the buildings sector more heat pumps can be deployed to meet the space heating demand. With electricity being generated from renewables, and with a higher share of electricity in the end-use sectors, the renewable energy share can still be doubled even with lower deployment of bioenergy.

In view of the uncertainties around reaching the total biomass supply growth estimated in REmap 2030, electrification for doubling the global renewable energy share was analyzed. Electrification as a hedging strategy to reduce biomass dependency is represented by the RE+ Options along with other strategies, namely modal shift and industry relocation. By deploying these options in addition to the REmap Options, the global renewable energy share can be more than doubled.

In REmap-E, biomass demand is assumed to increase to 65 EJ by 2030 instead of 108 EJ in REmap 2030. This translates to a modest increase of approximately 10 EJ in biomass demand by 2030 compared to today's levels. This growth assumes that the biomass demand in the industry and transport sectors remain at the Reference Case level. Compared to REmap 2030, this is halving the demand in these sectors. In the building and power sectors, demand is assumed to be reduced even further; about one-third below the Reference Case in 2030 (partly also because of traditional use of biomass).

In REmap-E, heat pumps deliver the required heat in the building and industry sectors instead of biomass. In the transport sector, modal shift (public trams, electric buses and trains) replaces liquid biofuel. Increased electricity demand of the end-use sectors is supplied by additional solar PV and wind on/offshore capacity. Additional solar PV and wind capacity also generates the power which would have otherwise been generated by biomass. In REmap-E, some industry plants are relocated. New capacities for electricity-intensive processes, namely primary aluminum smelters, electric arc furnaces and chlor-alkali plants are moved to locations such as the Middle East and Africa, Russia and Greenland. This raises electricity demand in these regions and this demand is supplied by additional CSP with storage, hydro and geothermal power plants.

The electrification strategy – REmap-E – described above takes the global share of modern renewable energy to 30%, around the same share as estimated for REmap 2030 (30% with energy access factored in, but not energy efficiency). Hence a mix of different electrification technologies supported by modest growth in biomass use can result in a doubling of the global renewable energy share.

Total renewable energy needed to double the global renewable energy share reduces from 132 EJ to 118 EJ due to the higher efficiency of electrification technologies to provide the same energy service. Better efficiency also effects the TFEC worldwide at a similar magnitude, resulting in identical renewable energy shares in both REmap 2030 and REmap-E.

Other important changes in REmap-E concern the decrease in the share of biomass in total global renewable energy use from 60% in REmap 2030 to 42%. In comparison, the contribution of renewable power increases from 37% in REmap 2030 to 51% in REmap-E. At sector level, there are also important changes. The share of electromobility doubles compared to the case of REmap 2030. The share of biofuels is halved from 13% in REmap 2030 to 6% in REmap-E. Total biomass share for heating/cooking decreases from 40% to 32%.

Through electrification technologies, the renewable energy use to double the global renewable share in 2030 would be 118 EJ instead of 132 EJ.

Another strategy for doubling the global renewable energy share is represented by the case of *REmap-U*. In this case, all countries are assumed to reach at least 30% renewable energy share by 2030 regardless of where they stand today. While some countries would need to substantially increase their renewable energy shares from today's very low levels (*e.g.* UAE) to 30%, others would meet, or even surpass, this level according to their business as usual (Reference Case) development (*e.g.* Denmark, Brazil, Germany).

A number of technology options and strategies are required to ensure that all countries reach at least 30% by 2030. According to REmap-U, the first strategy is to reduce energy demand by the implementation of energy efficiency measures. Depending on the energy consumption growth of any given country and its current energy intensity, the reduction potential would differ. For fast growing countries a total energy saving potential of up to 10% is assumed compared to their Reference Case (three-quarters of the absolute energy savings are assumed for heating/transport fuels and 25% for electricity use). The second strategy involves utilising increased electrification technologies for countries which do not achieve 30% after the REmap Options and energy efficiency improvements are considered. These electrification technologies for each country are the same as those used in REmap-E, with the exception of industry relocation, which is not considered. However instead of the technologies substituting biomass they instead substitute fossil fuels. Finally if the country has not yet reached 30%, the third strategy is to make more use of biomass imported from countries which already achieved their 30% share. This requires international trade of even higher volumes of biomass. However total world biomass demand does not change, rather its use is shifted from one country to another. Therefore by improving energy efficiency, introducing electrification in the end-use sectors, and increasing biomass trade, all countries can achieve at least a 30% renewable energy share.

Figure 3.18 compares the renewable energy share of REmap countries according to the cases of REmap-E (dark orange bars) and REmap-U (light orange bars) with REmap 2030 (green bars) and the Reference Case (blue bars). In REmap-U, all countries reach at least 30% renewable energy share. Denmark, Brazil, Germany, Canada and several others reach even higher shares as their Reference Case is already higher than 30%. As a result the global renewable energy share in REmap-U reaches 32% even before energy access needs are considered. Some countries need to make an enormous effort compared to their current levels and even beyond their national plans such as Russia, South Korea or Saudi Arabia.

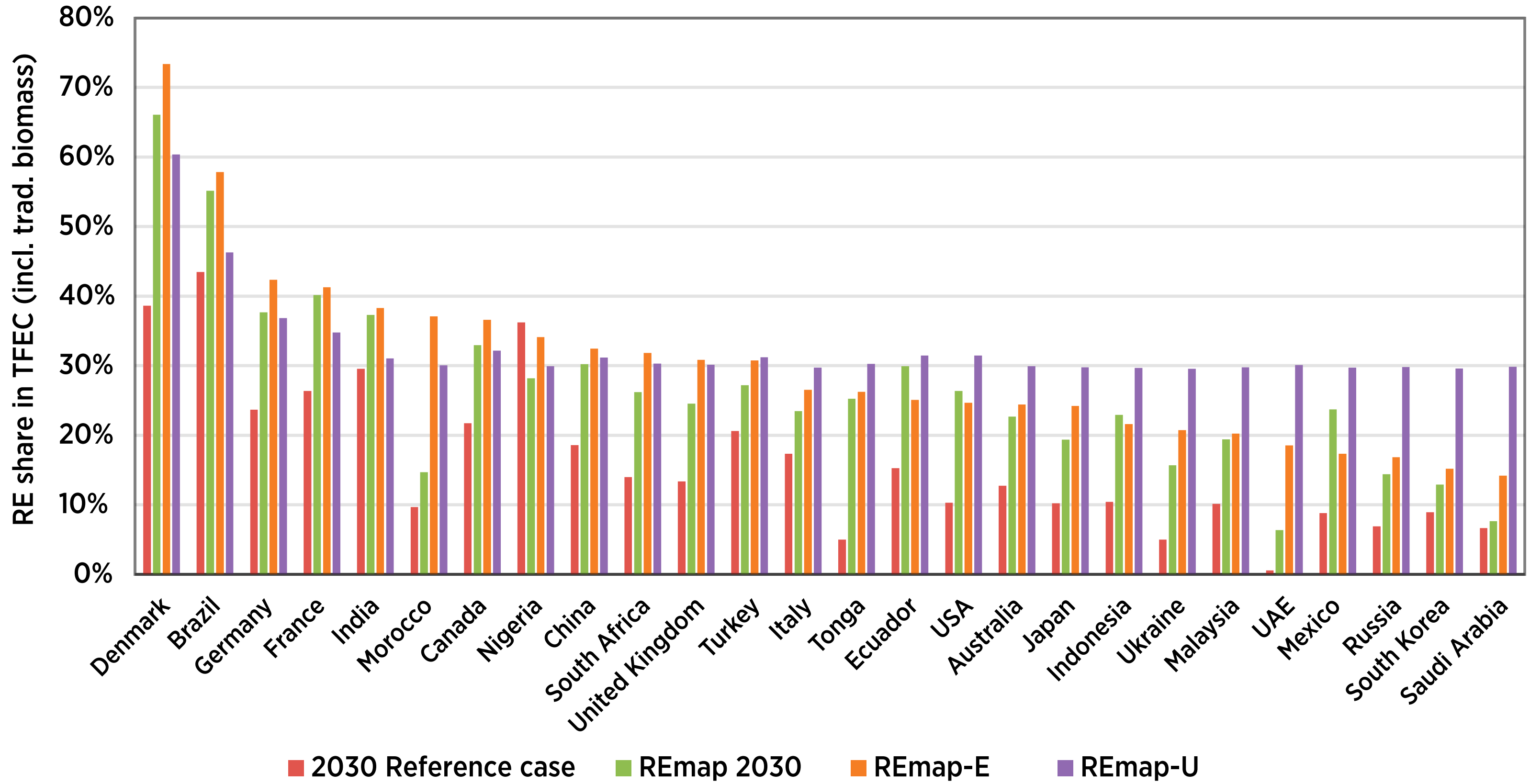
In REmap-E, electrification takes the renewable energy share of most countries higher than what is achieved in REmap 2030. In some others (*e.g.* the US, Indonesia), REmap-E is slightly lower than REmap 2030. This is explained by the fact that the amount of biomass in the REmap Options is considerable and difficult to meet with electrification technologies alone. In the case of the US, large additional potential of biomass for industrial process heat generation is assumed as REmap Options, and in Indonesia there is a large amount of additional liquid biofuels potential. While efficient electrification technologies supplied with renewable power generation capacities fulfil the same useful demand, the amount of final energy required is lower compared to REmap 2030.

Electrification in end-use sectors results in an increase in the installed renewable power plant capacities since all renewable electricity demand is supplied via renewable sources (Table 3.6). Total global installed renewable power capacity increases by nearly 60% from about 4 870 GW_e in REmap 2030 to 6 455-8 055 GW_e in REmap-E. The installed capacity for solar PV and CSP triples. Global solar PV reaches 2 500-3 600 GW_e and solar CSP 290 GW_e. Wind onshore/offshore capacity also increases from approximately 1 635 GW_e to 1 900-2 400 GW_e. Compared to REmap 2030, much higher growth in capacity deployment is required but these totals heavily depend on how the increased power generation sourcing need is allocated. However, what is clear is that there will be a need to integrate even higher penetrations of variable renewable, and this could present a challenge to for REmap-E. In REmap-U, there is no change in biomass demand, but an increase of about 10 EJ in international biomass trade. The increase in renewable power capacity (solar PV and wind) is also limited.

Table 3.6 Global biomass demand and trade and power generation capacity

	REmap 2030	REmap-E	REmap-U
Total biomass demand (EJ/yr)	108	65	108
Biomass trade (EJ/yr)	23–40	5–15	35–50
Hydro (GW_e)	1600	1640	1600
Wind onshore/offshore (GW_e)	1635	1900–2 400	1650–1800
Solar PV (GW_e)	1250	2 500–3 600	1600–1900
CSP (GW_e)	83	290	83
Biomass (GW_e)	390	125	390

Figure 3.18 Comparison of renewable energy shares in Reference Case, REmap 2030, REmap-E and REmap-U by countries



Improved energy efficiency, introducing electrification in the end-use sectors, and increasing biomass trade, would be needed to achieve at least 30% renewable energy share in all countries.

The substitution costs of transport modal shifts and industry relocation would be much higher compared to the biomass-based technologies. However, heat pumps costs are comparable. In some cases more passengers can use the existing tram and train network at zero additional cost. However achieving the substantial modal shift in transport according to REmap-E requires investments in the development of new vehicles and infrastructure.

Initial estimates have the global average substitution costs increasing from USD 2.5 per GJ in REmap 2030 to about USD 5-12 per GJ in

Table 3.7 Comparison of the global renewable energy share and costs

	RE share in TFEC (%)	Substitution cost (USD2010/GJ TFEC)	Incremental system cost (bln. USD in 2030)
2010	18%	NA	NA
2030 Reference Case	21%	NA	NA
REmap 2030	30%	2.5	133
REmap-E	30%	5-12	205-500
REmap-U	32%	3-10	180-600

REmap-E (Table 3.7). This is equivalent to net incremental system costs of USD 205-500 billion per year. Compared to REmap-2030 costs of USD 125 billion, this is an increase of USD 80-375 billion per year in 2030.

Costs of REmap-U are also estimated to be higher than REmap 2030. According to Table 3.7, substitution costs of REmap-U are estimated to be USD 3-10 per GJ, and the related net incremental system costs at around USD 180-600 billion per year in 2030. There are two reasons to this increase. The first one relates to the increase due to modal shifts. The second one, and the more important, is related to the international trade of biomass which is required to raise the renewable energy share in all countries to 31%.

3.4 RE+ Options: Going beyond a doubling

3.4.1 A portfolio approach to deal with uncertainty and risk

The previous chapter has shown the main challenges, uncertainties and risks for successful deployment of the portfolio of technologies according to the REmap 2030 roadmap.

The set of power sector transition options – 40% of the total modern renewable energy uptake to raise its renewable energy share worldwide to 44% by 2030 – is robust compared to those in the three end-use sectors.

Doubling the global renewable energy share by 2030 relies heavily on the success of biomass. More than 70% of the total biomass potential is located in heating and transportation applications. If the biomass-based transition in the end-use sectors does not materialise, other renewable energy carriers must be considered. These strategies include:

- More electrification: heat pumps for heating, direct use of electricity as a fossil fuel substitute;
- Production of hydrogen, biogas and/or synthetic natural gas and delivery through existing gas pipeline systems;
- Wider use of district heating systems in combination with renewable heat generation;
- More-seasonal heat and cold storage;
- Relocation of demand to centres of supply: for example, move industry to hydropower locations and arid locations with solar power;
- Adjust demand to meet supply: redesign industrial processes to use variable renewable electricity (*e.g.*, steel making and water desalination); ensure that future buildings are energy efficient and able to operate with low-temperature heat supply.

These strategies are either more costly or require a longer gestation time, as the technology solutions are not mature. Likewise, the life span of existing capital stock extends well beyond 2030; therefore, existing plants have not been included in the core group of REmap Options.

More than 70% of total biomass potential lies in heating and transportation applications.

There could also be breakthroughs in some technologies selected already among the REmap Options, or their deployment could fail. These developments would also affect the global renewable energy share.

The rest of this chapter elaborates on the strategies which would be required to deal with the uncertainties and risks and how the portfolio of technologies can be broadened for doubling the global renewable energy share and going beyond.

Strategy 1: Increase the share of electricity use in end-use sectors

Modal shift

In the REmap Options, a large share of land transportation for passengers and freight still operates with engines combusting either biofuels or fossil fuels. The share of electricity use in the transport sector remains small but could be increased in a number of ways. Passengers travelling by plane or car could switch to high-speed trains, electrified public transportation, electric vehicles or sharing schemes. Truck-based long-range freight transportation can also be replaced by trains in many cases.

Demand for some travelling can also be reduced to some extent with sustainable city planning, if, for example, commuters can travel shorter distances with bikes or trams.

Free parking for electric vehicles in cities, expanded rail freight possibilities and better urban public transportation (*e.g.*, subways, trams) are some examples of policies to accelerate modal shifts. Large infrastructure development to support such a transition will be required.

Electrification

The share of electricity use in the building and transport sectors increases in the REmap 2030 by about 4-8 percentage points to about 30% by 2030, a relatively modest increase, but the electricity share can be increased further to meet the heating and cooling demand of both sectors. Efficient deployment of electricity is key – for example, based on heat pumps.

It is already common in the primary aluminium sector for smelters to be located next to hydropower plants to ensure the continuous supply of cheap electricity, *e.g.* in Iceland, Norway and Mozambique (Reinaud, 2008). Where aluminium production is expected to grow, the relocation of plants next to renewable electricity plants is an option considered in this study. New industrial process technologies can be developed to substitute heat-based production processes (discussed under breakthrough technologies).

The thermal efficiency of buildings can be improved significantly with Passive House architecture for new builds to reduce demand for fuels. With increased use of efficient electric appliances for heating, cooling and cooking (*e.g.*, heat pumps and electric cook stoves), the electricity share in buildings can be increased further.

Strategy 2: Early retirement

Renewable energy deployment depends on the current age of the capital stock and how much of that will exist by 2030. Forty years is a typical

Box 3.4 Bio-based feedstocks

This study does not assess the substitution potential of fossil fuels as feedstocks for chemical and polymer production because these are excluded from total final energy consumption (often referred to as "non-energy use" in energy statistics). Today, fossil fuel feedstock represents about 5% of the total primary energy supply. With increasing demand for polymers in different branches of the economy (*e.g.*, packaging, transportation and construction), demand for feedstock will gain more importance in the next few decades. Biomass offers the only alternative to the use of fossil fuels in feedstock applications.

Biomass can be used to produce all types of chemical and polymers, such as polyethylene terephthalate (PET) used in bottles, or ethylene which is the building block of the organic chemical sector. Today, the global capacity of bio-based polymers has reached 1.4 million tonnes (EB, 2013), about 0.6% of global polymer production. An example of bio-based chemicals produced today is polylactic acid (PLA), an alternative to PET (Shen, Haufe and Patel, 2009); research also focusses on the development of other alternatives such as polyethylene furandicarboxylate (PEF) (Avantium, 2014). A plant in Brazil also produces bio-based ethylene from the dehydration of sugar cane-based ethanol. There are many opportunities in the future for bio-based feedstocks to gain a larger market share, as R&D shows.

Consideration of wood and natural fibre-based materials as a substitute for synthetic organic materials and wood as building materials to substitute for bricks and concrete are other options for biomass to substitute bulk materials.

technical life span for power plants, for example. In that case, around 60-65% of the existing fossil fuel and nuclear capital stock will still be in operation by 2030, while the remaining 35-40% will be eligible for replacement. If early retirement of the remaining capacity is considered, the potentials for renewables would grow substantially. As with power plants, a large share of the global stock of gas pipelines, refineries, buildings and industrial plants will remain in operation by 2030. Early retirement in these sectors would create additional potential for renewable energy.

Early retirement of existing plants can accelerate the deployment of renewable energy in final energy consumption.

Strategy 3: Emerging and breakthrough technologies

Hydrogen as renewable energy carrier

Hydrogen produced from renewable electricity or biomass to be used in fuel cells is a renewable and energy efficient alternative to internal combustion engines in transportation. Limited amounts of hydrogen can be added to natural gas pipelines for industrial use. Hydrogen can also be used as a raw material for the production of various chemicals, such as ammonia or methanol. Hydrogen can also be used as an electricity storage medium.

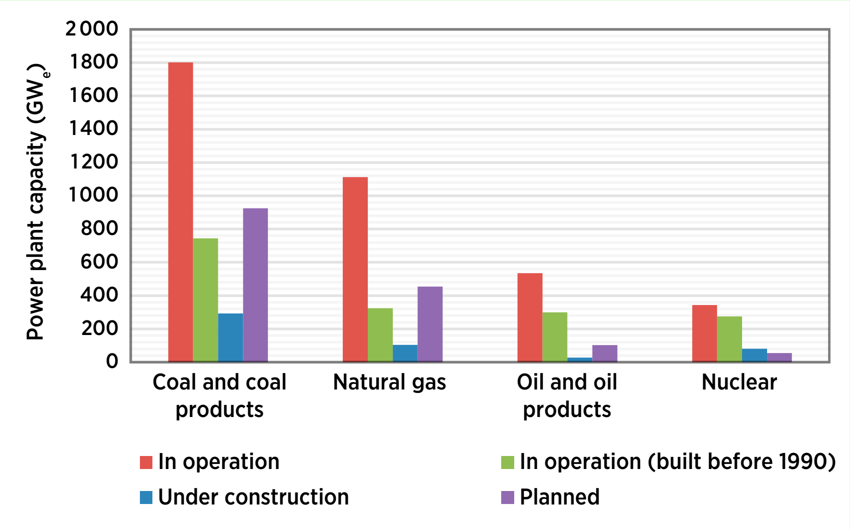
Box 3.5 Age of capital stock, planned investments and early retirement

Figure 3.19 shows the age profile of existing fossil and nuclear power plants in the Platts database, representing a total of nearly 4 000 GW_e (Platts, 2013).

Coal-fired power plants account for nearly half of the total existing capacity (1 800 GW_e), and nuclear power plants for about 10% (340 GW_e). If today's planned capacities are all realised in the coming years, total installed fossil fuel and nuclear power plant capacity would increase by 40% to 5 330 GW_e. Most planned capacity is related to coal-fired plants (925 GW_e). This would raise the total existing coal-fired power plant capacity by half. Planned natural gas-fired plants (450 GW_e) represent about 40% of its total existing capacity.

More than 85% of the total planned coal-fired power plants, and about half of all planned nuclear and oil-fired power plant capacities, are in China, India and other developing Asian countries. Planning procedures are flexible and efficient in some of these countries, which would allow the planned fossil fuel and nuclear capacities to be adapted with renewable alternatives if there is sufficient push from policy makers. For other regions, renewable energy strategy and policies are required to avoid construction of these planned capacities and instead to deploy renewable energy technologies.

Figure 3.19 Age profile of existing fossil and nuclear plants



Source: IRENA analysis based on Platts (2013)

The average age of the capital stock worldwide ranges from 18 years (natural gas) to 27 years (nuclear). The newest plants (mostly younger than 20 years) are in Asia, Latin America and the Middle East. The oldest plants are in Europe and North America (Platts, 2013).

Forty years is a typical technical life span. Plants can run longer, for example because of the difficulties in construction (e.g. nuclear power plants), but then usually require major refurbishment. Figure 3.19 shows that around 40% of coal capacity, a quarter of natural gas, more than half of all oil capacity and four-fifths of nuclear capacity will be more than 40 years old in 2030 and therefore eligible for replacement in the REmap analysis. Around 35-40% of existing fossil and nuclear capital stock is eligible for replacement.

The share of capacity in each world region that would be eligible for replacement depends on the age of the capital stock. With the exception of Asia, Latin America and the Middle East, more than 70% of the coal capacity worldwide was built before 1990. Only the economies in transition have a high share of natural gas power plants built before 1990 (70%). For nuclear power plants, Asia and Latin America countries have only 30% built before 1990, while more than 80% of the plants in other regions were built before 1990.

While these capacities will be eligible for replacement, demand will also continue to grow, as will total installed capacity – from 5 183 GW_e today to somewhere between 8 000 GW_e and 9 000 GW_e. The number will depend on the type of technology deployed; variable renewables will have a lower capacity factor, so more capacity will be needed to arrive at the same output. Thus, around three-quarters of total power generation capacity in 2030 represents the market potential for renewables, if early retirement of existing plants is excluded.

Figure 3.18 also shows the new capacities which are considered or planned to be built in the coming years: 1 000 GW_e of new coal, 450 GW_e of gas and smaller amounts of oil and nuclear. More coal and natural gas capacity is planned compared to the total capacity that could potentially be retired by 2030. Coal and natural gas power plants will thus remain important in most parts of the world. The majority of new coal capacity is planned in China. Most natural gas plants are planned in Asia, Europe and North America (more than 60% of the total planned capacity worldwide).

The average age of manufacturing industry plants is similar to that of power plants when world regions are compared (see Table 3.8) – in the OECD countries, between 20 and 30 years for various sectors. The plants in developing countries are newer in comparison. Economies in transition have the oldest capital stock. Production growth in the next two decades is projected to be limited in most OECD countries. The largest growth is projected to be in India and other developing Asian, African and Latin American countries. Worldwide, 50-60% of the existing capacity is estimated to remain in operation by 2030 (IRENA, 2014d).

There is a large potential for integrating production processes with renewable energy technologies in new plants to generate process heat, especially in non-OECD countries. In comparison, the potentials in OECD countries is lower and can be realised only when new plants are built to replace the aging capacity that should retire in coming decades. However, revamps could extend the lifetimes of these plants, limiting the integration potential for renewables in these countries even further.

Table 3.8 Average age of industry sector facilities by region

	OECD Countries	Developing Countries	Industrialised Developing Countries	Average Lifetime
	age in years			
Iron and steel	25-35	15-20	40	65
Chemical and petrochemical	20-30	10-15	25-30	40
Pulp and paper	20-25	10-25	20-30	40
Non-ferrous metals	25-35	15-25	30-35	50
Non-metallic minerals	25-35	15-20	35-45	50

Source: IRENA (2014d)

Much of the existing coal and nuclear gas capacity will continue to operate by 2030. The market potential for renewables could be higher if some of these plants are retired before their planned amortisation date. Unfortunately, early retirement of existing plants tends to be expensive. For example, electricity production from a wind plant in China is estimated to cost USD 6.5 cents per kWh, 50% more than the production costs of a new coal plant in China (USD 4.4 cents per kWh). Thus the substitution of a new coal plant with a wind plant in China costs USD 6 per GJ of final energy. If an existing coal plant were retired before its life time instead (generation cost of USD 1.8 cents per kWh), the substitution costs could be as high as USD 15 per GJ (based on competition with incumbent marginal cost). While early retirement of existing plants offers further potentials, they would come at a much higher cost.

3

Synthetic natural gas

Synthetic natural gas (SNG) is a renewable alternative to fossil-based natural gas. It can be used directly in existing natural gas grids. SNG can be produced from the gasification of biomass and cellulosic material. It is also similar to the application of upgraded biogas and can be used in all applications where natural gas is used today, such as power and heat generation. The size of SNG plants is expected to reach up to 200 MW. In Sweden, E.ON is building a plant for the high-temperature gasification of second-generation biomass from forests for SNG (the "Bio2G" project). The plant is expected to start operation in 2015 (EBTP, 2013). Biogas upgrading and pipeline injection is growing, for example in Germany and Sweden.

The REmap Options show that a mix of technologies must be deployed in the next few decades. Continuing to increase the renewable energy share in the global energy mix beyond 36% will require different strategies and breakthrough technologies. New energy policies will be required, barriers for renewable energy deployment need to be eliminated, and innovation in technology development will be key. Because the development of new technologies can take decades, an innovation push is needed now if the renewable energy share is to grow further.

3.4.2 The need for innovation: patents, RD&D, technology transfer and quality assurance

REmap 2030 suggests that it is possible to double the global renewable energy share. However, there is still a two-thirds reliance on non-renewable energy. Part of that will be resolved over time as old capital stock retires, but part of energy use is in markets where renewables have a difficult stand because of economics and technical feasibility. These include, for example, the substitution of fuels for aviation and shipping, fuels used for process heat generation and as feedstocks industry, and to an extent the fossil fuel demand of the existing building stock.

It does not mean that if a technology has considerable potential, it will be deployed at that same magnitude in 2030. Moreover, there is no guarantee that all emerging technologies today will reach commercial readiness in the coming years. For these reasons, technological research and innovation are crucial to develop new renewable energy technologies that will allow going beyond a doubling and developing cost-effective alternatives to fossil fuels. Innovation is not limited to technology. Governmental support and investment in technological R&D is required to ensure both the development of new technologies and the improvement and deployment of mature and existing technologies.

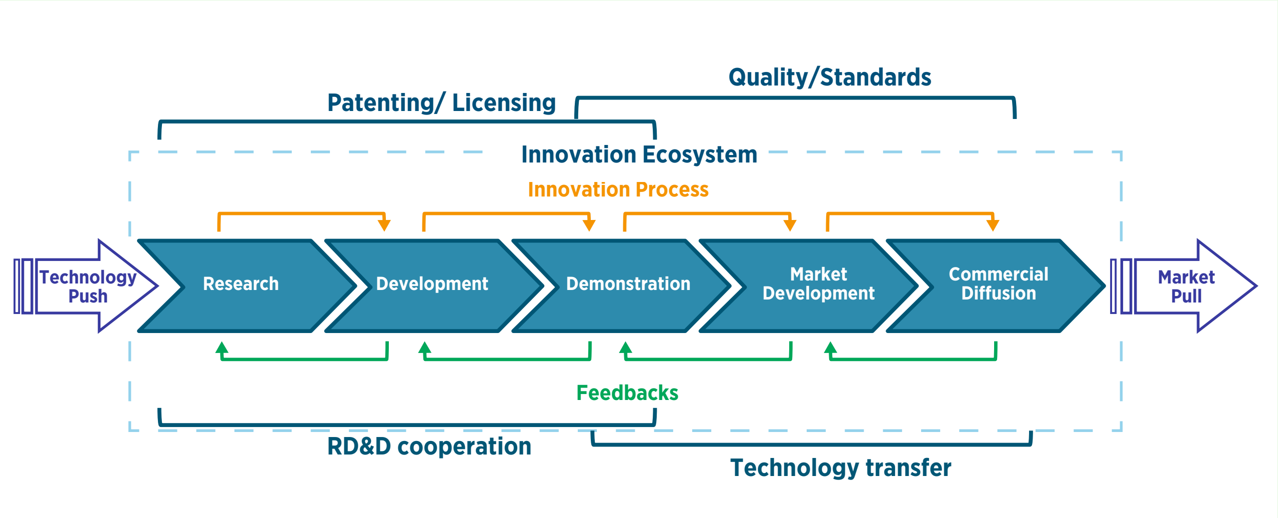
Both emerging and existing technologies require innovation for further development and deployment.

Examples of emerging possibilities for basic and applied R&D are found in areas such as advanced methods for geothermal extraction at low atmospheric pressure, new materials for thin film solar cells, organic and hybrid solar PV, bio-refineries, energy storage, solar thermal facades and innovative mechanisms for wave energy conversion (EC, 2013). Various governments have already identified these R&D opportunities and invested substantial financial efforts and human resources to stimulate the deployment of innovative technologies.

One example of these endeavours is the UK's commitment to the development of ocean technologies by granting and funding RD&D, analysing mechanisms to de-risk pre-commercial arrays of ocean energy technologies and streamlining the licencing process of the technological prototypes that have already overcome the "valley of death" in the innovation process. Also, Germany recognises technology innovation as a crucial element in its energy transition (*Energiewende*) to reach a share of 80% renewable energy in the power sector by 2050 (Böll Foundation, 2013a).

During the last two years, IRENA has worked on some of the specific instruments listed, such as RD&D co-operation, technology transfer, Quality Infrastructure (QI) and Intellectual Property Rights (IPR). Figure 3.20 shows the points of intervention of the four innovation instruments in the life cycle of technologies.

Figure 3.20 Innovation in the technology life cycle



Patenting and licensing, high-quality infrastructure, research and development co-operation, and technology transfer are the main means of innovation instruments in the technology life cycle.

Source: Adapted from Tawney et al. (2011)

RD&D co-operation applies to the first stages of the technology life cycle (basic and applied R&D/demonstration phases). Here, co-operation reduces investment costs and adapts technologies to local needs. Co-operation among countries, sectors (private and public) and institutions (intergovernmental organisations, non-governmental organisations and academia) helps to transmit knowledge, scale up technologies, finance RD&D, better use human resources, enhance access to decision makers and opinion leaders and create critical mass and continuity.

Technology transfer fosters demonstration, market development and commercial diffusion. It stands for "the making available to a recipient of industrial and agricultural processes and products and the relevant enabling technology for practical realisation". Some of the means by which technology transfer is achieved are 'the disclosure of results from research and development, the licensing or assignment of intellectual property rights related to such results, exchange of information, education and training, and joint ventures' (OECD, 1996).

QI certificates appraise conformity agreements for quality services: metrology, standardisation, testing, certification and accreditation (Harmes-Liedtke and Oteiza Di Mateo, 2011). QI enables long-lasting technological solutions by reducing the replacements needed in technological plants and equipment, thus directing the capital that would be aimed at repairing infrastructure towards the deployment of new technology. In this way, QI reinforces the reliability of renewable energy technology markets and helps spread awareness about technological achievements and the fulfilment of energy needs (Gonçalves and Peuckert, 2011).

IPR, patents and licences boost innovation by ensuring that inventors have a certain monopoly over the benefits of their creations. Researchers and investors cover the large expenses that R&D activities entail in this way. On the other hand, extreme IPR may slow down innovation growth. Further investigation of the role of patents and their use for accelerated renewable energy dissemination and deployment is needed (IRENA, 2013h). For example, the role of patent information in the development of new technologies is an issue for debate.

Technological innovation is crucial to push the current trends of renewable energy deployment to commercial scale. However, penetration of novel technologies in technology markets is a lengthy process. Therefore, strengthening the efforts to boost technological innovation today is essential to see commercial technology solutions in decades to come.

Reaching technology readiness requires significant investments in R&D, co-operation of the principal actors and stakeholders, creation of networks, as well as time. Table 3.10 shows that the time for innovation to commercial readiness is higher by a factor of three in the energy sector (10-15 years) compared to, for example, the information and communications technology (ICT) and telecommunication sectors (1-5 years). This means that if R&D starts now, it will reach maturity for market uptake only after 2030.

Table 3.9 also shows other differences in innovation in the energy sector compared to others. Such differences include the high capital required to innovate and the low risk tolerance. These differences indicate that experience from other technology sectors cannot be used simply as a reference for the energy technology sector when discussing the challenges towards and pace of technology innovation and transformation. The aforementioned characteristics of innovation in the energy sector need to be addressed when designing plans and support mechanisms to develop and commercialise renewable energy technologies.

Reaching commercial readiness means that a technology is ready to start its path towards commercialisation. However, this does not imply a significant penetration rate in the market. In fact, experience in the energy sector has shown that obtaining a considerable market share could require a longer time than all other steps of technology development combined.

A number of examples can be further discussed to understand how innovation played a role in the development of some of today's commercialised technologies in the energy sector. Examples include wind turbines, solar PV, sugar cane ethanol and EVs. These are also among the key technologies, according to REmap 2030, which contribute to doubling the renewable energy share in the global energy mix.

Table 3.9 Innovation in various sectors

	Pharmaceutical	Software & IT	Energy
Time Required to innovate	10–15 years	1–5 years	10–15 years
Capital Required to innovate	Medium to High	Low to Medium	High
New Products Primarilly Differentiated By	Function/Performance	Function/Performance	Cost
Actors Responsible for Innovation	Large Firms Reinvesting in R&D; Biotech startups, often VC & govt. funded; Govt. (NIH, NSF)	Dynamic Startups, often VC-funded; Large Firms Reinvesting in R&D	Various: Utilities, Oil & Gas Co.s, Power Tech Co.s, Startups, Govt.
Typical Industry Risk Tolerance	High	High	Low
Innovation Intensity	High	High	Low
Intellectual Property Rights	Strong	Modest	Modest

New energy sector solutions take 10-15 years for commercial readiness followed by a period for market uptake. Innovation needs to start today for technologies to be ready for deployment by 2030.

Source: Adapted from Jenkins and Mansur (2011)

In Denmark, the pioneer wind power developers initiated research on connecting existing wind turbines to the country's grid in the late 1940s. However, it took decades to achieve an installed capacity of several gigawatts in the 2000s (Boshell, 2006; EERE, 2013; EPIA, 2013; GWEC, 2012). Basic R&D played an important role in wind technology development, in particular in the innovation of blade materials. But there is more room for innovation, such as in improving the efficiency of turbines. The development of laser wind turbine control systems to measure the speed and direction of the approaching wind could allow for better yaw control and increase power production (Schlipf *et al.*, 2011). Failure of gearboxes and other components are among the main reasons behind increased operation and maintenance (O&M) costs and thereby the levelised cost of energy (LCOE) of wind turbines. Digital displacement transmission technology, for example, eliminates the need for a gearbox (Sharpley, 2013).

Although the capital cost of the technology is currently more expensive, reductions in O&M costs are significant. Also, new developments in electrical generators and materials (*e.g.*, for magnets) are important to enable the integration of larger machines in power grids. Developments in batteries are important for off-grid applications and for generators that need to adhere to strict generation profiles. In the coming years, innovation will need to focus on resolving how huge wind turbines in a global market can be transported.

For solar PV, innovation has focussed not only on technology development, but also on support mechanisms to leverage economies of scale and reduce costs by two orders of magnitude. This process took five decades. During the 1970s and 1980s, technology development was dominated by R&D in efficiency improvement and manufacturing processes of crystallised silicon PV panels. An additional decade was required for market formation. In order to make the jump from R&D to an initial penetration in the electricity market, the focus tended towards manufacturing economies of scale through long-term demand programmes. From the early 2000s on, efforts were expanded to reduce installation costs.

Although R&D played a major role in the first two decades of PV uptake, an additional 30 years were required to put in place all the elements attributed to the success of the technology. Apart from R&D, these essential elements consisted of long-term demand subsidies, niche market formation and industrial co-ordination (Nemet, 2012). Innovation will continue to play a role in reducing the costs of and deploying new technologies to improve the efficiency of solar PV, such as multi-junction solar cells. Other emerging technologies include organic materials or nanowire-based solar cells. Recent developments in tandem and organic solar PV cells have focussed on their increased flexibility and the comparatively easy manufacturing process, which allow for rapid scale-up.

Next to wind and solar PV developments, marine-current plants are progressing rapidly. The importance of continued development of enabling technologies for the power sector, particularly power electronics, smart grids and storage systems, is also essential. For a real transformation of the power market into a renewables-based one, innovation will need to encompass a portfolio of technologies.

The case of bioethanol in Brazil reveals that more than three decades of intensive co-operation between the government and the private sector reduced bioethanol production costs, making the fuel cost competitive. The cornerstone of the existing ethanol industry is technological and agricultural basic and applied research, which enabled innovation 1) in the development of different phases of agricultural production, such as new varieties of cane, planting systems and fertiliser application; 2) to improve the conversion efficiency of sugar cane to ethanol and 3) to improve heat and power generation from bagasse. In addition, bioethanol subsidy policies need to be adapted to meet diverse market requirements. The first articulation of these policies occurred in 1975. Current bioethanol policies incentivise supply, regulate demand at fixed prices, provide consumer incentives, and reduce taxes and licencing fees on bioethanol and flex-fuel vehicles.

At the same time, the Brazilian government co-operated closely with the national oil company, Petrobras, to implement these policies. The monopoly of bioethanol distribution was conceded to Petrobras, so subsidies were collected from fossil fuel distributors and delivered to bioethanol producers. More than 40 years of combined and intensive research and policy application were needed to make bioethanol a commercially competitive fuel and to support it with a well-developed industry (Meyer *et al.*, 2012).

Innovation needs to meet the six-fold growth in liquid biofuels demand, according to REmap 2030, are in the areas of developing advanced biofuels and alternatives to fossil fuel use in shipping and aviation. Combined bio-processing and research on enzymes are reducing the production cost of biofuels using cellulosic feedstock. Three commercial cellulosic biofuel plants are already in operation, the most recent one in Crescentino, Italy, with an estimated annual production capacity of 75 million litres of cellulosic bioethanol. This progress will enable the use of a variety of feedstocks which will not compete with food production, and will create new opportunities for biomass availability in semi-arid lands. The development and commercialisation of multi-output bio-refineries for the production of chemicals and paper next to biofuels is another area that innovation should focus on.

Additional challenges related to the deployment of innovative renewable energy solutions are technology lock-in and failure risk. The current road transport regime is based on an infrastructure that has supported the use of internal combustion engine vehicles since the 19th century. The possibility of electric vehicles to escape the lock-in of liquid fuel-based cars remains limited. On the contrary, investments in R&D, which only gradually improves the features of internal combustion engines, surpass by far the funds in EV R&D. Limited range and lower maximum speeds for EVs than conventional cars remain key technical challenges to be addressed by innovation. Furthermore, the lack of infrastructure (public charging stations) for EVs has curbed their deployment. Nevertheless, technically, EVs are reliable and ready to be commercialised. Important breakthroughs in batteries and fast-charging have been made in recent decades. Car consumers are also substantially evolving towards more environmentally friendly means of transport. These steps towards a transition in the road transport sector maintain the EV as a technology with high potential in the future transportation market.

Although there are numerous emerging technologies, there is always an associated risk of failure, and not all emerging technologies of today will become successful in reaching full commercial readiness. Two examples are biomass gasification and pyrolysis. Trials of biomass gasification and co-gasification report outstanding results in converting various types of biomass into fuels, heat or power. To some extent, technical issues have limited the deployment of gasification, but the main challenge is the high cost of gas cleaning (Simell *et al.*, 2009). With regard to pyrolysis, bio-oil has a complex structure and the main challenge has been identifying viable applications, as existing combustion equipment and engines may not readily accommodate the fuel based on its properties (E4tech, 2009).

Not all emerging technologies will reach full commercial readiness. Innovation and technology development depend not only on technological factors, but also on political, economic and social factors.

The cases described above show that innovation and technology development depend not only on technological factors, but also on political, economic and social factors. The time that R&D entails, together with investments and the co-operation of stakeholders, influence the innovation and commercialisation rates.

In conclusion, new energy sector solutions take 10-15 years for commercial readiness followed by a period for market uptake. Therefore, innovation needs to start today for technologies to be ready for deployment by 2030. Policies need to focus on all emerging technologies and options since only a few technologies will become successful, and future success or failure is difficult to predict. Innovation should also focus on incremental improvements in existing technologies which are equally important in improving efficiencies and reducing costs.

Key points

- Including net fuel cost savings, REmap 2030 will require net incremental system costs of US Dollar (USD) 93 billion per year above the Reference Case in the 26 REmap countries. Important learning effects help to keep costs down, as the costs of solar and wind in particular will continue to fall.

- Net incremental investment needs above the Reference Case by 2030 amount to USD 200 billion per year. More than 60% of this is in the power sector, 30% in the building and 10% in the industry sector. The subsidy needs for renewables more than double to USD 238 billion in 2030 in the 26 REmap countries, especially in the power sector (80% of the total), with solar PV and wind accounting for more than 80% of the sector's total. The transport sector's subsidy needs are largely for electrification and advanced biofuels.

- Global fossil fuel use will grow by approximately 39% between 2010 and 2030 in the Reference Case. Implementation of all REmap Options could reduce this growth to 12%. Total renewable energy supply will exceed individual coal, oil and gas demand.

- Renewables will offset more coal consumption by 2030 than it offsets natural gas and oil combined. Coal use can be reduced by about 26%, and gas and oil use by 15%, compared to the Reference Case in 2030. As demand for fossil fuels declines compared to increased renewable energy use, prices of fossil fuels will also fall.

- The Reference Case CO_2 emissions of 41.4 Gt in 2030 could be reduced by 8.6 Gt through the full deployment of the REmap Options. REmap Options together with energy efficiency could reduce total CO_2 emissions to nearly 25 Gt by 2030. This could keep the CO_2 concentration in the atmosphere from surpassing 450 parts per million (ppm).

- Consideration of external effects reveals significant net savings of USD 2.3-13.8 per GJ of additional renewable energy for all REmap Options. These benefits exclude reduced fossil fuel subsidies and fossil fuel price decline benefits, and should be considered a conservative estimate.

- Deployment of all REmap Options will result in 3.5 million additional jobs in renewable energy between today and 2030, equivalent to 0.9 million net jobs added for the whole energy sector. This is one example of macroeconomic benefits. Trade balance and economic activity are to be assessed.

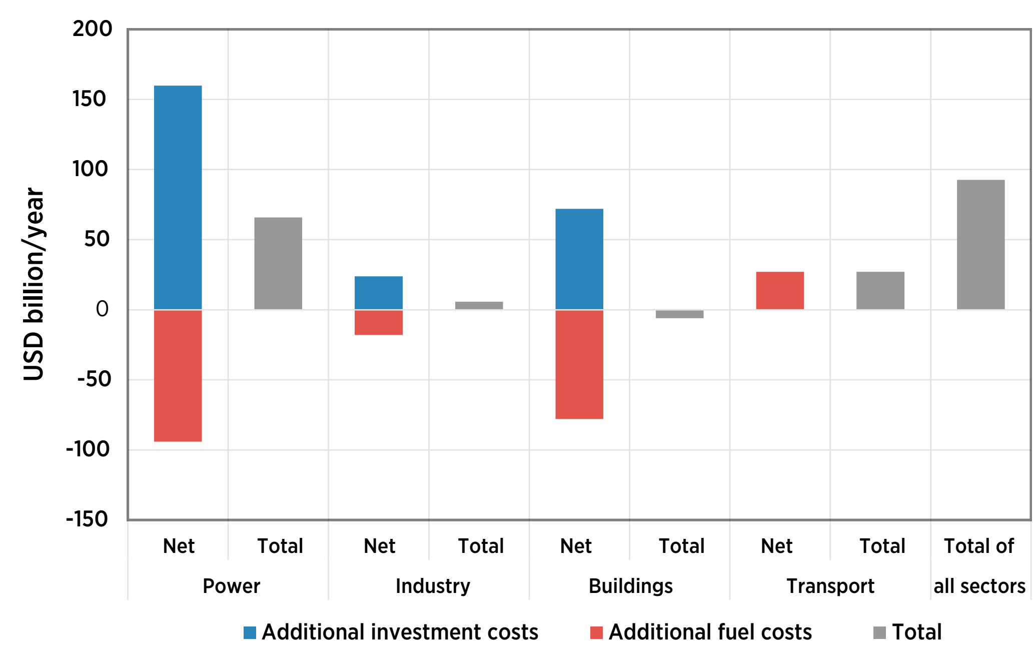
- It is important to consider renewable energy and energy efficiency jointly in order to raise the renewable energy share.

This chapter is divided into three parts. **Chapter 4.1** estimates the total costs of doubling the global renewable energy share by sector and technology. **Chapter 4.2** presents the benefits from incorporating externalities related to climate change mitigation and improved human health due to reduced fossil fuel use. **Chapter 4.3** discusses the socio-economic benefits from increased renewable energy use in REmap 2030.

4.1 Policy cost analysis

Along with basic awareness, a lack of accurate, reliable data on the cost and performance of renewable technologies is a significant barrier to their uptake. IRENA's cost-analysis programme and publications to date are a response; IRENA has the most robust and up-to-date assumptions. Renewables are becoming competitive with fossil fuels in countries across the world and are already the least-cost option in a growing number of markets. Data for current costs are extracted from the IRENA Renewable Cost Database where available, or from other sources if no coverage is available for that particular REmap country. Projections of cost trends to 2030 are based on extending previous analyses conducted by IRENA for 2020 or 2030. Chapter 4.1 focuses on the results of the 26 REmap countries only, but not for the world as a whole.

Figure 4.1 Annual average incremental capital cost and fuel savings for REmap Options by sector in the 26 REmap countries, 2010–2030



4.1.1 Total incremental costs

Total incremental systems costs in the REmap 2030 over and above the Reference Case average USD 93 billion between now and 2030 for the 26 REmap countries. The blue bars in Figure 4.1 represent the annualised incremental investment cost; the orange bars represent fuel savings. In absolute terms, the incremental investment costs amount to USD 4 trillion from 2010 to 2030. The investments will increase over time as prices come down, so incremental investment needs will amount to an additional USD 200 billion per year in 2030.

The largest single contributor to total incremental costs is the power generation sector, due to the relatively high share of renewables achieved in REmap 2030. More expensive renewable resources than in the Reference Case have to be exploited to raise the share of renewables to the REmap goal. The technology options deployed in power generation result in a net incremental investment need of slightly more than USD 150 billion per year above the Reference Case. However due to significant cost savings resulting from fuel savings, the incremental costs in the power sector amount to USD 66 billion per year to 2030.

The transport sector is the next largest contributor to total incremental costs over the Reference Case in REmap 2030. The transport sector's incremental costs amount to USD 27 billion per year, driven entirely by increased

Box 4.1 Financing renewables – time for a fresh look?

The time-value of money is an important impediment in financing renewables. Compared to fossil fuel technologies, the initial investments in wind and solar in particular make up a much larger share of total costs than with fossil fuel because wind and solar have no fuel costs and little operation and maintenance (O&M), so nearly the total cost is incurred in the beginning.

Since financing costs reflect a number of real and perceived risks, changing the risk perception of finance institutions can have a major impact on the overall attractiveness of renewables. Financial institutions express their perception of investment risks partly in the weighted average cost of capital (WACC) or the discount factor. Renewable energy projects are less attractive where WACC is high (*e.g.*, in Africa and on islands). WACC depends on factors like the equity loan ratio, exchange rate risk, debt audits, Libor rates, etc. Some renewable energy projects carry special risk, such as geothermal or drilling. Spreading risk can reduce the cost of capital.

The impact of discount factors is particularly high where project developers depend on external investors and finance institutions. For example, grid-connected solar PV systems (without storage) generate less-expensive power than diesel generators, and the cost of installing solar PV systems can be quickly recovered from savings in diesel fuel. Yet many islands find it more difficult to finance projects with solar PV systems than those solely based on diesel generators. Institutional investors ask for lower returns than commercial banks do, but the former require large "chunks" of loans. Therefore, packaging smaller projects into large chunks can reduce the cost of borrowing.

Figure 4.2 Relationship between the discount rate and LCOE for a diesel generator and solar PV in a Pacific island

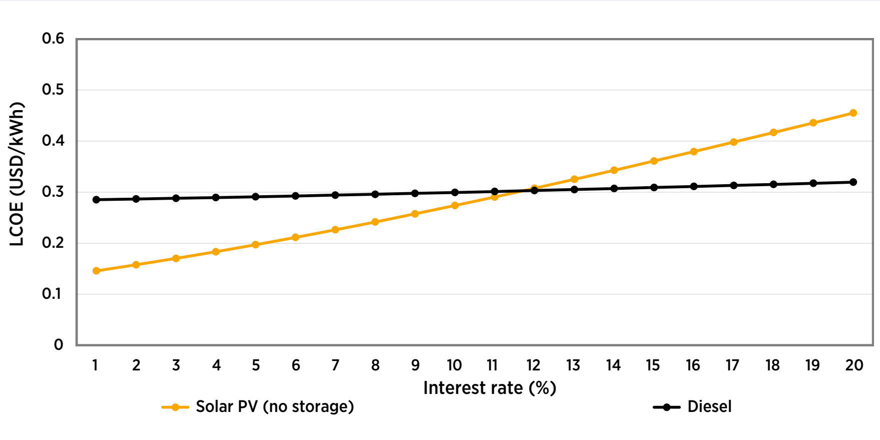


Figure 4.2 shows – based on a real-life case study in a Pacific island state – how critical the discount factor is on the levelized cost of electricity (LCOE) of solar PV and a diesel generator. A high discount factor would make it unattractive to install solar PV, although it is cheaper overall. Re-evaluating the discount factors used for renewable energy projects could change the outlook and the deployment of renewables around the world. This financing issue is a major barrier to scaling up renewable energy investments, even when forward-thinking policies and effective financing vehicles are in place.

fuel costs. In the industry and building sectors, the net incremental costs in REmap over the Reference Case are USD 6 billion for industry, but negative for buildings at USD 6 billion per year less than in the Reference Case due to the large savings in oil and, to a lesser extent, natural gas. This outcome is highly sensitive to biomass costs and therefore subject to significant uncertainty. The result of the REmap Options across all sectors is a total net incremental system cost of 93 billion per year in 2030.

These incremental system costs for the transition in REmap are relatively modest, as they take into account the impact of the many options that have negative costs compared to incumbent technologies. Subsidy requirements are by definition higher than the net incremental costs and by 2030 are USD 49 billion per year for transport and USD 189 billion per year for power generation in REmap over and above the Reference Case.

Additional investments need to be made in the power sector.

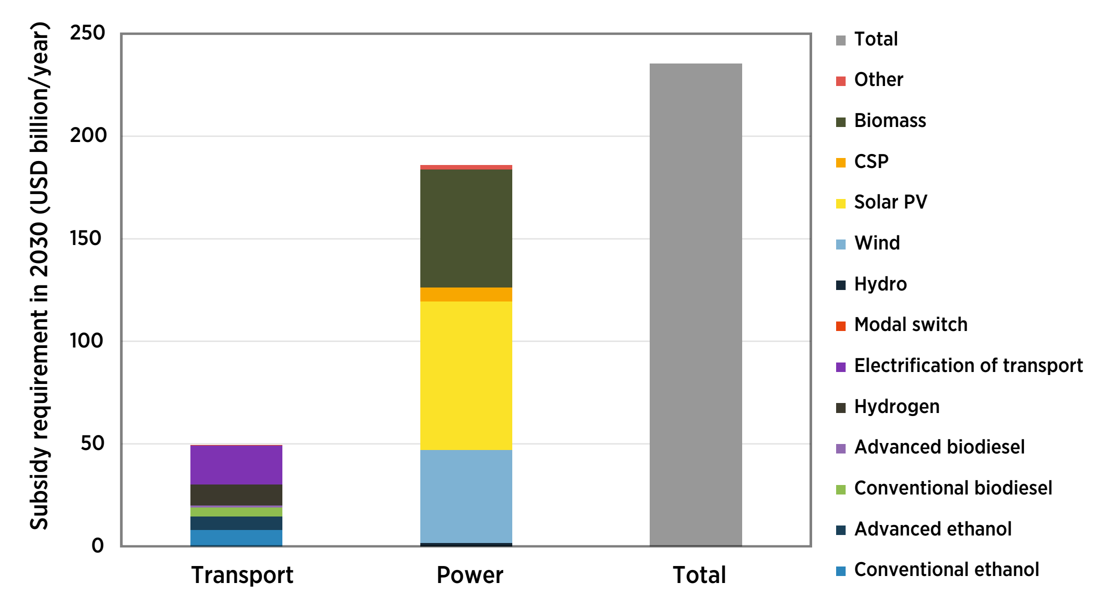
Subsidies are needed for those options with positive substitution costs, assuming that the benefits as discussed later in this chapter are not priced. By 2030, subsidies are negligible or zero for around half of the

26 REmap countries' power sectors due to the cost reductions from technological learning; subsidy needs originate from the remaining countries. In the transport sector, subsidies required per country peak within the REmap time frame for biofuels between 2017 and 2025 in general, depending on the country, as biofuels become cheaper than fossil fuel options[1].

No additional subsidies are needed for renewables in industry or buildings.

In the transport sector in 2030, most subsidies are therefore legacy costs from earlier deployment of renewable solutions, with the exception of electrification options; at wholesale prices for fuels excluding taxes and subsidies, some additional new subsidies are still required. The largest subsidy requirements for electrification (USD 19 billion per year) and hydrogen (USD 10 billion per year) account for around three-fifths of the total subsidies required for transport, with legacy subsidy payments for bioethanol of USD 14 billion per year and for biodiesel of USD 6 billion per year.

Figure 4.3 Subsidy requirements by technology in the power and transport sectors for REmap Options in the 26 REmap countries, 2030



The main subsidy requirements are for solar PV and wind in the power sector.

Subsidy needs in 2030 are calculated as USD 238 billion per year in 2030 for the REmap Options, excluding subsidies for renewables deployed in the Reference Case (see Figure 4.3). Around 80% of the subsidy needs in 2030 are for the power sector, with 20% for the transportation sector. With USD 32 billion in subsidy requirements in the Reference Case for power generation and USD 6 billion for transport, the total subsidy needs in Remap 2030 would be USD 276 billion in 2030. This assumes that all options with net cost are subsidised for the economic life of the investment[2] and that no CO_2 pricing or other policy instrument price other external costs from fossil fuels.

With USD 32 billion in subsidy requirements in the Reference Case for power generation and USD 6 billion for transport, total subsidy needs amount to USD 238 billion in 2030 (see Figure 4.3). This assumes that all options with net cost are subsidised for the economic life of the investment[3] and that no CO_2 pricing or other policy instruments price externalities of fossil fuels.

1 This make the assumed length of subsidy payments for biofuels critical. If subsidies are granted for 15 years, then these legacy payments would be just USD 31 billion per year in 2030. This scenario would be reasonable for conventional biofuels, where installed plant costs are very low, but may be too short for some advanced biofuels plants, where capital costs can be a much high percentage of total biofuel production costs.

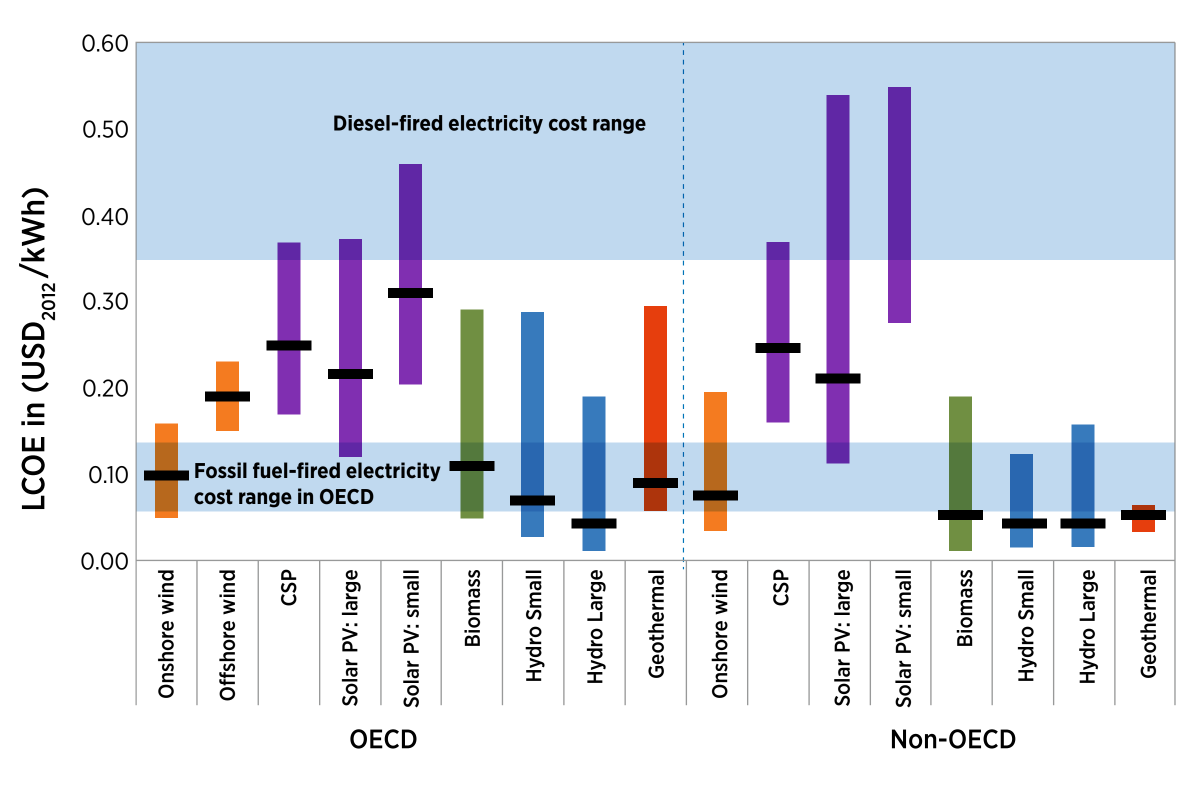
2, 3 Note that this is not typically the case today; subsidy regimes are usually in effect for a shorter time period than the economic life of the project.

Compared to today's subsidy levels of USD 101 billion per year, quadrupling modern renewable energy use between 2010 and 2030 requires tripling of total subsidy requirements in absolute terms worldwide. However, per gigajoule (GJ) of renewable energy, this translates to a halving of the subsidy requirements, from about USD 3.3 per GJ in 2010 to approximately USD 1.8 per GJ. Furthermore, pricing of CO_2 emissions at USD 20-30 per tonne would reduce the need for subsidies and result in the implementation of all REmap Options at no cost.

4.1.2. REmap 2030 power sector costs

Renewables account for almost half of new installed electricity capacity additions worldwide. IRENA's analysis of over 8 000 projects and a range of literature sources shows that the rapid deployment of renewables, working in combination with the high learning rates for some technologies, has produced a virtuous circle which is leading to significant cost declines and is helping to fuel a renewable revolution.

Figure 4.4 Weighted average and range for the LCOE by technology and region



Renewables are already cheaper than electricity from diesel, and are increasingly competitive with conventional power.

Note: Assumes a 10% discount rate.

Renewable power generation technology additions in 2012 exceeded 100 gigawatt-electric (GW_e), with 45 GW_e of new wind power capacity installed, 31 GW_e of solar PV, 30 GW_e of hydropower, 3 GW_e of biomass, 1 GW_e of CSP and 0.3 GW_e of geothermal power (REN21, 2013; EPIA, 2013).

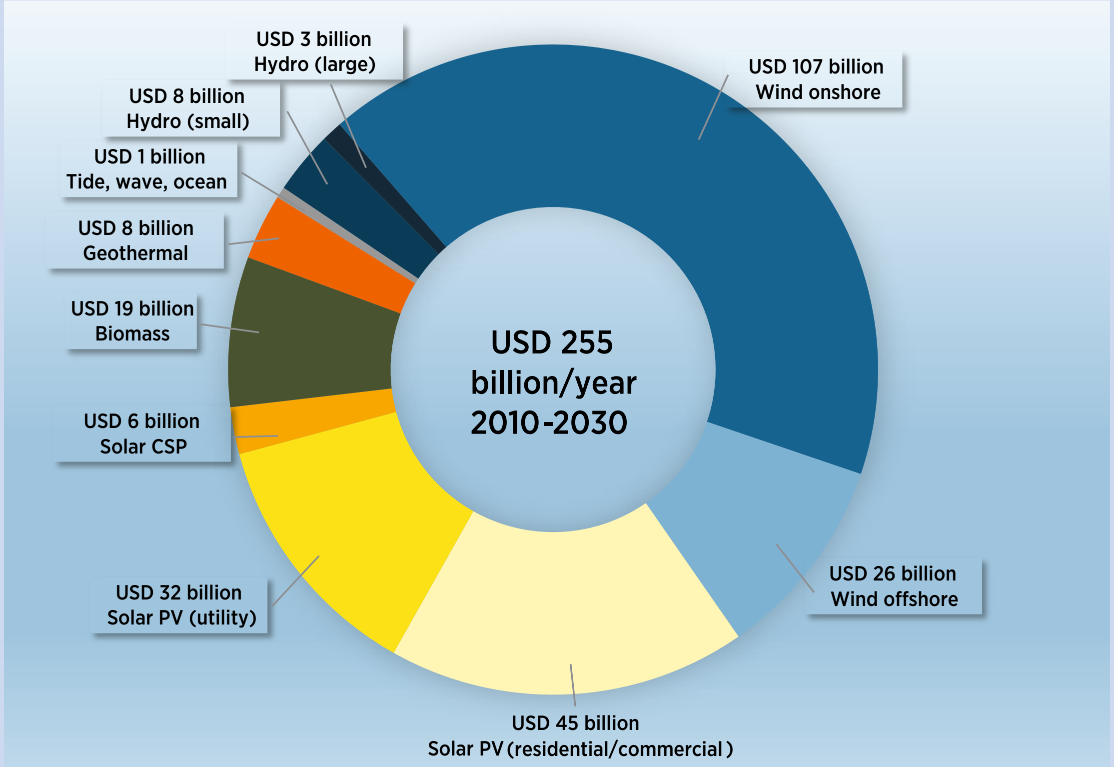
The levelised cost of electricity (LCOE) is declining for wind, solar PV, CSP and some biomass technologies, while hydropower and geothermal electricity produced at good sites are still the cheapest way to generate electricity (see Figure 4.4). Renewable technologies are therefore increasingly becoming the most economical solution for new capacity and for new grid-connected capacity where good resources are available. As renewable markets expand, renewable technologies and prices are becoming more competitive.

In REmap 2030, the average annual additional costs for electricity production to implement all REmap Options average USD 66 billion per year for the REmap countries between 2010 and 2030, or USD 1.3 trillion over the whole period.

Additional investment in renewable power generation technologies accounts for an average of USD 255 billion per year over and above the Reference Case, while additional costs for biomass feedstocks for power generation add USD 11 billion per year on average. These additional costs are offset by reduced investment in conventional generation technologies of USD 97 billion per year and reduced fossil fuel and nuclear fuel cycle costs which are USD 103 billion lower.

A breakdown of the incremental investment needs is shown in Figure 4.5. Onshore wind accounts for 42% of the total incremental investment needs in renewable power generation in the REmap Options over and above the Reference Case, with offshore wind contributing a further 10% of the total. Solar PV and CSP account for 33% of the total[4]. Biomass, geothermal and large-scale hydro account for the majority of the remaining incremental investment needs.

Figure 4.5 Average annual investment needs for renewable power generation in REmap Options in the 26 REmap countries



Wind and solar projects account for 75% of total investments needed in the power sector for renewable energy.

4.1.3 Capital cost for renewable technologies today

There are significant differences in installed capital costs among technologies and regions; collecting comprehensive real-world project data is thus crucial to properly evaluate the costs and potential of renewables. With the exception of hydropower upgrades and biomass co-firing, where the existing investment in dams or coal-fired power plants have already been made, the lowest capital costs for renewable technologies are for wind and biomass in developing countries and economies in transition.

The costs of utility-scale solar PV rival those of wind in some regions and have not yet finished their downwards trajectory. The installed cost range for wind in the major markets is relatively narrow compared to other renewable technologies, not only because of the large share of wind turbine costs in the total, but also because of the more homogenous nature of wind farm developments.

In contrast, the total installed costs for residential solar PV systems in the second quarter of 2012 in Germany were as low as USD 1 600 per kilowatt-electric (kW_e) for the cheapest systems (an average of

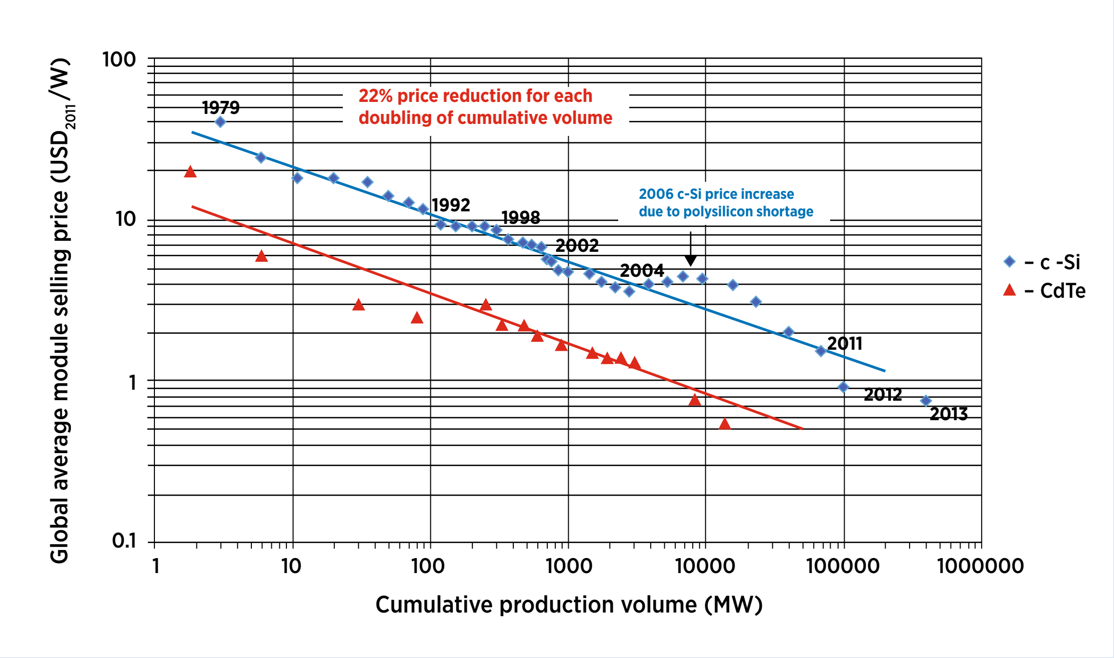
4 The costs related to solar PV in the building and industry sectors are allocated to the power sector.

USD 2 200 per kW_e), but rise to USD 8 000 per kW_e for the most expensive systems in the United States (with an average of USD 5 500 per kW_e). Some of this difference can be attributed to structural factors, the competitiveness of the local market, or the impact of policy support, but many factors remain unexplained.

4.1.4 REmap 2030 deployment, cost reductions and learning investments

In the REmap Options, deployment of onshore wind and solar PV accelerates gradually. By 2030, total installed capacity of onshore wind in REmap countries reaches around 900 GW_e, with around 1 400 GW_e installed globally. Compared to total installed capacity at the end of 2012 reaching this total by 2030 requires more than 2 times doubling of the existing capacity today[5]. For offshore wind, the growth is much more dramatic, with capacity growing from around 6 GW_e at the end of 2012 to around 231 GW_e in 2030 worldwide, or more than 5 times doubling of the existing capacity today.

Figure 4.6 Crystalline silicon PV module learning curve, 1979–2013



Solar PV cost reductions follow a predictable path.

Source: Based on data from EPIA and the EU PV platform, 2011; Liebreich, 2011; pvXchange, 2012 and IRENA analysis

The rate of growth in deployment of solar PV falls between onshore wind and offshore wind, with total installed capacity in REmap countries reaching around 970 GW_e and 1 200 GW_e globally, roughly more than 3 times of the existing capacity today.

The recent cost declines for crystalline silicon solar PV modules have seen prices drop below the learning curve in 2012 (see Figure 4.6), with average selling prices of just USD 90 cents per watt in 2012 and further declines to an average of around USD 75 cents per watt in 2013. A slowing in price declines is forecast for the next year or two, but with deployment in the REmap Options by 2030, prices for crystalline silicon modules could fall to an average of just USD 30-40 cents per watt in 2030.

With the era of cheap solar PV modules now a reality, solar PV economics will now be determined predominantly by the success of reducing balance-of-system costs and by ensuring that the cost of capital is as low as possible. By 2030, solar PV installed costs are expected to average USD 1 000 per kW_e for utility-scale projects and USD 1 500 per kW_e for small-scale rooftop systems. However, even these cost scenarios may prove too pessimistic if solar PV module costs fall further than expected and solar PV modules increasingly become building components, at least for new builds and where roofs or façades require replacing/refurbishment.

5 According to the experience curve approach, overnight capital costs decline at a constant rate with each doubling of cumulative capacity growth.

Wind turbine prices in markets outside of China and India have come off their peak in 2009 (IRENA, 2013b). In China and India, a somewhat different dynamic is occurring, as already low wind turbine prices (around USD 600 per kW_e) are being maintained, despite growing turbine sizes. By 2030, with the REmap Options, turbine prices outside of China and India are anticipated to fall from around USD 1 150 per kW_e to USD 900 per kW_e, assuming a 10% learning rate[6]. Average installed costs, including connection to the grid, would drop to around USD 1 400-1 500 on average outside of China and India in 2030 in the REmap Options, while in China and India total installed costs are likely to remain stable at USD 1 300 per kW_e as increasing labour and material costs, as well as increasing turbine sizes, offset learning effects.

The installed capacity of onshore wind, offshore wind and solar PV in REmap 2030 could be more than double the capacity in the Reference Case.

The outlook for learning effects and cost reductions for other technologies in the REmap countries are mixed. Hydropower, geothermal and some biomass technologies are mature but would see some cost reductions from market growth in the REmap Options. Some biomass technologies are much less mature, particularly gasification, and can be anticipated to have cost reductions of 20-40% by 2030.

For power generation, total learning investments to lower the cost of renewables amount to USD 950 billion for REmap countries by 2030 in the REmap Options[7]. A total of 63% of the learning investments are in solar, with a further 32% from wind – not a surprising outcome, given their high share of deployment and higher learning rates than the other technologies.

6 The learning rate is the percentage reduction in capital costs after each doubling of cumulative capacity growth.

7 Note that these are the total learning investments for renewables in power generation to 2030. It is not the incremental learning investments in the Reference Cases, which cannot be linearly interpolated from the total.

4.1.5 REmap 2030 transport sector costs

Recent developments in the commercialisation of advanced biofuels, biomethane and electric vehicles potentially herald the beginnings of widely available, competitive renewable options for transport. By 2030, these technologies could compete with conventional transport based on fossil fuels if support policies are enhanced and expanded.

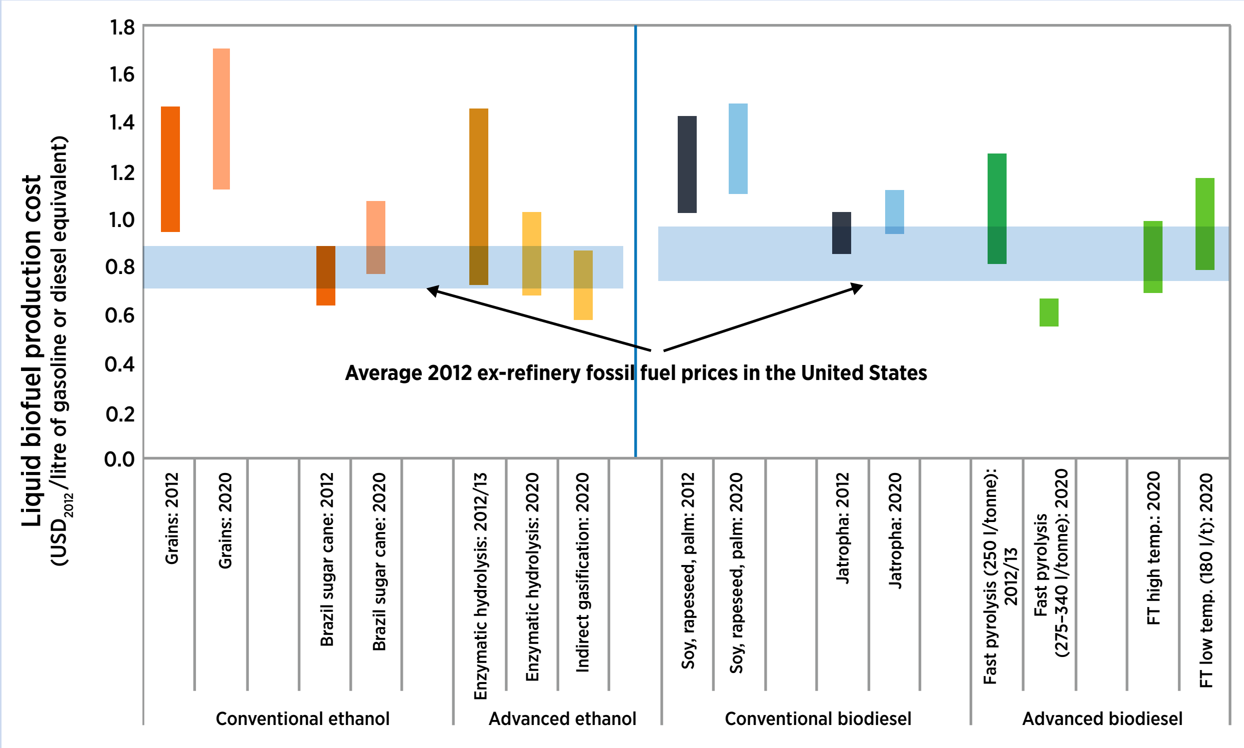
Renewable energy use is currently low in the transport sector – accounting for only 2.5% of energy consumption for all types of transport and 3.3% for road transport – and will have to grow in the REmap case if a doubling of renewables is to occur.

Conventional biofuels have suffered due to the price volatility of feedstocks, which are closely tied to food crops. Advanced biofuels – with less linkage to food prices – are just starting to be produced at commercial scale and need further support for research, development and deployment (RD&D) to find the least-cost technologies.

With as many as 15 commercial-scale advanced biofuels plants to come on line within a few years, more meaningful cost data is starting to emerge. The signs are promising: a range of technology pathways are being explored amidst competition to prove the efficiency, reliability and "up-scalability" of innovative new renewable transport fuels. These projects, if successful, will lead to larger, more economic plants which could provide large reductions in greenhouse gas emissions at costs equal to or less than fossil fuels by 2020 if policy support is expanded.

Electric vehicles (EVs) are also part of the intensifying competition, with mass-produced plug-in hybrids and pure EVs appearing from a range of manufacturers, amidst encouraging signs for mass commercialisation. Costs will come down with further deployment, making the outlook for EVs in 2020 promising, as long as support policies are enhanced and in-

Figure 4.7 Conventional and advanced biofuel production costs, 2012 and 2020



Cost effectiveness is within reach for advanced biofuels.

vestment grows in the necessary recharging infrastructure. Bio-methane could be an important transport fuel but may need investment in refuelling infrastructure to promote uptake.

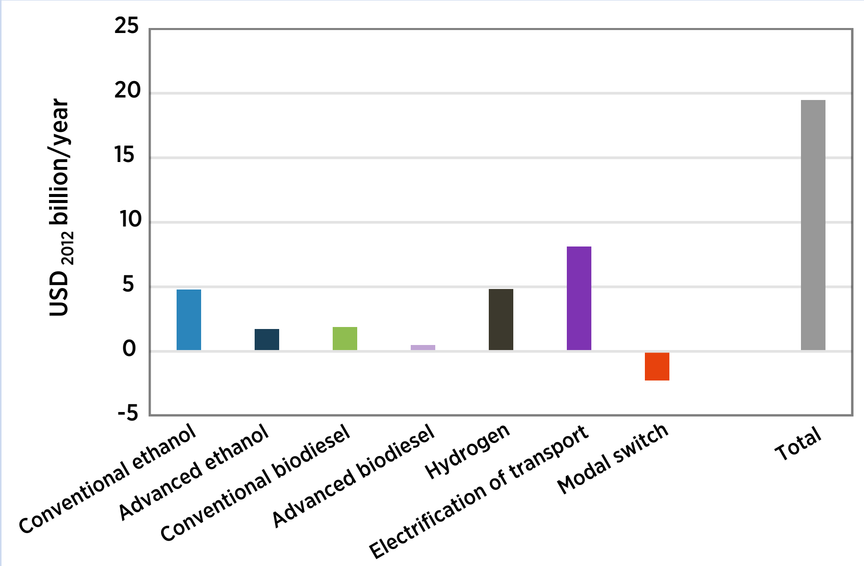
Figure 4.7 presents conventional and advanced biofuel cost ranges now and in 2020. Little change is anticipated between 2020 and 2030; however, this finding is highly uncertain as it depends on single estimates of feedstock costs and the timing of advanced biofuels commercialisation. Average estimates of conventional biofuel feedstock price projections beyond 2020 are highly speculative, the main reason why little change was assumed for this period. Advanced biofuels are only just at the early stage of commercialisation, and estimated production costs are still high. But with accelerated policy support by 2020, it is expected that high cost reduction can be achieved. The key challenge is proving which technology pathways will work reliably at commercial production scales.

As a result of these options and opportunities for a modal shift, the total costs of the transition in the REmap Options to 2030 for transport average around USD 19 billion per year between now and 2030 in the REmap case (see Figure 4.8). The largest single component when evaluated at wholesale prices is the additional cost of plug-in hybrids and pure EVs at an average annual cost of USD 8 billion per year to 2030 in REmap, followed by hydrogen from renewable sources used in fuel cell vehicles and conventional ethanol, both at USD 5 billion per year. Biodiesel (advanced and conventional) and advanced bioethanol amount to around 2 billion a year each. Opportunities for a modal shift and the use of increased public transport have negative average costs over the period to 2030 in REmap.

4.1.6 REmap 2030 industry sector costs

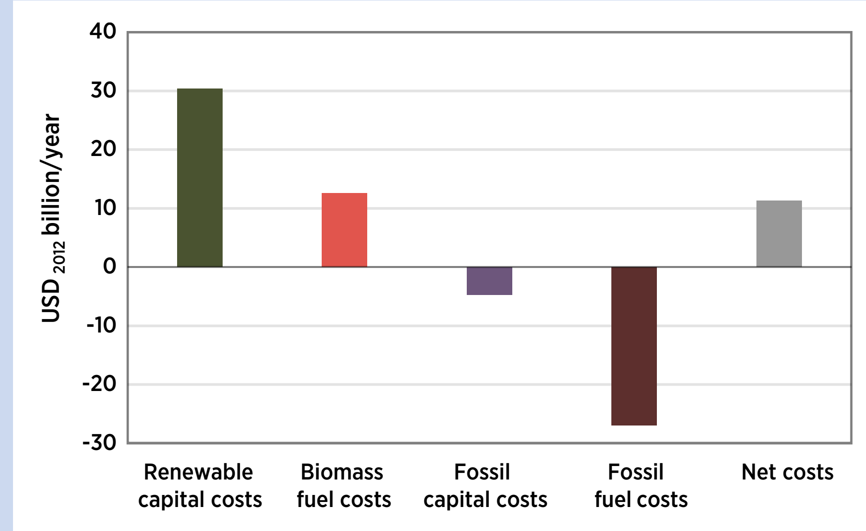
Renewables can provide process heat and cooling in industry. There are also significant opportunities for renewable power generation in industry, either in conjunction with process heat production with CHP or as stand-alone installations (*e.g.*, solar PV on factory rooftops). Biomass use in the REmap Options more than doubles, with much of this additional supply as both heat and power. The use of solar thermal for low- and medium-temperature process heat also expands significantly in REmap 2030. The net incremental cost for industry in the REmap Options is USD 225 billion to 2030, or USD 11 billion per year on average (see Figure 4.9).

Figure 4.8 Annual average incremental costs for REmap Options for the transport sector in the 26 REmap countries, 2010–2030



The main investment cost relates to electric vehicles.

Figure 4.9 Annual average incremental costs for REmap Options for industry in the 26 REmap countries, 2010–2030



The net cost of doubling renewable energy in the industry sector is near zero.

The incremental investment needs for the REmap Options stem mostly (two-thirds of the total) from the deployment of solar thermal for process heat. Biomass for process heat (in stand-alone boilers or gasifiers) accounts for 13% of the total. Biomass-fired combined heat and power (CHP) technologies account for the majority of the remaining additional renewable investment needs (see Figure 4.10).

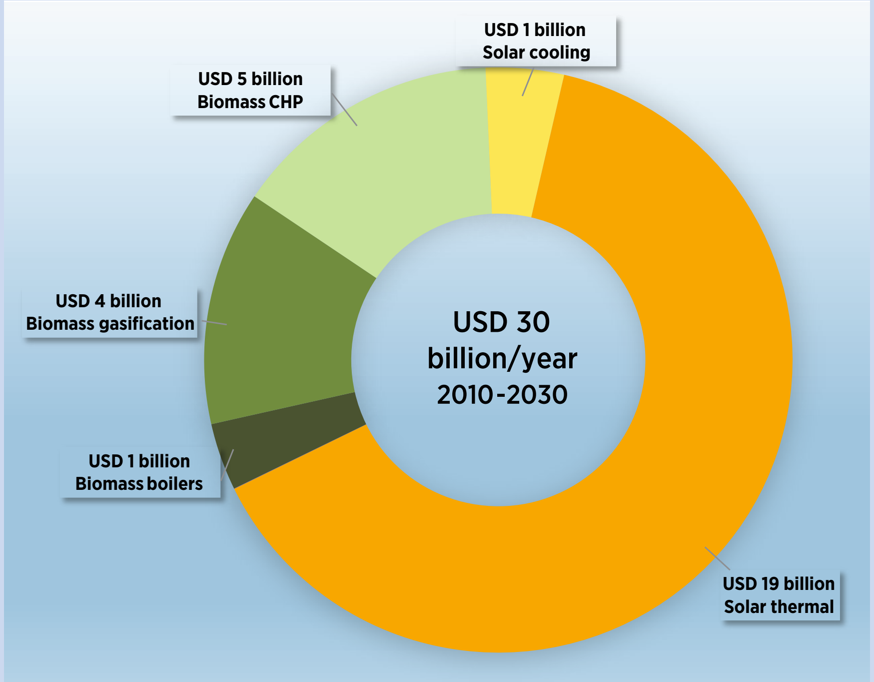
4.1.7 REmap 2030 building sector costs

The building sector accounts for around a third of TFEC. The main end-uses where renewables can achieve higher levels of penetration are space and water heating, space cooling and cooking. In addition, with the decarbonisation of the electricity sector, certain electrification options to accelerate the deployment of renewables also become attractive. However, achieving access to modern energy services for all and reducing traditional use of biomass in inefficient cook stoves to negligible levels is not only an important goal, but a challenging one in terms of the complexity of deployment, if not costs.

With rising fossil fuel prices and the improvement in the competiveness of renewables, the REmap Options actually save money compared to the Reference Case. The total energy service costs of the sector are USD 1 billion lower per year on average to 2030 than in the Reference Case (see Figure 4.11).

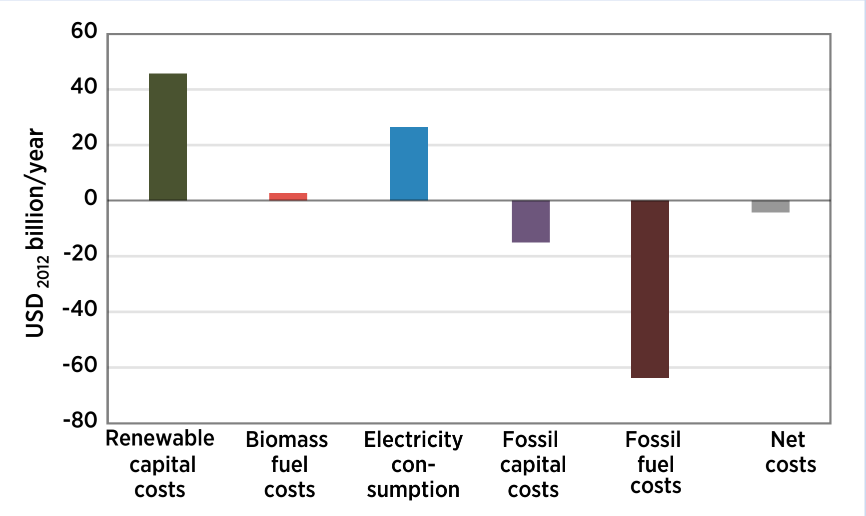
An important difference from the industry sector is that the electrification options used in the building sector, notably geothermal and air-to-air heat pumps for space and water heating and some electrification of

Figure 4.10 Annual average investment needs for REmap Options in industry, by resource in the 26 REmap countries



Solar thermal accounts for two-thirds of investments for renewable energy in industry.

Figure 4.11 Annual average incremental costs for REmap Options for buildings in the 26 REmap countries, 2010–2030



Fossil fuel cost savings in buildings are significant over USD 60 billion per year.

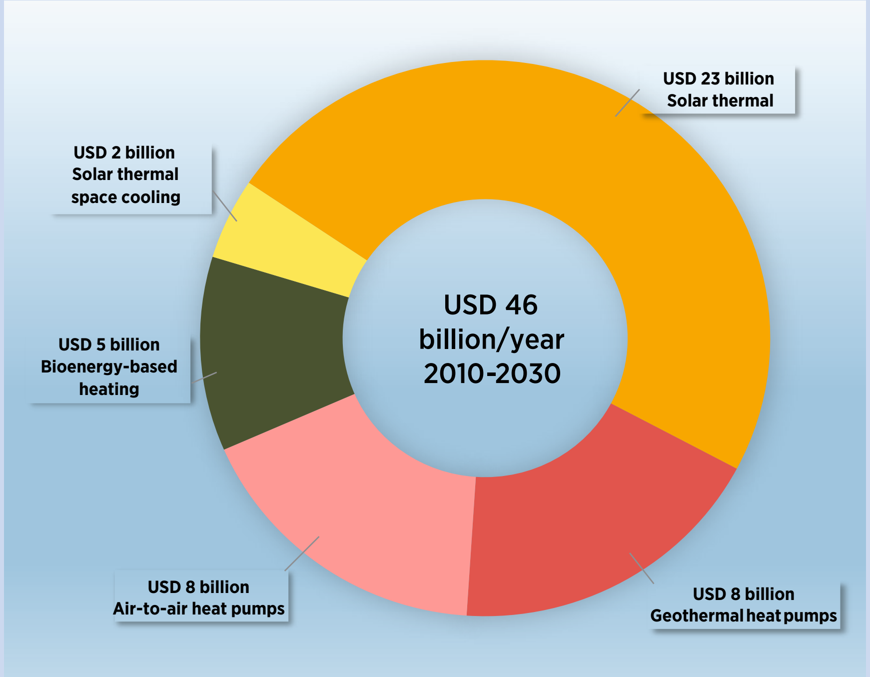
cooking, result in increased electricity use. However, even at retail electricity rates, the combined incremental costs for biomass[8] and electricity consumption to 2030 are exceeded by the savings in fossil fuel costs. The incremental bioenergy and electricity costs in the buildings sector in on average USD 30 billion per year between today and 2030. This is USD 33 billion per year lower compared to the savings in the energy purchases from fossil fuel substitution estimated at USD 62 billion per year in REmap 2030.

8 This is the incremental cost of "modern" bioenergy (*e.g.*, biofuels and biogas) used in the sector compared to traditional biomass.

The investment needs in the building sector over and above the Reference Case in REmap for renewable technologies average USD 47 billion per year to 2030, with around half of this required for solar thermal systems for space and water heating (see Figure 4.12). Heat pumps, both geothermal and air-to-air systems, account for around 36% of the total.

The key challenge in industrialised countries is that the growth in the building stock and the renovation rate are low. The costs for renewable options for retrofits, particularly for some electrification options like heat pumps, are much higher than for new buildings. In developing countries and economies in transition, continued urbanisation, growth in the building stock and much shorter useful lives of the buildings being built mean that there is much greater opportunity for the low-cost integration of renewables into the residential and service sectors.

Figure 4.12 Annual average investment needs for REmap Options in buildings, by resource in the 26 REmap countries



4.2 Reduced external effects

Implementing all REmap Options reduces demand for fossil fuels in 2030 compared to the Reference Case. The change in fossil fuel demand at a global level is discussed in the following sub-chapter. Subsequent sub-chapters discuss the implications of reduced consumption of fossil fuels on associated negative impacts, such as greenhouse gas (GHG) emissions and adverse human health impacts. To the extent possible, these impacts are assessed in monetary terms. Additional benefits of reduced fossil fuel consumption, such as increased energy security and reduced adverse impacts on ecosystems, are outside the scope of the current analysis.

4.2.1 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 all REmap Options implemented, the resulting fossil fuel consumption in REmap 2030 grows only 12%. Coal growth would be flat, and oil and natural gas would increase by 10% and 35%, respectively. Renewables will offset more coal consumption than natural gas and oil consumption combined by 2030.

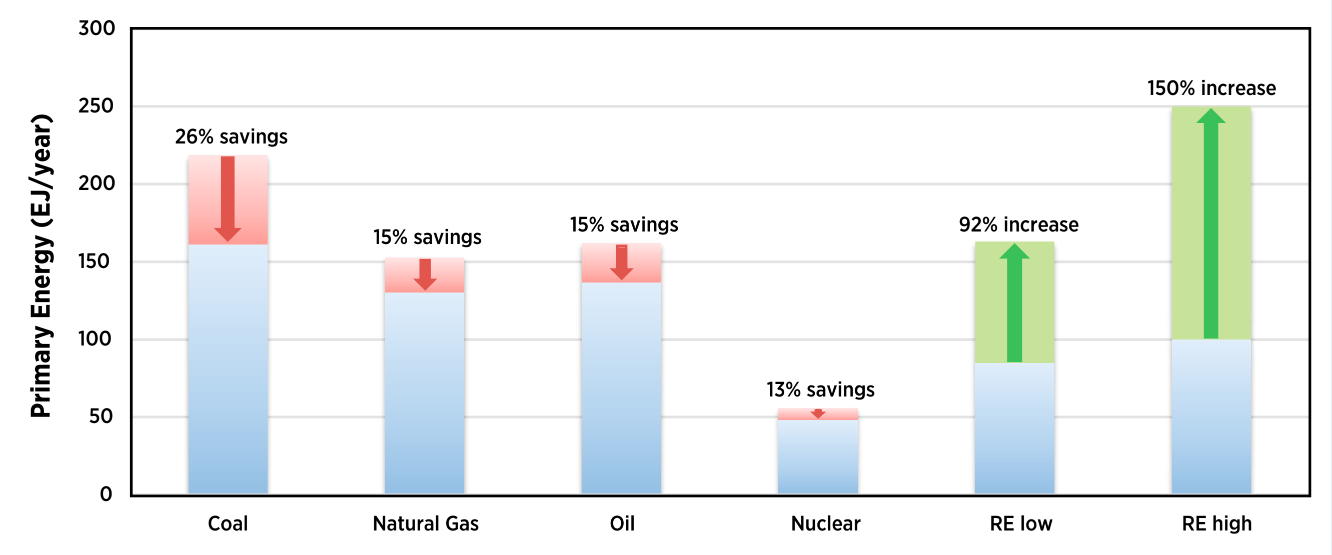
Renewable energy options can offset more coal consumption than natural gas and oil combined.

The total reduction in fossil fuel use with all REmap Options deployed is 105 EJ worldwide in 2030 compared to the Reference Case (see Figure 4.13). Of this total, 45 EJ is related to end-use sectors: 14 EJ in industry, 20 EJ in transport and 11 EJ in buildings. In comparison, total renewable energy use (primary energy) will increase by 90-150% in REmap 2030, depending on which accounting method is applied to measure primary energy. Compared to the consumption of different conventional fuels, which range between 60 EJ and 160 EJ per year in REmap 2030, renewables use will grow to between 160 EJ and 250 EJ per year.

Petroleum products are traded internationally. Lower demand would reduce the most costly projected production, which includes oil sands in Canada and Venezuela, Arctic oil and ultradeep offshore oil. Typical marginal production costs in these areas are in the range of USD 50-70 per barrel. In comparison, the international price for high-quality oil is around USD 110 per barrel, so there is a rent in the range of USD 40-60 per barrel. The average rent for all oil is higher, as the marginal production cost can be as low as USD 10-20 per barrel for production in the Middle East.

Gas and coal, in contrast, are traded partially internationally and partially in national or regional markets. The price impacts of remote gas fields may vary by market – these fields might not be taken into production, and connecting pipelines may not be built. The same may apply for liquefied natural gas (LNG) projects. Even today, significant amounts of associated

Figure 4.13 Global change in energy use due to REmap Options, 2030



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

Note: Figure shows the future level of fossil fuel use in the Reference Case and the savings (in red) when the REmap Options are pursued; savings from the doubling of energy efficiency are excluded. Coal consumption excludes blast furnaces and coke ovens of 13 EJ.

gas – equivalent to 30% of total gas consumption in the European Union (EU) – are flared in producer countries because there is no economic way to get the gas to the market. Natural gas prices today vary from USD 5 per GJ in the United States to more than USD 15 per GJ in the East Asia region.

With the right policies, renewable energy could become the most important energy source worldwide by 2030.

For coal, the gap between prices and the production cost is much smaller. The rents in coal are much smaller than for oil and gas, and coal is much cheaper per unit of energy than gas or oil. Therefore, it is financially easier for governments to forgo coal mining than oil and gas production if local renewable energy is available. Also, international coal trade volumes are much smaller than oil and gas trade volumes. The only major exception is Australia, but the bulk of the coal exported from there is high-quality coking coal, which would be least affected by the introduction of renewables.

4.2.2 Mitigation of greenhouse gas emissions

CO_2 is a GHG that causes the atmosphere to heat up and global temperatures to rise. The largest source of human-caused CO_2 emissions is the burning of fossil fuels to generate electricity, power transport and heat buildings.

The Intergovernmental Panel on Climate Change (IPCC) estimates that a CO_2 concentration of 450 parts per million (ppm) in the atmosphere would result in a global average temperature rise of 2 degrees Celsius (°C) by 2100 (IPCC, 2007b). At the start of 2014, the annual average CO_2 concentration in the atmosphere was 398 ppm (NOAA, 2014). Beyond 2 °C, experts predict serious consequences for the earth's climate (we are currently 0.7 °C above pre-industrial levels). Since the Industrial Revolution, the atmospheric concentration of CO_2 has increased at an accelerating rate, rising by 1 ppm annually during the 1960s and by 2 ppm annually from 2000 to 2010.

More than 80% of human-caused CO_2 emissions come from burning fossil fuels. Of that, 44% comes from coal, 36% from oil and 20% from natural gas. An estimated 40% of CO_2 emissions are stored in the oceans and soil, and 60% in the atmosphere. To avoid a further buildup of atmospheric CO_2, we need to lower energy-related CO_2 emissions by 60% from today's levels, to 12.5 gigatonnes (Gt). Given the remaining emissions space we have before reaching 450 ppm, this should be achieved by 2050 at the latest.

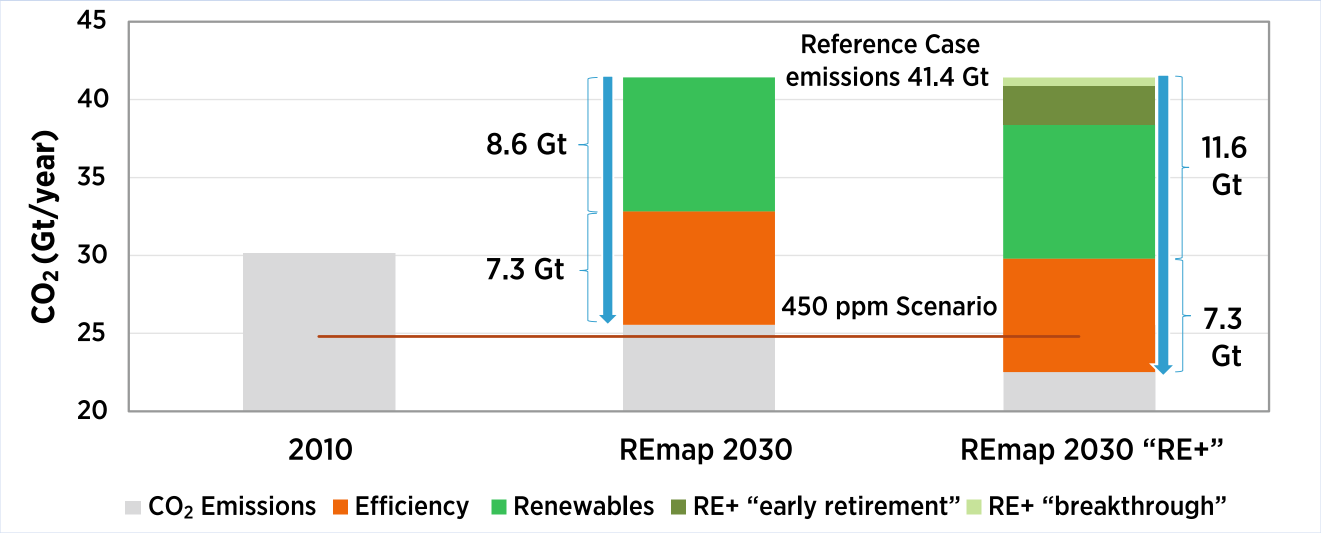
Assuming a constant pace of reduction, we would need to lower annual CO_2 emissions from energy to 20.8 Gt by 2030, to keep CO_2 levels at 450 ppm. The IEA says 25 Gt CO_2 would be enough; this would require an acceleration in emission reductions after 2030.

There are four ways to reduce CO_2 emissions from energy use: improving energy efficiency, renewable energy, nuclear energy and carbon capture and storage (CCS) from fuel combustion. CCS is the technology whereby CO_2 emissions are caught before they go into the atmosphere. New options may emerge in the future, such as nuclear fusion, but they are in their infancy. It is unlikely that nuclear and carbon capture and storage will play a substantial role in CO_2 reduction between now and 2030. Typically it takes a decade to build a new nuclear plant, and CCS development has lagged far behind needed levels (most countries have stopped its development). This leaves energy efficiency and renewable energy. Renewable energy production does generally emit no or negligible amounts of CO_2.

Annual CO_2 emissions continue to grow and could easily reach more than 41 Gt by 2030 in the Reference Case (see Figure 4.14). Assuming that all REmap Options are carbon neutral, the estimated emission savings in the end-use sectors of the 26 REmap countries are equivalent to 2.7 Gt of CO_2 per year. By 2030, about 42 EJ of fossil fuel (mainly coal) and nuclear energy could be substituted in the power sector of the REmap countries if all REmap Options are deployed, thereby reducing CO_2 emissions by about 3.3 Gt by 2030.

Along with small reductions in the district heat sector (0.2 Gt of CO_2), the total emissions savings estimated for the 26 REmap countries is 6.2 Gt of CO_2 in 2030 compared to the Reference Case, equivalent to 8.6 Gt worldwide and approximately 21% lower than the Reference Case emissions of 41.4 Gt. When all REmap Options are deployed, CO_2 emissions worldwide would be 32.8 Gt. REmap Options together with energy efficiency could reduce total Reference Case CO_2 emissions nearly to the level required for the 450 ppm scenario (by an additional saving of 7.3 Gt of CO_2). When the RE+ Options of early retirement and breakthrough technology are added in (an additional 3 Gt of CO_2 emissions), annual CO_2 emissions could be reduced to around 22.5 Gt.

Figure 4.14 Carbon dioxide emission saving benefits of REmap Options



Potential CO_2 reductions from renewable energy are on par with those from better energy efficiency.

Note: Only emissions resulting from fossil fuel combustion are shown. Upstream emissions from fuels production and land use change related emissions are excluded. CO_2 emission savings from energy efficiency are based on its share in total emissions in the IEA World Energy Outlook 2012 (IEA, 2012d). IRENA applies this share to the total Reference Case emissions of 41.4 Gt of CO_2 to estimate approximately 7.3 Gt of CO_2 emission savings related to energy efficiency in REmap 2030.

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Box 4.2 Renewable energy and energy efficiency

One of the Sustainable Energy for All (SE4ALL) objectives is doubling the energy efficiency improvement rates.

Historically, global energy intensity – or the amount of energy (in GJ) required to produce a unit of economic activity (1 USD of GDP) – has decreased by 1.3% per year. International goals aim to raise the intensity improvement rate to 2.6% per year. Under current policies, the improvement rate will stay at the level of 1.3% per year. If all REmap Options are implemented, energy intensity improvements would increase to 1.6% per year. Pursuing renewable energy will help to achieve energy efficiency goals.

There are two main sources of energy efficiency improvements: greater technical efficiency, and structural change that results in the production and consumption of goods with lower energy intensity. For example, use of electric bicycles instead of cars.

Greater technical efficiency comes from introduction of new capital stock (such as modern industrial processes, machinery and buildings) and goods (such as modern cars and electronics) with higher energy efficiency. Retrofit can also help, for example in the case of buildings. Also use of energy management systems such as the new ISO 50 001 help to raise the efficiency of energy use.

Economies that grow rapidly have more opportunity to improve efficiency than those that are stagnant. Economies with ageing capital stock that needs replacement also have more opportunity to improve efficiency than those with young capital stock. In Organization for Economic Cooperation and Development (OECD) countries, energy intensity has dropped by 1% per year; in China, it has dropped by 4% per year over the last two decades.

REmap 2030 analysis of ten scenarios shows a clear correlation between energy use, energy efficiency and the share of renewable energy (see Figure 4.15). If there is no change in the rate of efficiency improvement, the world can reach a 20% share of renewable energy. If the rate of efficiency improvement doubles, it could reach a 40% renewable energy share.

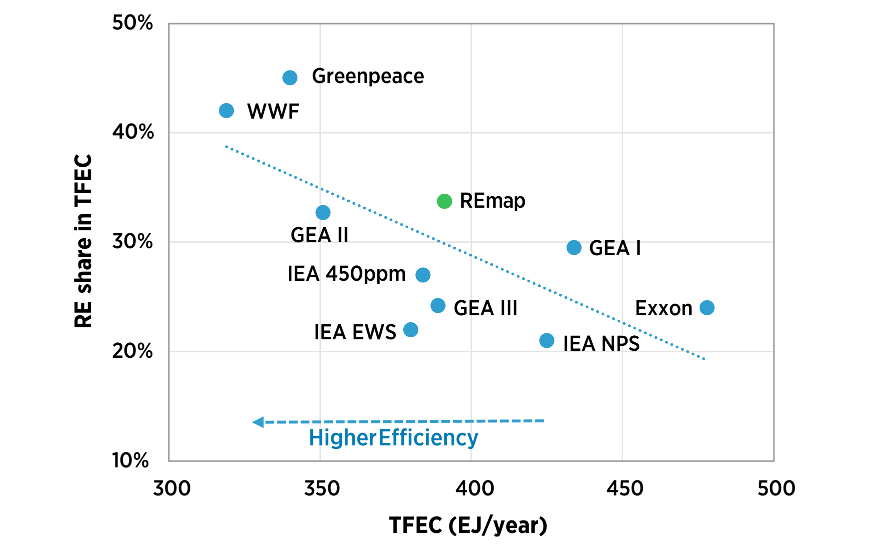
Conversely, a higher share of modern renewable energy technologies benefits energy efficiency. Its a combination of technical gains and accounting that leads to this result. For many renewables such as hydro, solar and wind, power generation is assumed to take place with 100% efficiency. Fossil fuel power plant incur a significant energy loss in the conversion from primary fuel to final electric energy. Therefore renewables yield significant efficiency gains.

But also for end uses renewables can raise efficiency. Clean cooking based on advanced technical stove designs double the efficiency of biomass use. Electrification based on renewable electricity increases efficiency. Electric vehicles are two to three times as efficient as vehicles with internal combustion engines. Heat pumps can raise efficiency threefold compared to efficient gas boilers.

Renewable energy and energy efficiency create a virtuous circle: one enhances the other. To reach international objectives for sustainable energy, both must be treated jointly.

Countries can raise the energy efficiency improvement rate through standards and regulations, as well as financial incentives for new equipment and retrofit. They must also encourage innovation of new products and services with lower energy intensity. On the demand side, governments can work on city planning, public transportation and other areas of structural change. On the production side, outsourcing of industrial manufacturing may reduce energy intensity in one country, but raise energy intensity elsewhere.

Figure 4.15 Renewable energy and energy efficiency projections in global scenarios for 2030



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

Note: Projections for the share of renewable energy in TFEC in 2030 (IRENA, 2013a) are based on WWF/Ecofys/OMA (2011); BP (2012); ExxonMobil (2012); GEA (2012); Greenpeace/EREC/GWEC (2012); and IEA (2012b). EWS is the "Efficient World Scenario" and NPS is the "New Policies Scenario" of IEA (2012d). The sum of REmap Options would be placed in the middle of the field in terms of the expected level of energy consumption by 2030 (at around 390 EJ per year) but towards the top of the field in terms of the share of renewable energy.

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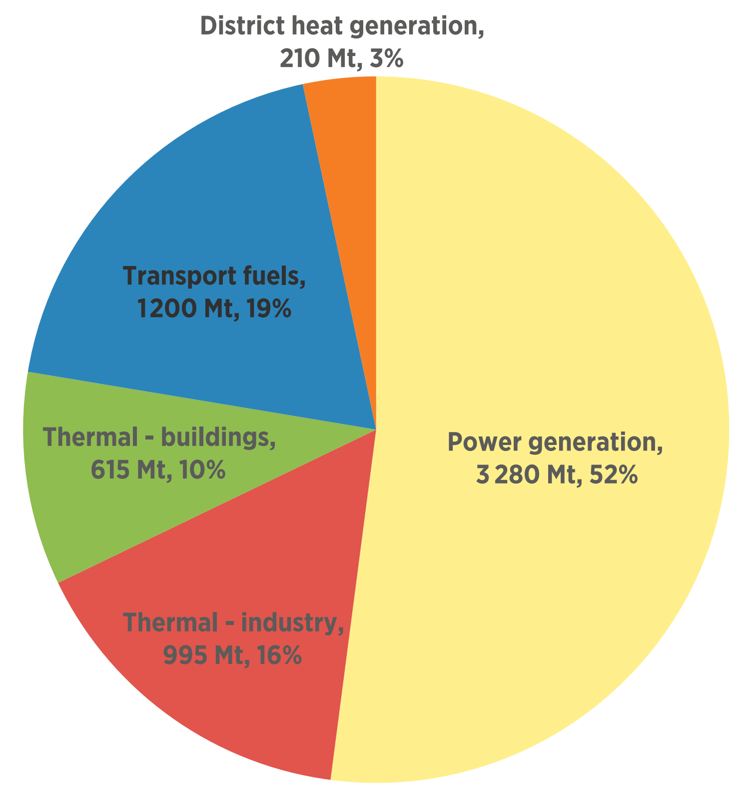
There are also reductions in other greenhouse gas emissions, such as methane (CH_4) emissions from the substitution of traditional use of biomass. The substitution of 9 EJ of traditional use of biomass in the 26 REmap countries would abate 10 million tonnes of methane emissions in 2030. Based on a 100-year global warming potential of 34, this is approximately 340 million tonnes of CO_2-equivalent. When the modern energy access objective is considered worldwide (the complete substitution of traditional use of biomass worldwide is another 20 EJ), total abated methane emissions could reach 30 million tonnes by 2030, or 1 Gt of CO_2-equivalent. Along with 8.6 Gt of CO_2 emission reductions from fossil fuel use, total greenhouse gas emission reductions are estimated at 9.6 Gt of CO_2-equivalent by 2030 worldwide.

Renewables and efficiency alone can keep the global concentration of CO_2 in the atmosphere below 450 ppm.

Figure 4.16 shows the breakdown of CO_2 emission reductions by sector in the 26 REmap countries in REmap 2030 relative to the Reference Case. Approximately half of the total emission reductions in the 26 REmap countries are located in the power sector, amounting to 3.3 Gt of CO_2 per year. This is due mainly to the substitution of carbon-intensive coal-fired power plants in most countries. Developing strategies to substitute these power plants will be the key to meeting the climate change mitigation goals. Total reductions in end-use sectors and the district heat sector account for another half (2.9 Gt of CO_2 per year). At the country level, China, the United States, Canada and India account for two-thirds of total emission reduction potential in the 26 REmap countries (see Figure 4.17), indicating the importance of their contribution to international climate policies.

Figure 4.16 CO_2 emission reductions by sector in the 26 REmap countries, 2030

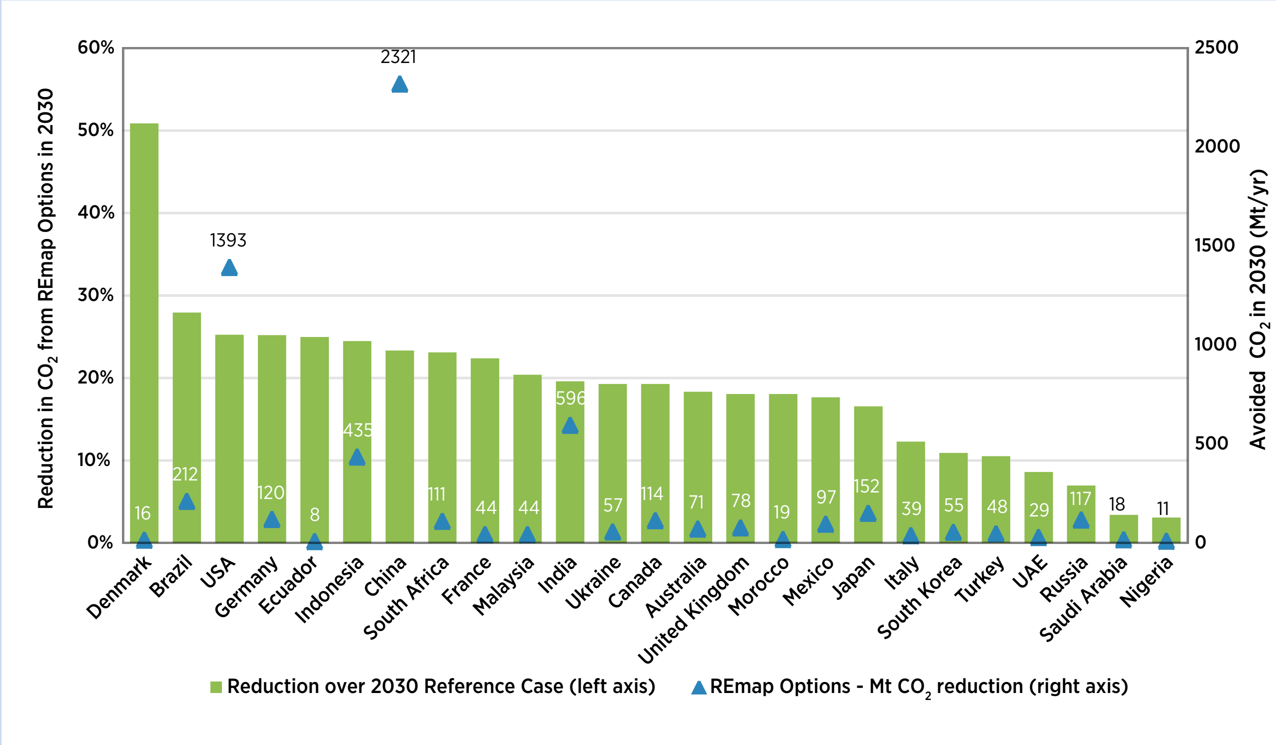


4.2.3 Reduced negative health effects

All forms of fossil fuel energy generation and energy usage are known to have negative environmental and human health impacts. "External costs" (also known as negative externalities) are the monetised impacts of these effects passed on to society at large without being compensated. External costs are not internalised by the energy provider nor passed on to consumers through energy pricing; however, the cost to society remains and is "paid" through other means, such as higher healthcare costs or lower labour productivity.

Among the well-defined external costs are the negative health impacts associated with 1) outdoor air pollution from fossil fuel combustion and 2) indoor air pollution from the use of coal and traditional use of biomass. Premature deaths attributable to urban outdoor air pollution are

Figure 4.17 CO_2 emission reductions by country in the 26 REmap countries, 2030



In the 26 REmap countries, half of all emission reductions will come from the power sector; at the country level, China alone will account for a third of the total emission reductions.

dominated by energy-related emissions from vehicles and from power generation. Note that other important external costs such as ecosystem damages due to air pollution, or noise from urban transport, are not assessed in this analysis.

The number of people dying each year from the effects of fossil fuels is high. Worldwide, about 2 million people – mainly women and children – die annually from illnesses related to indoor air pollution from the use of different types of solid fuels. (Indoor air pollution from biomass combustion results in the death of about 0.9 million people per year.)

Another 1.5 million people die each year from pollution (mainly particulate matter) caused by urban transportation. According to the World Health Organization (WHO) (2008), coal-related air pollution deaths have reached 1 million people per year. China accounts for half of this total. In India alone, 400 000 people have died per year because of indoor air pollution caused by the combustion of different solid fuels. In Africa, pneumonia attributable to cooking smoke kills 500 000 children younger than five years annually.

According to the study by Lim *et al.* (2012), the three leading risk factors for global disease burden in 2010 were high blood pressure (6.2-7.7% of global disability-adjusted life years), tobacco smoking (5.5-7.0%) and household air pollution from solid fuels (3.4-5.3%).

Table 4.1 shows fossil fuel use by sector in 2010 and 2030 based on the Reference Case and REmap 2030. When assessing external effects, it is also important to look at traditional use of biomass in the building sector, which amounted to 16 EJ of consumption in the 26 REmap countries.

The indicative external cost range associated with the human health impacts are due to 1) particulate matter (PM2.5), mono-nitrogen oxides (NO_X) and sulphur dioxide (SO_2) emissions from fossil power generation; 2) PM2.5 and NO_X emissions from light-duty vehicles and 3) indoor air pollution associated with domestic use of coal and traditional biomass. For 2010, the sum of these external costs is estimated at USD 325-825 billion per year worldwide (see Table 4.2), with indoor

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Table 4.1 Fossil fuel use in the power, transport and building sectors by energy carrier in the 26 REmap countries, 2010-2030

	Coal (incl. blast furnaces and coke ovens)			Oil (excl. international marine/aviation bunker fuels)			Natural Gas		
	2010	Reference Case	REmap 2030	2010	Reference Case	REmap 2030	2010	Reference Case	REmap 2030
	(PJ/yr)								
Power (incl. CHP)	81	115	85	6	4	2	29	46	43
Transport	0.1	0.1	0.1	63	87	72	3	4	4
Buildings	4	3	1	10	11	10	20	23	17

By 2030, under the Reference Case, fossil fuel demand for power generation in the 26 REmap countries increases, while the use of traditional biomass and coal in buildings decreases (see Table 4.2). Reflecting the trend that the external costs per unit of energy should decline due to efficiency improvements and more stringent pollution-control measures for energy systems, the external costs related to fossil fuel use in the 26 REmap countries are estimated to decrease to USD 195-490 billion in 2030 worldwide (see Table 4.2).

air pollution accounting for about a half of this. The range reflects the variation in the method to value mortality, which is about factor of 3.

About half of the total external costs from indoor and outdoor air pollution are related to the use of traditional biomass and coal in the residential sector.

Lower fossil fuel use in the power sector resulting from the REmap Options reduces external costs by USD 23-60 billion in the 26 REmap countries (see Table 4.2). China and India will continue to depend on coal for power generation by 2030. In China and India, substitution of about 1 140 terawatt-hours (TWh) and 320 TWh of coal-based power generation, respectively, results in external cost savings of USD 5-15 billion and USD 1-4 billion per year, respectively, in REmap 2030.

Table 4.2 External costs in the 26 REmap countries and globally

	2010	Reference Case	REmap 2030	Avoided external costs
	(USD billion/year)			
Power sector (fossil fuel)	125-350	80-220	57-160	23-60
Indoor air (coal and traditional biomass)[1]	70-165	55-135	15-35	40-100
Transport sector (passenger car fuels)	90-255	35-100	28-80	7-20
Total	285-770	170-455	100-270	70-180
Total – global	325-825	195-490	115-290	80-200

1 *These are conservative estimates based on the low-end of externality cost related to indoor air pollution. Based on the high end of externality costs found in the literature, the avoided external costs could be USD 135-275 billion per year.*

The use of traditional biomass and coal in the residential sector is expected to decrease under the Reference Case in 2030. However, combustion of these fuels is expected to still result in 1 million premature deaths by 2030, which translates to external costs of about USD 40-100 billion in the 26 REmap countries. REmap Options substitute 8 EJ of traditional use of biomass and 2 EJ of coal with modern forms of bioenergy and other renewables by 2030.

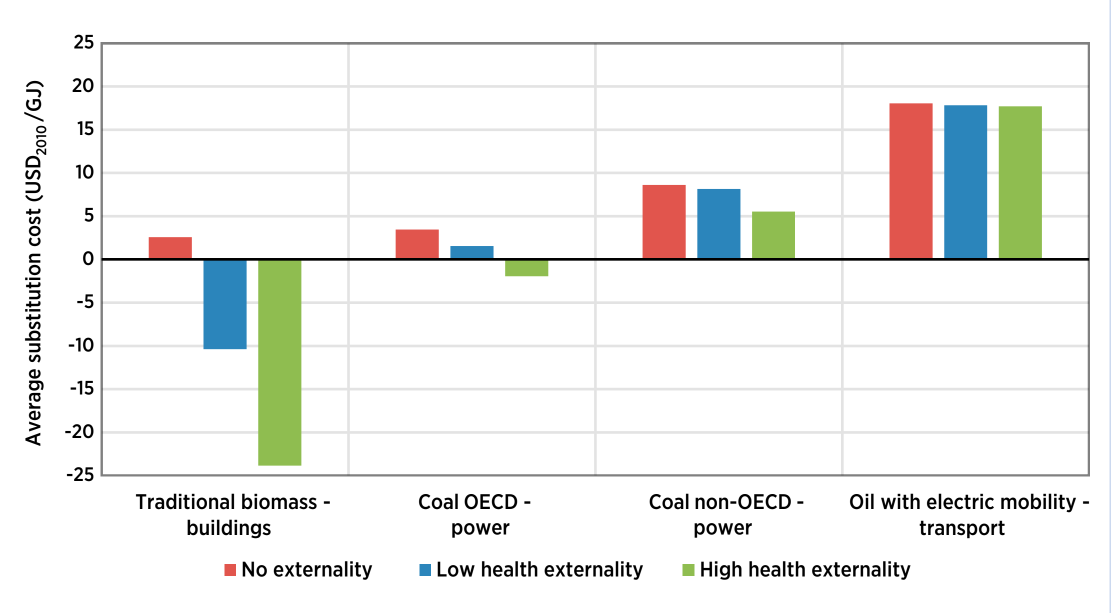
Under the Reference Case, gasoline and diesel use in the transportation sector grows, reflecting the increased use of cars in fast-growing developing countries. If all REmap Options for transportation are implemented – including biofuels, the use of electric vehicles and clean solutions for mass transit – the result is a total reduction of 17% compared to the Reference Case. REmap Options collectively reduce the external costs in this sector by USD 7-20 billion compared to the Reference Case in the 26 REmap countries (see Table 4.2).

In total, if all REmap Options are implemented, external costs related to indoor and outdoor air pollution from power generation, traditional use of biomass and road transport could be reduced by on average 40%, or USD 80-200 billion, per year worldwide compared to the Reference Case.

The role of externalities applied to specific technologies is shown in Figure 4.18. Substitution of traditional use of biomass for heating and cooking applications represents the largest opportunities for cost reduction due to prevented health implications and fatalities. Figure 4.18 shows the substitution of traditional use of biomass with modern renewable energy sources with an estimated average substitution cost of USD 2.6 per GJ. When externalities are accounted for, substitution costs can be reduced substantially to more than USD -20 per GJ. A weighted average substitution cost for coal power plants is estimated at USD 3.4 per GJ for industrialised countries and USD 9.6 per GJ for developing countries and economies in transition. Accounting for externalities, coal substitution in industrialised countries can result in net savings, and could be nearly zero in the rest of the world.

The switch from passenger road vehicles consuming oil to electric or hybrid vehicles has a negligible effect on the substitution costs. This is explained by the rather narrowly defined system boundaries of the analysis, where the focus is limited to 1) health impacts due to air pollution but not to noise, 2) PM2.5 and NO_x emissions but not emissions of carbon monoxide (CO), SO_2 and volatile organic compounds (VOCs) and 3) the operation phase, but not the whole life cycle. Therefore, the estimates for the external costs associated with the transport sector are rather conservative.

Figure 4.18 Effects of health externalities on average substitution costs and benefits for specific technologies in 2030



Including the external costs of health effects has the largest impact on the substitution costs of traditional use of biomass.

4.2.4 Fossil fuel subsidy reductions and substitution costs by sector with externalities

Governments and taxpayers pay two forms of energy subsidy:

- Pre-tax subsidies, which are what taxpayers contribute to a consumer's energy bill;

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- Tax subsidies, which include the cost to society of pollution caused by burning fossil fuels and nuclear power, such as environmental degradation and higher health bills. We might consider this second form of subsidy as a form of pollution subsidy.

The IEA estimates that governments spent USD 409 billion in pre-tax fossil fuel subsidies in 2010, USD 523 billion in 2011 and 544 billion in 2012: a rise of 135 billion in two years (IEA, 2011, 2012d, 2013a). Pre-tax subsidies for renewable energy grew from USD 66 billion in 2010 to USD 101 billion in 2012, a rise of 35 billion over the same period.

The bulk of tax subsidies were polluter subsidies. According to the International Monetary Fund (IMF), tax subsidies for fossil fuels include value added tax exemptions (around USD 300 billion per year), the public health care cost caused by air pollution (USD 400 billion) and climate change (USD 720 billion) in 2011 (IMF, 2013). In contrast tax subsidies for renewables are negligible. Fossil fuel tax subsidies exceeded pre-tax subsidies by a factor of three.

Pre-tax subsidies in 2012 were more than five times higher for fossil fuels than for renewables.

Combining pre-tax and tax subsidies, the world paid a total USD 1 900 billion in fuel subsidies in 2011, almost exclusively for fossil fuels. Fossil fuel subsidies exceed 50% of coal, natural gas and crude oil supply cost.

Per unit of energy produced, modern renewables get 50% more pre-tax subsidies than fossil fuels. But renewable energy solutions produce no pollution and reduce healthcare cost. Also these are 'learning investments', which help to reduce technology cost and improve competitiveness over time. By contrast, fossil fuel subsidies sustain declining industries and degrade the environment.

REmap 2030 shows that if we use more renewable energy, we save money. REmap Options save between USD 120 to 740 billion on a post-tax basis in 2030, the net result of additional cost of USD 133 billion on a pre-tax basis and savings of USD 255-870 billion in tax subsidies.

Renewables energy subsidies are beneficial, while fossil fuel subsidies are harmful.

Implementing all REmap Options would require subsidies of USD 315 billion per year – a tripling of renewable energy subsidies compared to the level in 2012. Per unit of modern renewable energy delivered, the subsidies would halve. This assumes that harmful external effects of fossil fuels are not priced. If for example CO_2 emissions due to fossil fuel use are priced around USD 35 per tonne – a low estimate of the damage they cause – the cost of fossil energy supply rise and REmap renewable energy options are cost neutral on a pre-tax basis.

Table 4.3 compares the substitution cost of REmap Options by sector and the total energy system from the perspective of the government. As shown in Chapter 3.3, the substitution costs of the total of all sectors is USD 2.5 per GJ. Taking into account the low and high ends of the human health benefits would reduce the average substitution costs of all REmap Options by USD 1.9-5.1 per GJ.

Taking into account the externalities related to greenhouse gas emission reductions, the substitution costs could be reduced by USD 2.9 (for a price of USD 20 per tonne of CO_2) to USD 11.2 per GJ (for a price of USD 80 per tonne of CO_2).

Renewables energy subsidies can be contained even while doubling the share of renewables in the global energy mix.

Combining the avoided external costs related to CO_2 emissions and human health achieved through the REmap Options, the average substitu-

Table 4.3 Comparison of substitution costs for the 26 REmap countries and the world as a whole

	REmap Options	CO_2 Emission Savings	Avoided External Costs (USD bln/yr)		Substitution Costs in 2030 (USD/GJ)			
	(EJ/yr)	(Gt CO_2/yr)	CO_2	Human health	Excluding externalities	With human health only	With CO_2 only	With CO_2 and human health
Industry[1]	11	0.9	18 – 70	8 – 30	5.0	2.2 – 4.3	-1.6 – 3.3	-4.4 – 2.6
Buildings[2]	8	0.6	16 – 50	40 – 100	1.6	-9.8 – -3.2	-4.1 – -0.3	-15.5 – -5.1
Transport	9	1.2	17 – 80	7 – 20	-4.1	-6.2 – -4.8	-12.4 – -6.0	-14.5 – -6.7
Power	12	3.3	69 – 260	23 – 60	5.7	0.6 – 3.9	-15.3 – 0.1	-20.4 – -1.7
Total (incl. direct heat)	41	6.2	120 – 460	78 – 210	2.5	-2.6 – 0.6	-8.7 – -0.4	-13.8 – -2.3
Total - global	53	8.6	165 – 640	90 – 230				

Net costs vary widely by sector, from USD 0 to USD -15 per GJ.

1 Externalities in the industry sector related to human health are estimated based on the same data used for the power sector estimates.

2 When the high end of the external costs for indoor air pollution are applied, the substitution costs with human health and CO_2 decrease further to USD -31 to -14 per GJ.

tion costs of the system as a whole would decline from USD 2.5 per GJ to between USD -2.3 and USD -13.8 per GJ.

Table 4.3 also shows developments at the sector level. When avoided external costs relating to the health and CO_2 benefits of the implementation of the REmap Options are accounted for, the result is cost savings across all sectors.

The substitution costs of the building sector show the largest change when externalities are included. Air pollution related to the combustion of traditional use of biomass in open fires is a major source of health problems in the developing world. When traditional use of biomass is substituted with forms of modern renewable energy, the avoided external costs reduce the average substitution costs in the residential and commercial sectors (buildings) by more than USD 15 per GJ. In the power sector, the substitution of coal results in both improved public health effects and a significant reduction in emissions. If the avoided external costs relating to both health and CO_2 are applied to the substitution cost in the power sector, the substitution cost will be reduced by at least USD 7.4 per GJ and result in cost savings.

Energy policy must take into account health and environmental effects in order to reflect the full value of renewable energy development.

The analysis shows that externalities should be included in new policies in order to ensure that the overall savings from the implementation of all REmap Options are accounted for properly.

4.3 Socio-economic benefits

IRENA finds that doubling the share of renewable energy would have a minor, but positive effect on global employment in the energy sector, although the effects will differ from one country to another.

Table 4.4 Employment effects of REmap Options

	Additional Direct Jobs (million)[1]	
	Cumulative (2013-2030)[2]	Annual Average (2013-2030)
Renewable Energy Sector Only	60	3.5
Conventional Energy Sector Only	-44	-2.6
Energy Sector (RE and conventional)	16	0.9

The REmap Options would generate 3.5 million jobs in the renewable energy sector and 900 000 net jobs in the energy sector as a whole.

Note: Direct jobs refers to employment which is generated directly by core activities without taking into account the intermediate inputs necessary to manufacture renewable energy equipment or construct and operate facilities; e.g., the jobs in steel or plastic industry are not included but those in solar PV manufacturing and installation industry are.

1 Difference in employment between the Reference Case and the implementation of all REmap Options.

2 Cumulative jobs are calculated by multiplying the additional jobs with the years of employment. In the specialised literature, this is referred to as "job-years".

Compared to the Reference Case, the deployment of REmap Options would result in an additional 16 million cumulative direct jobs in the energy sector as a whole (conventional and renewable) between 2013 and 2030. As a result, 900 000 additional jobs on average per year would be created in the sector in the same period. Jobs would be gained in the renewable energy sector and some would be lost in the conventional energy sector. The increase in jobs in the renewable energy sector would equal 60 million cumulative direct jobs, or on average 3.5 million jobs annually (see Table 4.4)[9].

Figure 4.19 shows the cumulative global employment effects from 2013 to 2030, considering all the energy sources for the Reference Case and REmap 2030, and shows the employment effects on each.

9 It was assumed that traditional biomass does not have any associated employment, given the difficulty in estimating informal employment in the sector. Hence, substituting traditional biomass does not have negative employment effects.

Figure 4.19 Cumulative employment effects by energy resource category in Reference Case and REmap 2030

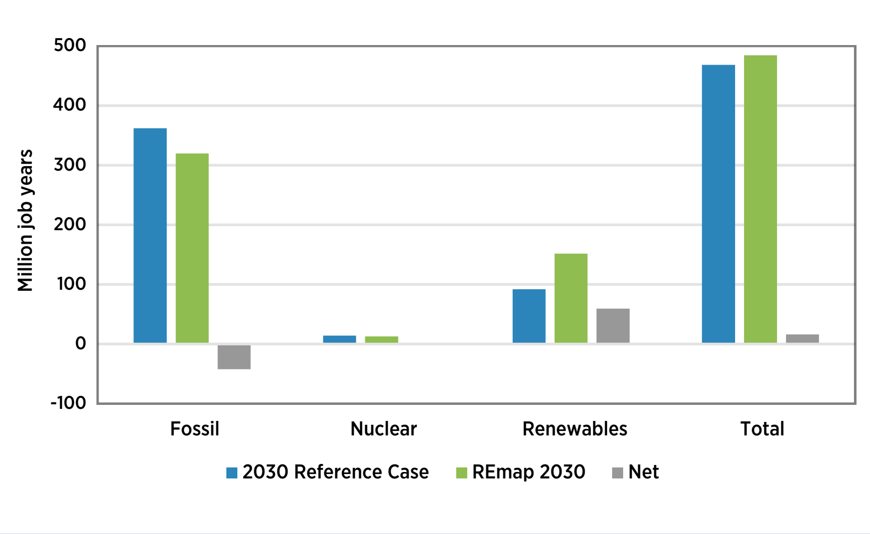

Figure 4.20 Net cumulative employment effects of the REmap Options, per segment of the value chain

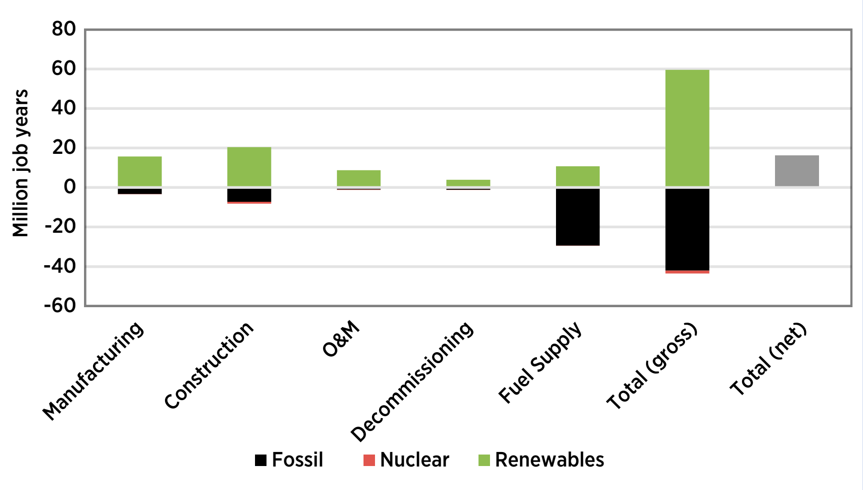

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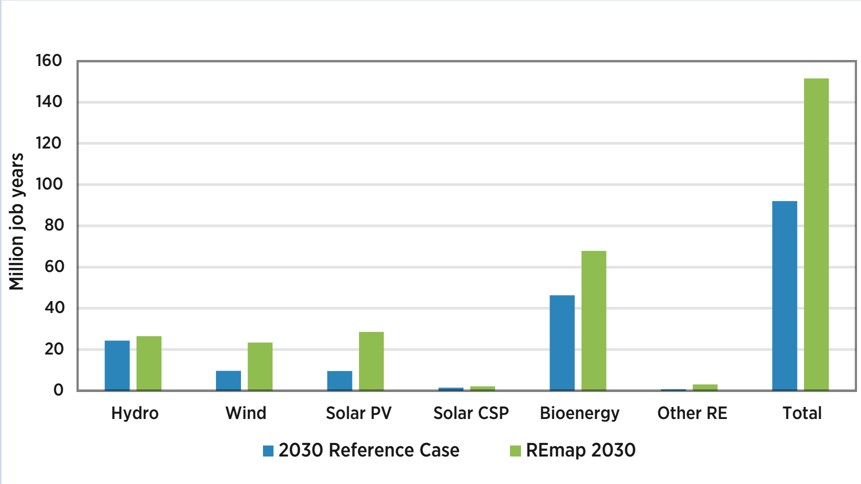
Figure 4.21 Global employment effects by renewable energy technology, cumulative 2013-2030



As more renewables are used, conventional energy consumption decreases. As a result, employment is reduced in the fossil and nuclear industries. However, the jobs created in the renewables industries exceed the ones lost in the fossil fuel and nuclear ones, leading to a positive net effect[10]. Figure 4.20 allows us to better understand what lies behind the net effects in each family of energy technologies (*i.e.*, fossil fuels, nuclear and renewables) with respect to the different elements of the value chain.

As shown in Figure 4.20, the net effect in the fossil fuel industry is negative (-42.1 million job-years), due mainly to job losses in fossil fuel production. The net effect in the nuclear industry (-1.5 million job-years) stems mainly from the construction segment of the value chain. The net positive effect in the renewable energy industry (+59.6 million job-years) comes predominantly from the construction of renewable power generation facilities, followed by manufacturing, fuel supply (biomass and biofuel supply for power generation, buildings, industry or transportation), and O&M and decommissioning.

Figure 4.21 shows the breakdown of the total cumulative employment effects in the renewables industry by renewable energy technology. Most renewable energy jobs are created in the bioenergy sector, due mainly to the labour intensity of production, followed by solar PV and hydro.

10 Excluding the jobs in the traditional biomass sector.

Key points

- The REmap Options increase the renewable energy share in power generation to 44%. Including power and district heat consumption from renewable sources, the share in the end-use sectors is 38% in buildings, 26% in industry and 17% in transport. Excluding power and district heat, the share in end-use sectors is 35% in buildings, 19% in industry and 15% in transport.

- The renewable energy share in the power sector of countries based on REmap 2030 ranges between 15% and 97%.

- Countries significantly underestimate the impending power sector transformation. Solar photovoltaics (PV) could grow to 1 250 gigawatt-electric (GW_e), considerably more than the 500 GW_e projected in the Reference Case. Onshore wind power capacity could grow five-fold.

- An additional 5 400 terawatt-hours (TWh) of renewable power in 2030 will be split across 43% onshore and offshore wind, 23% biomass, 19% solar PV, 5% hydro and 3% geothermal.

- The average age of existing fossil fuel and nuclear plants is 20-28 years. Around 900 GW_e of new coal plants is planned in the Reference Case between 2010 and 2030. It is critical that this planning is reconsidered.

- If all REmap Options are deployed, eight countries will reach above 40% variable renewable energy in their capacity mix: Denmark, Germany, the UK, South Africa, Japan, Australia, France and India. Grid integration is therefore a priority issue.

- The renewable energy share in the building sector of the 26 REmap countries ranges between 15% and 91% in REmap 2030. A large difference exists in heat demand per household or floor area across countries, which explains the wide range in renewable energy shares. Modern biomass use in the building sector reaches 13 exajoules (EJ), and other renewables for heating (solar thermal and deep geothermal) total 9 EJ.

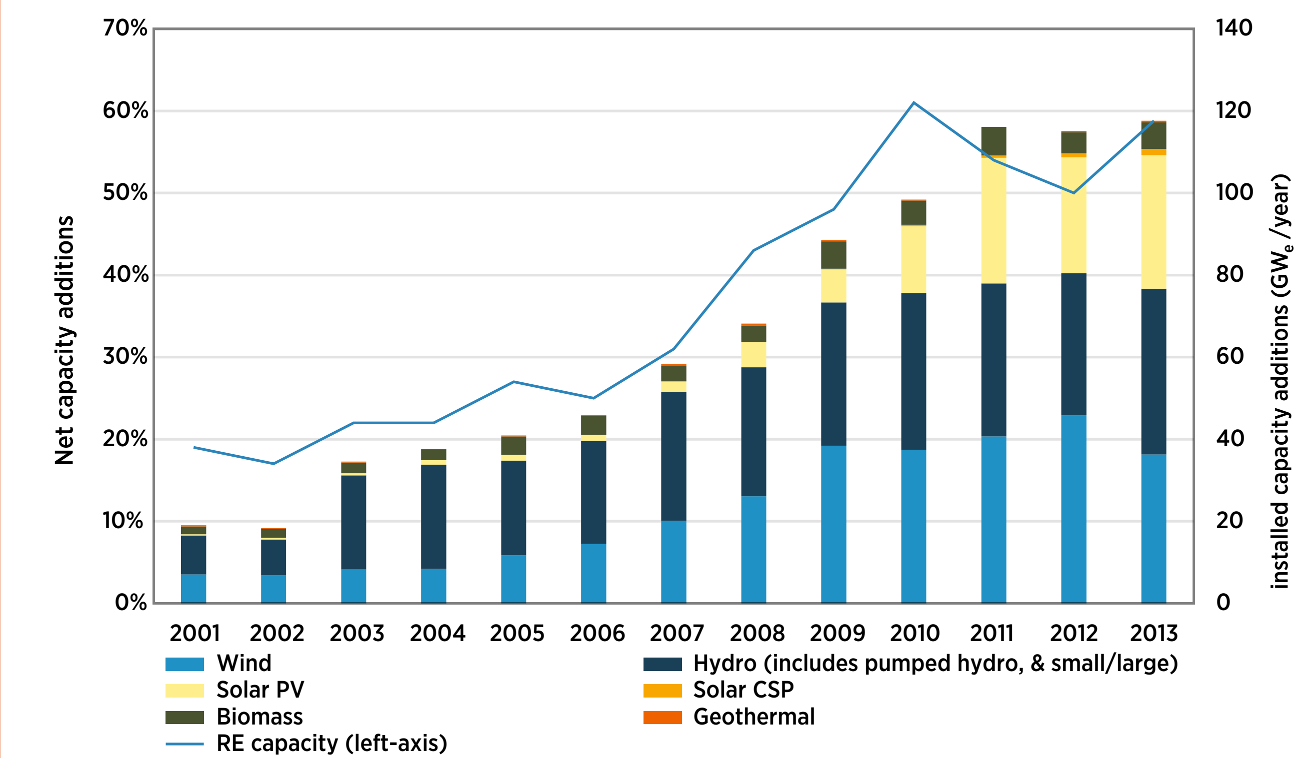
- The renewable energy share in the transport sector of the 26 REmap countries ranges between 0% and 51% in REmap 2030. A projected 16 EJ of biofuels will be consumed, with 2 EJ of renewable power for electric vehicles and other electrified transportation systems.

- The renewable energy share in the industry sector of the 26 REmap countries ranges between 4% and 87% in REmap 2030. A projected 21 EJ of bioenergy will be consumed, with 3 EJ of other renewables such as solar thermal, geothermal and heat pumps.

- The potential of biomass supply ranges between 95 EJ and 145 EJ per year by 2030, split into a maximum of 66 EJ of agricultural and food residues, 42 EJ of forestry regrowth and residues, and 37 EJ of energy crops. REmap 2030 implies as much as 108 EJ of primary biomass demand, more than twice today's level and close to the lower estimate of the supply potential for 2030. Both quantities and supply cost and prices are subject to considerable uncertainty, however.

This chapter provides further details of the REmap 2030 findings for the power (**Chapter 5.1**) and individual end-use sectors (**Chapters 5.2 to 5.4**). For each sector, an overview is provided which explains the situation in 2010, outlining the demand segments and the developments between 2010 and 2030 by country and technology, according to REmap 2030. This is followed by the characteristics and market situation of the key technologies of each sector. The last section (**Chapter 5.5**) discusses the detailed results of the biomass analysis, the resource estimated to have the largest contribution for doubling the global renewable energy share by 2030.

Figure 5.1 Renewables as a share of global power sector capacity additions, 2001-2012



Renewables account for half of global new capacity additions globally today.

Source: GlobalData.com (2013)

Note: The y-axis refers to the share of renewable power capacity compared to the net capacity additions in a given year. Net capacity addition is the total newly installed capacity minus capacity additions used to replace the retired capacity in that year.

5.1 Power Generation

5.1.1 Overview

The power sector is composed of power plants, combined heat and power (CHP) plants and self-generators. In 2010, nearly 20% of all the electricity generated worldwide – 21 408 TWh from 5 183 GW_e of total generation capacity – came from renewable sources (IEA, 2012d). Hydropower makes up the greatest share of renewable electricity by far, accounting for 16% of total power generation, roughly four-fifths of the 19% share of renewable power (REN21, 2011). In 2011, total renewable capacity additions exceeded the capacity additions for fossil and nuclear power generation, if one accounts for closures of old plants. Behind this increase in annual capacity additions lies a doubling of investments within just a decade. Yet wind and solar power surpassed hydro in 2012 in terms of new capacity (see Figure 5.1), a repeat performance after impressive growth in 2011.

Total power generation in the 26 REmap countries is projected to increase from 15 500 TWh per year in 2010 to about 27 900 TWh per year in the Reference Case, according to national plans. If all REmap Options are

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Box 5.1 Capacity factors

What is the difference between "generation capacity" and "power generated"? The former indicates the generator's size; the latter, its size multiplied by the time it runs. A generator with a rated capacity of 1 megawatt-electric (MW_e) produces 1 megawatt-hour (MWh) if it runs at full capacity for an hour. It then has a capacity factor of 100%. If it lies idle for the next hour, its capacity factor is 0% for that hour and 50% for the two together.

Conventional central-station power plants, such as coal and nuclear, tend to run at high capacity factors up to and exceeding 90%. In contrast, depending on local resources, wind turbines have capacity factors of 20-50%, and solar panels closer to 10-30%. Generally, an installed MW of conventional capacity produces more MWh of power than a MW_e of renewable capacity.

But the comparison is misleading. Solar replaces roofs and fields that do not generate any electricity; without a solar array, that sunlight is lost. Likewise, when we do not build wind turbines, the wind we get every day remains unused. In other words, capacity factors for renewables always add to our resource efficiency, whereas fossil and nuclear consumption always subtracts resources from our environment.

implemented, total generation could increase by 1 000 TWh per year to 29 000 TWh per year in REmap 2030 because of electrification in the end-use sectors. Worldwide, this is equivalent to about 1 250 TWh per year of additional power generation.

The global power generation capacity would increase from 5 183 GW_e in 2010 to 8 000-9 000 GW_e by 2030. Compared to total generation, demand from the end-use sectors is about 85%; the other 15% is losses and consumption in the energy sector. This ratio is slightly higher than the 2010 levels of 80%, explained in part by the increasing demand of power from end-use sectors and the decrease in losses in power transmission, distribution and generation.

Electricity is a key energy carrier that can raise the renewable energy share in end-use sectors (see Figure 5.2). The share of electricity is projected to increase only slightly in the industry sector in REmap 2030 compared to the Reference Case. In buildings, the share of electricity increases much higher in REmap 2030. For the transport sector, the share doubles. Power consumption in end-use sectors worldwide will reach nearly 31 300 TWh per year, about 1 300 TWh higher than in the Reference Case due to increased electrification.

Figure 5.2 Electricity-use share in total energy use by sector worldwide, 2010-2030

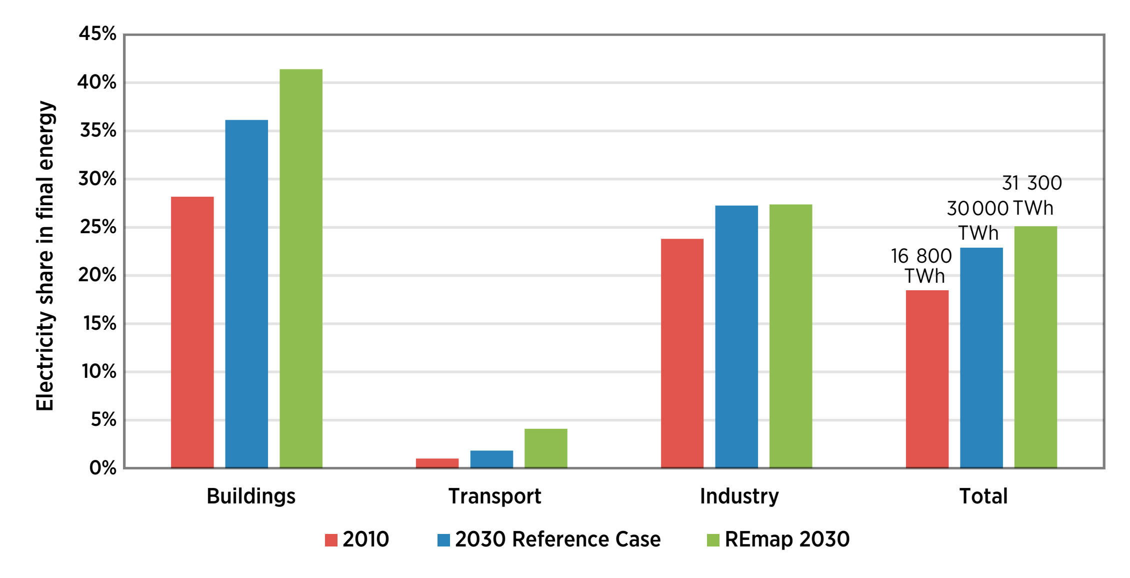

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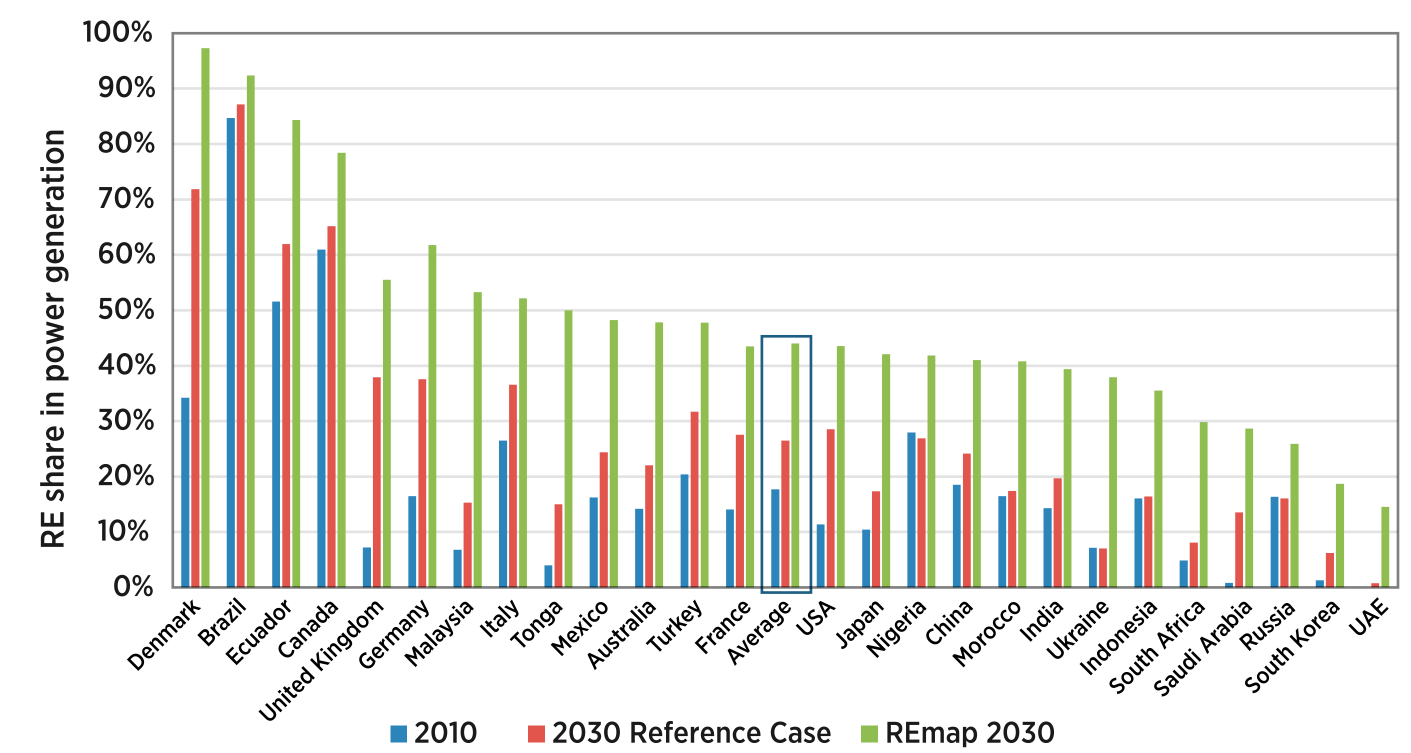
Figure 5.3 Current and projected share of renewable energy in power generation by country, 2010-2030



The average country share of renewables in each country's power sector could range from 15% to 97% in 2030.

In the power sector of the 26 REmap countries, the renewable energy share increases from 18% in 2010 to 44% in REmap 2030, a 2.5-fold increase. Figure 5.3 shows the detailed results by country. Most countries reach a share of at least 40%, up from current levels of 10-20%. With renewable energy shares of 97% and 92%, respectively, Denmark and Brazil will be close to their full potential.

As the power sector's renewable energy share increases in the REmap Options, more than 60% of the total installed capacity in the 26 REmap countries (4 000 GW_e) will be from renewable energy sources (see Figure 5.4). The REmap countries make up some 75% of projected demand, so the global figure will be a third higher at around 4 800 GW_e.

Hydropower is the biggest source of renewable power at present; other renewable energy sources will need to catch up with hydro for the global renewable energy share to double.

Figure 5.5 shows the installed capacities of the power sector for the 26 REmap countries in 2030 scaled to the global level based on the missing market segment. The chart displays the results for the Reference Case (red-filled squares) and REmap 2030 (red-filled triangles) separately. It also compares each technology to the global developments according to the projections of the IEA's medium-term market outlook report up to 2018 (grey-filled circles) (IEA, 2013b). Generally, the country projections should match the technology outlook. Wind (both onshore and offshore) will be the largest source of renewable power (1 635 GW_e), accounting for 30% of the total renewables capacity, followed by hydro (1 600 GW_e) and solar PV (1 250 GW_e). Other sources show a stronger growth rate but from a much lower base.

Yet the country projections are generally lower than technology market extrapolations. Clearly, countries significantly underestimate the upcom-

Figure 5.4 Installed global renewable power generation capacity by region, 2010-2030

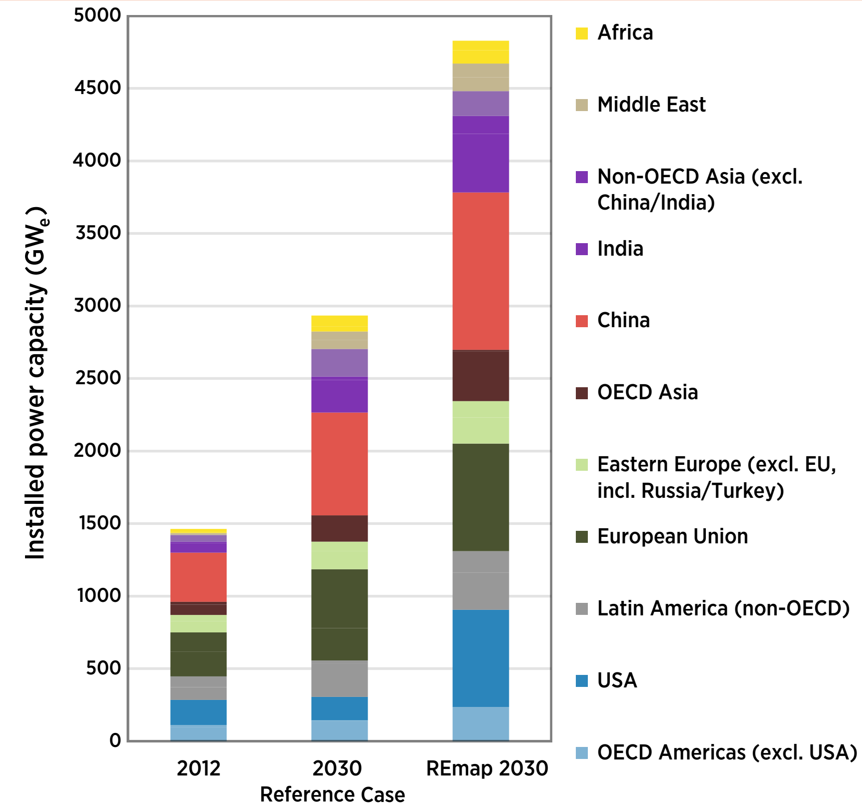
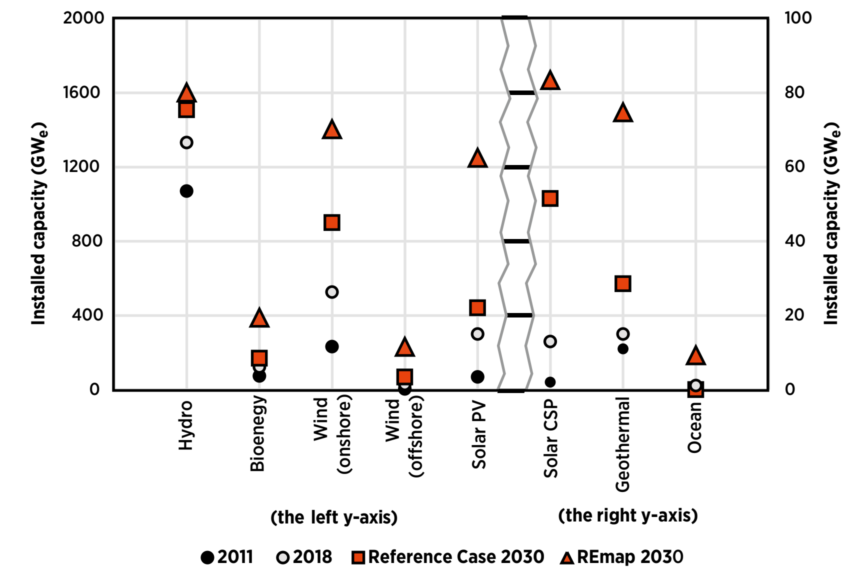


Figure 5.5 Growth projections for renewable electricity technologies



Government projections significantly underestimate the potential of renewable power growth.

Note: Pumped hydro is excluded because it is considered energy storage. Figures for 2018 are based on the IEA mid-term energy market report (IEA, 2013b).

ing transition towards renewable energy – with important consequences for policy frameworks. In absolute terms, the most significant gap exists for solar PV and onshore wind (for each, there is a nearly 1 000 GW_e gap between country projections and technology market projections).

In addition, for all technologies except hydro, the 2030 projection in REmap 2030 is significantly higher than the policy scenarios and also higher than the extrapolation of the technology market trends. The main differences in relative terms occur for niche power generation technologies, notably offshore wind (in the United Kingdom and the US) and geothermal (in the US and Indonesia), where policies can make an important difference. In the case of solar PV, policy reference scenarios suggest 470 GW_e, whereas consideration of all REmap Options would yield around 1 250 GW_e in 2030.

For hydropower, a technical potential exists to expand to 2 000 GW_e, especially if pumped hydro is included. However, planning periods are long, social acceptance is often an issue, power generation sometimes competes with other water uses, geopolitical issues can arise relating to water flow rights, and the suitability of some sites is questioned for geological reasons (such as in Arunachal Pradesh, the state with the main remaining

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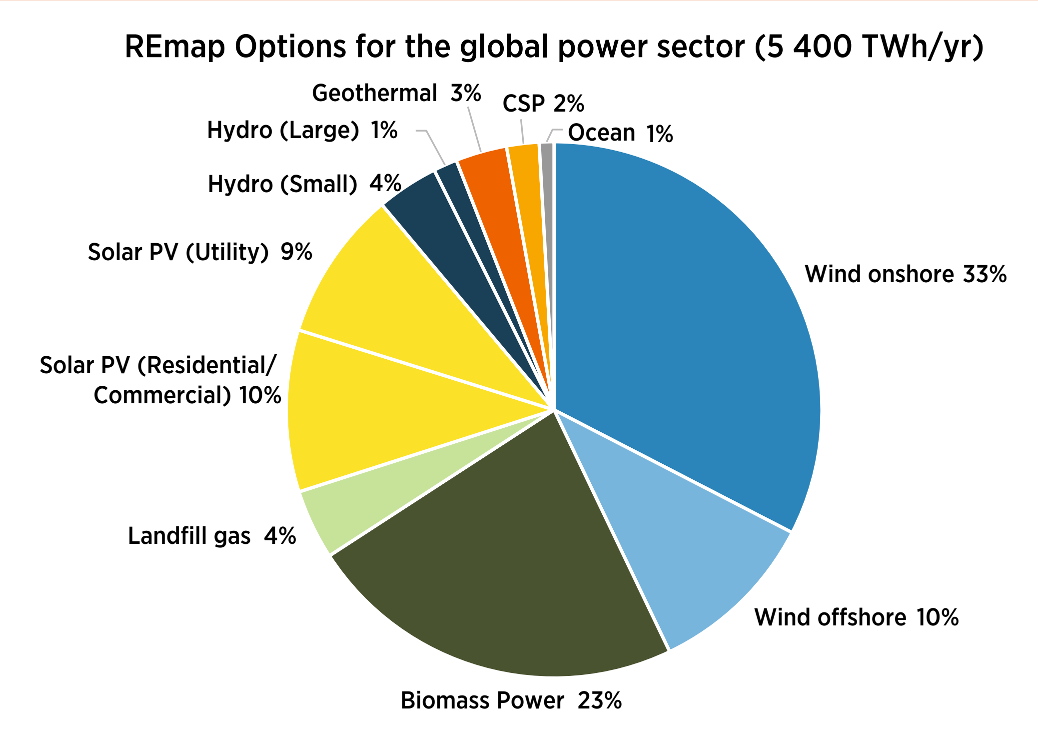
Figure 5.6 Global power generation by technology of REmap Options



Two-thirds of all REmap Options for power involve wind and solar energy.

hydro potential in India). It should also be noted that a major part of the remaining hydropower potential is concentrated in small markets (such as African countries and other Latin American, Central Asian and Southeast Asian countries) not included in the 26 REmap countries.

Figure 5.6 shows the breakdown of power generation according to REmap Options in the power sector by 2030, with the results of the 26 REmap countries scaled to the global level. In total, 5 400 TWh of additional power will be generated from renewable sources in 2030. Wind has the largest additional generation of about 2 350 TWh per year worldwide (three-quarters from onshore, a quarter from offshore) representing 43% of the total potential. Biomass follows wind with additional generation of more than 1 250 TWh per year (23% of the total). Solar PV and concentrated solar power (CSP) have an additional generation of 1 135 TWh per year (21% of the total). Additional hydro (270 TWh per year) and geothermal (160 TWh per year) power generation are less in comparison, hydro because significant growth is already included in the Reference Case, and the technical potential is a limiting factor. Finally, both power from landfill gas (215 TWh per year) and ocean power (50 TWh per year) contribute in small terms to overall potential.

Figure 5.7 provides the breakdown of power generation of 37 000 TWh per year worldwide in REmap 2030 by technology.

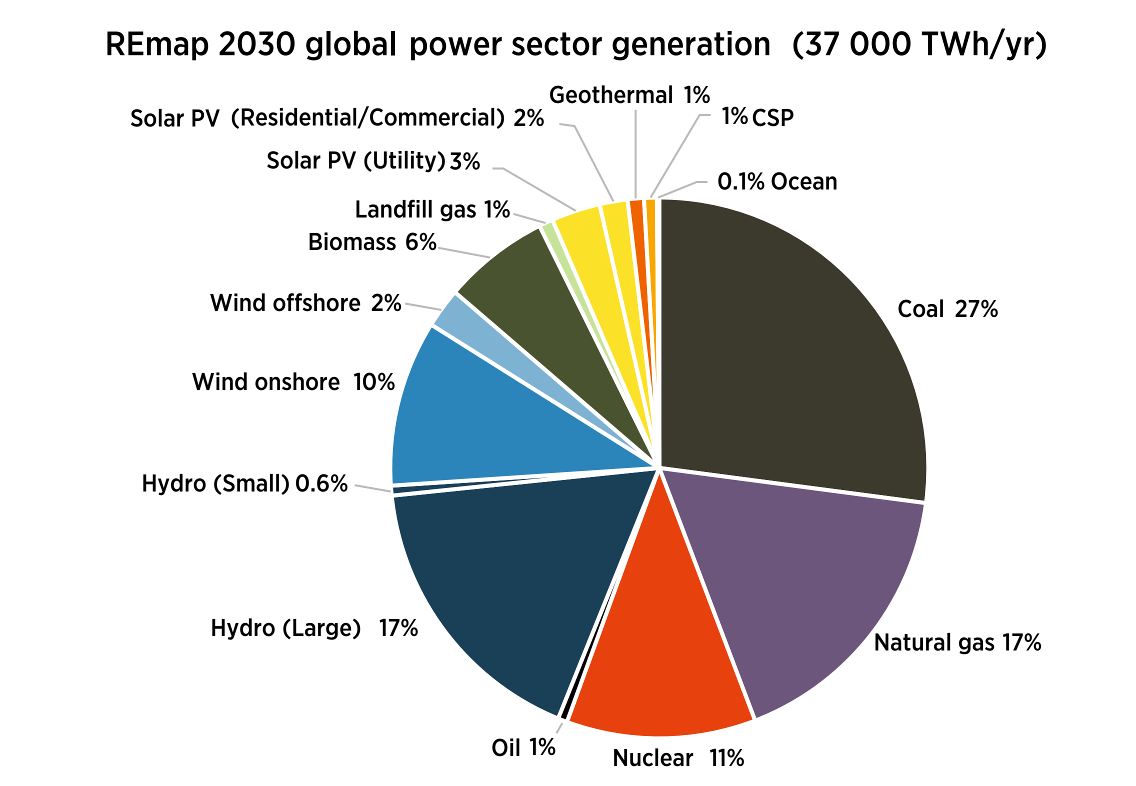
Electricity is the field in which renewables have drawn the most attention – and for good reason. Hydro produces the most renewable power today and is expected to remain the largest source in 2030 (see Figure 5.7). Wind and solar are the two technologies currently booming the most. As the renewable energy share in power generation will rise quickly, a switch to electricity – especially in the transport sector – will enable higher renewable energy shares for the whole economy.

Nonetheless, the role that the power sector plays in the energy transition can also be overstated. The share of electricity in total final energy consumption (TFEC) will be around 25% by 2030 if all REmap Options are implemented. It is therefore not possible to double the share of renewables in global TFEC by 2030 with deployment options in the power sector alone.

5.1.2 Wind power

Approximately 300 GW_e of wind power capacity had been installed worldwide by mid-2013. A kWh of wind power costs as little as US Dollar

Figure 5.7 Global power generation by technology in REmap 2030



Renewable energy accounts for 44% of all power generated; hydro is the largest renewable power source.

Most of the new wind capacity is onshore, with a noticeable trend towards larger turbines. The share of turbines worldwide with a capacity of at least 3 MW_e has grown from 2% in 2010 to 19% in 2012. The average rotor diameter in Germany increased from 60 metres in 2000 to 88 metres in 2012, with the average hub height also growing from 70 to 111 metres (Böll Foundation, 2013a). Such turbines have a higher capacity factor in a given site because wind speeds increase with height. At the same time, the number of suitable sites is also expanded.

There is also a split between technologies for sites with high and low wind velocities. In locations with high wind velocities, generators can be larger – around 260-280 watts per square metre (W/m^2), compared to 200 watts per square metre in sites with low wind speeds. In low-wind areas, rotor blades are made larger – often without increasing generator size – to cover a greater swept area, allowing more wind energy to be harvested. This may result in higher capacity factors compared to the use of conventional turbines in similarly low-wind sites. In Germany, the capacity factor of onshore wind turbines in windy locations is expected to increase from 28% to 39%, and in locations with low wind velocities from 17% to 29%.

(USD) 5 cents in the best locations, but the cost also depends on socio-economic conditions (*e.g.*, labour costs). Onshore wind is currently much less expensive than offshore.

Wind turbines can be installed not only in large clusters where wind resources are strong, but also as individual turbines to serve specific local needs. Furthermore, modern turbines are themselves highly scalable, from small generators of just a few kilowatts to giant, powerful towers with thousands of kilowatts.

Offshore wind is an emerging field which is expected to develop towards lower costs. Unlike onshore wind farms, which can be as small as a single turbine, offshore wind farms tend to be as large as possible. The average size of offshore wind farms is currently around 200 MW_e, but the ones now being built and planned have hundreds of megawatts; at the end of 2013, the London Array was the largest completed wind farm at 630 MW_e. At the end of 2012, around 6 GW_e of wind power capacity had been installed offshore worldwide (around 2% of the total installed capacity), with the UK being the largest market. One main enticement in the

Box 5.2 Integrating variable renewable power into the grid

Hydropower has been and remains the main source for renewable power generation, but wind and solar PV generation are expanding rapidly. In 2012, wind and solar PV comprised three-quarters of the total added renewable power generation capacity. The REmap countries expect their share to continue to rise. In their national plans, the share of wind and solar PV is projected to rise from 2.5% of global installed capacity today to 15% in 2030. If all REmap Options are explored, this share will increase to 34%.

The unprecedented growth rates for wind and solar PV are fuelled by both technology and economics (*e.g.*, financial support incentives). Both technologies are modular and can be built quickly at many different locations, whilst their costs have reached those of conventional power. Yet the output of wind and solar PV depends on the availability of wind and sunshine. This raises concerns about the extent to which these variable renewables can be integrated into the existing electricity system[1].

The concerns surrounding the integration of variable renewables into the grid are not new. Traditionally, the transmission and distribution grids are designed to take electricity from large centralised power stations through transmission and distribution lines to the consumer. Although electricity demand has always highly fluctuated, grid operators manage to adjust power supply to demand based on years of experience[2]. When consumers started to produce their own electricity, mainly through wind turbines and solar PV panels, both the transmission and distribution operators were confronted with a completely new situation. Now, both supply and demand need to be predicted.

The last ten years have already shown that many of the concerns by grid operators can be overcome with tools and technologies already in place. Today, Denmark's grid operators deal with an electricity system supplied more than 30% by wind, while Germany and Italy handled 4.7% and 6.7%, respectively, of solar PV in their annual gross electricity consumption in 2012. Wind has already peaked at more than 100% of demand in Portugal and Denmark. Examples of mature technology and techniques that have helped grid operators to deal with variability are peaking plants, reserve capacity, load forecasting techniques, pumped hydro, demand-side management or response, and interconnection.

However, technical issues are becoming apparent as countries transition towards higher shares of renewables. Issues like instantaneous penetration levels of variable renewables of 100% or more, location constraints for renewable resources, the connection of thousands of installations to low-voltage grids, and the non-synchronous nature of variable renewables are new to most grid operators.

In a few countries – except for small isolated countries like island states – these technical issues will affect the system in the next couple of years. At a global level, only a handful of countries – Denmark, Spain, Ireland, Portugal and Germany – have variable renewable energy shares above 10%. However, all countries will have to start planning for these issues today if a transition is considered.

Figure 5.8 shows the penetration level of variable renewables in the power sector – wind power, solar PV and CSP without storage – in terms of capacity and power generation if all REmap Options are implemented in the power sector by 2030. Only 4 of the 26 REmap countries will have variable renewables in capacity and generation beyond 30% by 2030 in addition to Denmark today: Australia, Germany, Morocco and the UK. India and Japan have variable renewables shares in capacity higher than 40%; however, their share of variable renewables in generation is around 20%. Different countries have different strategy and policies to deal with the increasing share of renewable energy. Countries with the highest variable renewable energy share according to the REmap 2030 will face the biggest challenges.

Denmark, which has the highest share (86%), is part of the Nordic Power Exchange, and it has a well-structured interconnector capacity with Germany, Sweden (nuclear power) and Norway (pumped hydro). New interconnections are considered with the Netherlands, and the existing capacities are planned to be expanded (MII, 2008; EC, 2012). Denmark uses advanced tools for improved demand forecasting. Biomass is expected to play an important role in power generation, next to wind. Many studies are being prepared which support the country's grid expansion plans and the electricity transmission grid; they also contribute to a better understanding of the challenges ahead.

Germany has the second highest variable renewable energy share (74%). Grid development plans (separately for offshore) with a ten-year horizon are being

1 Run-of-river hydro, wave and tidal power are also considered to be variable renewable energy technologies, but their penetration levels compared to wind and solar PV are small.

2 Most central-station power plants provide dispatchable power, which means that they can generate electricity upon demand and at predetermined output levels.

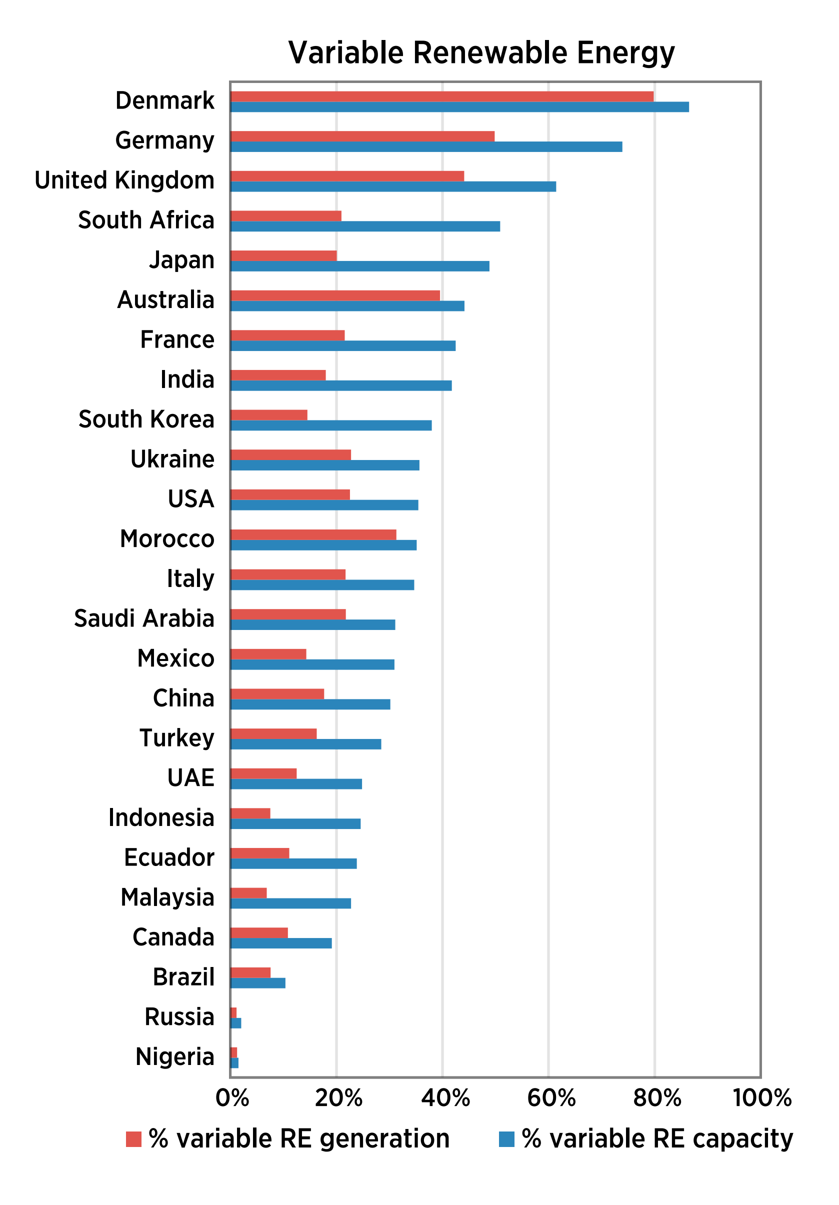
prepared by the transmission system operators as requested by the Power Grid Expansion Act. These are inputs to the Federal Grid Plan, which proposes planned projects for approval. The Grid Expansion Acceleration Act provides support for planning, approving and implementation of projects as well as creates the optimal investment conditions. The Energy Industry Act was expanded to better support storage and smart grids (BDEW, 2013). New storage facilities do not need to pay access charges to the grid. Variable electricity tariffs are offered to consumers to reduce peak hour demand. Many power system analyses conducted by national and private organisations look into accommodating variable renewable energy at the country and region levels (DENA, 2011).

In the cases of France and the UK, the consequences from the increased share of variable energy are also being analysed through power system models. Plans for raising the interconnector and energy storage capacities to meet variable renewable energy shares of nearly 40% and the growth in peak demand are being analysed and discussed in France (RTE, 2011; Loisel *et al.*, 2014). Similarly, in the UK, grid integration needs are being modelled for high shares of wind capacity as estimated in REmap 2030 (Carbon Trust, 2008; National Grid, 2013). However, increased solar PV (8 GW according to REmap 2030) use in the UK is not included, and the limited north-south transmission capacity is often highlighted as a barrier for increased variable renewable share. Hence, it may be challenging for the UK to reach the very high shares as indicated by REmap 2030. This is also the case for Japan, as the country is isolated, the demand and supply locations are not necessarily next to each other and there is limited intergrid connection across the country's nine grids (Takehama, 2013).

Despite the similarities in estimates of variable renewable energy share between countries themselves and REmap 2030, findings should be used in country power-system models to better understand the consequences. This will be useful for gaining further experiences and developing plans for dealing with high shares of variable renewables, which in general show the following areas as discussed by IRENA's forthcoming grid report (IRENA, 2014e):

- Variable renewable energy is manageable on the power grid,
- The additional cost is affordable (< 10% of total),
- Technology development is rapid, and
- There is no "one size fits all" solution (it depends on the system).

Figure 5.8 Global power generation by technology in REmap 2030



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offshore sector is less public opposition when, for example, projects are owned locally as opposed to foreign investor ownerships; another benefit is higher capacity factors of 40-50%, bringing offshore wind closer to baseload reliability.

Where cities and densely populated areas border the sea, offshore wind can be especially attractive. On the other hand, the cost tends to be higher than for onshore wind, and grids need to be expanded more often to accommodate offshore wind farms. The average distance from shore is projected to increase from 60 kilometres today to 100 kilometres by 2020 (Roland Berger, 2013). In Europe alone, offshore wind capacity is projected to grow to 40 GW_e by 2020.

Offshore wind turbines tend to be larger than those designed for onshore. Commercial turbines available today have a capacity of 5-7 MW_e, and turbines with a capacity of 10 MW_e are currently being developed. All offshore turbines currently built have fixed-bed foundations, although floating platforms are being tested in Denmark, Norway, South Korea and Japan. This new technology will allow turbines to be built in waters deeper than 100 metres (MIC, 2013).

The focus on sites with great wind resources may, however, provide a cheaper kilowatt-hour on site only to entail higher transmission costs if the power has to travel a long way to reach consumers. These costs can largely outweigh whatever cost benefits that the focus on good wind resources provides.

Fichtner and Prognos (2013) assessed the cost-reduction potential for offshore wind in Germany. It is projected that the investment cost for offshore wind turbines with fixed-bed foundations will decline 17-27% by 2023, down from approximately USD 5 600 per kW_e in 2013 (including grid connection). At the same time, operation and maintenance (O&M) costs are projected to decline 19-33%. The nominal weighted average cost of capital (WACC) will decline from 9.9 to 7.7%, and electricity generation per kilowatt will increase by around 10%. The next result is a fall in the levelised cost of electricity (LCOE) from approximately USD 17-20 cents in 2013 to approximately USD 10-13 cents per kWh in 2023.

5.1.3 Solar PV

Over the past few years, the price of solar PV has plummeted so quickly that many scenarios in the Reference Case have become grossly outdated. The trend is expected to continue, with a kwh of solar power costing less than USD 10 cents practically everywhere by 2020. Grid parity – the point at which solar power from a residential roof costs less than power from the grid – could mean that households will increasingly install PV without further governmental incentives. By 2030, solar PV could make up such a large share of power supply thanks to citizen investments as

Box 5.3 Seasonality

Solar PV is often a great way of reducing the price of peak power. Generally, power consumption peaks during midday, which coincides nicely with peak solar power production. Likewise, power demand is greater in the summer than in the winter in countries that rely heavily on air conditioning, such as Japan and the United States.

In contrast, Germany generally has its peak power demand for the year in evenings at the end of November, several hours after the sun has gone down. In this case, solar PV does not help cover peak annual demand. Germany also has the most PV installed as a share of peak power demand: roughly 34.5 GW_e at the end of July 2013, compared to peak annual demand of around 80 GW_e. During the summer, all of this solar PV offsets a chunk of the medium load, not just the peak load, so spot power prices sometimes fall below zero.

This outcome is positive for consumers but problematic for firms which provide backup capacity when not enough solar power is available. Backup generators may not always be able to run for enough operating hours to remain profitable.

to disrupt the conventional power sector in numerous countries, such as Australia (RENEW, 2013).

In 2012, solar PV grew to more than 100 GW_e of installed capacity, two-thirds of which went up in Europe. Markets are shifting, however, with Asia accounting for the most gigawatts installed in 2013. Solar PV is extremely scalable, ranging from off-grid solar home systems of just a few dozen watts to residential roof arrays of a few kilowatts and large-scale ground-mounted farms of dozens of megawatts. The largest solar PV plant in the world currently has a capacity of around 500 MW_e, but India has announced plans to construct a 4 GW_e plant – more than two times the country's existing grid-connected capacity. By end of 2016, the project's first phase is expected to be finished with a total installed capacity of 1 GW_e (CleanTechnica, 2013a).

There is a clear trend towards PV systems that allow for remote control by grid operators. Inverters also increasingly come with enhanced functionality, such as frequency control and reactive power. The hybridisation of mini-grids is also progressing with more advanced controllers, allowing diesel generators to run optimally and only when there is not enough renewable electricity.

For solar PV to move beyond around 10% of total power demand in a given country, power storage will increasingly be needed. Both large-scale technologies (such as pumped hydro) and distributed battery-storage systems are projected to grow significantly in the coming years.

There has been some concern about whether distributed solar PV would eventually destabilise power grids, but there have been no problems up to now in Germany. On sunny days, more than 20 GW_e of electricity from the roughly 35 GW_e installed (as of August 2013) can be produced – equivalent to around a third of total peak demand, and one of the highest ratios in the world (CleanTechnica, 2013b). High levels of production also have occurred in Italy, where the level of solar penetration has also not destabilised the grid. In general, distributed solar PV reduces the need for greater investments in grid expansion.

Although both wind power and solar PV are "variable" (meaning that power is only generated based on the weather), the variability of solar PV is different. Countries with wind turbines spread across a large geographical area have some level of wind power production practically all the time. For instance, wind power production peaked as high as 82.5% of installed capacity but was below 5% a fifth of the time in Germany (Chabot, 2013). However, wind gusts can result in significant local fluctuations on a second or minute scale. Regulatory demand for power management capability of wind turbines is rising to deal with these fluctuations, either through output curbs or battery storage. In addition there are further technical options to deal with fluctuating demand, whether electronically, mechanically (using the mass of the turbine) or by adding short-term storage like flywheels.

In contrast, solar panels reliably produce no power for roughly half of the time, when the sun is down. And because a certain threshold of insolation is needed for some light to be harvested, solar panels generally produce a significant amount of electricity for only around 10 hours a day out of 12 hours of sunlight in many locations.

5.1.4 Biomass power

In 2012, installed biomass power generation capacity reached more than 80 GW_e, equivalent to 1.5% of global power generation capacity. Solid biomass (including black liquor) and municipal solid waste (MSW) accounted for nearly 80% of the total capacity, with the remaining 20% being mainly biogas. Small amounts of liquid biofuels are also used to generate power (about 2 GW_e in total). In addition, increasing amounts of pellets are co-fired in coal plants. Because biomass power generation is an excellent way of providing renewable backup capacity for variable wind and solar, it is expected to be a cornerstone of renewable electricity targets worldwide (RE Focus, 2013).

Biomass generators are dispatchable and can provide reliable baseload power.

Because of the diversity of feedstock, technologies vary. Capacity expansion is likely in this decade across a range of conversion platforms, including dedicated greenfield facilities which burn biomass exclusively, brownfield biomass and coal co-fired plants, and anaerobic digesters which produce biogas. The type of biomass used for power generation depends on what is available in different regions. In Europe, for example, wood products and waste are used for power generation. In India, Brazil and some African countries, bagasse from sugar production is combusted in CHP plants. Co-firing with coal is common in the Netherlands and Finland.

Production from MSW is also increasing, by about 6% per year in the last decade. Today's installed capacity exists mainly in the EU, the US and Japan, but developing countries and economies in transition are catching up. Biogas capacity growth is even higher, at about 10% per year. As of the end of 2012, China (800 MW_e) and India (91 MW_e) together had nearly 900 MW_e of biogas capacity installed (RE Focus, 2013). In the EU, Germany has the largest capacity, and a vegetable oil-fired CHP plant in Italy with a capacity of 24 MW_e has been generating power and heat since 2005 (RE Focus, 2013).

Power generators fired with biomass are often smaller than large central-station coal plants and can be installed in farming communities and industries close to sources of biomass. The waste heat from power production is frequently used as a heat source in a process called cogeneration, one of the most efficient ways to use biomass for heat and power production. In such cases, the focus is usually on increasing the unit's overall efficiency; in practice, this goal is achieved by recovering as much heat as possible, not by increasing power output. The result is that power generation efficiency remains relatively low at 10-15%, although heat recovery increases the total system efficiency up to 80% or more. Much higher efficiencies are possible and are already achieved at existing plants, such as in Denmark. Efforts to increase the efficiency of power production alone can double power production but also increase overall cost.

Supported by strong policy and health incentives, the installed biomass power capacity in Europe has increased in the last decade. The region currently accounts for nearly 50% of the installed capacity worldwide, but capacity additions in Asia-Pacific and Latin America through 2020 are expected to result in a modest shift away from Europe. Growth in North America is contingent upon the anticipated rollout of bio-refineries for advanced biofuels. Navigant Research forecasts that, under an optimistic scenario, global installed biomass power capacity could reach 129 GW_e by 2020 (Navigant, 2013a).

5.1.5 Hydropower

Hydropower is an established technology, and the main goal now is to reduce its environmental and social footprint. Some parts of the world still have great hydropower potential, while further growth in other areas will come mainly from refurbishing existing plants and developing small hydro. Efficiency gains can only be modest because levels are already in the range of 90-95% for new systems.

In 2013, hydro capacity in operation reached more than 1 000 GW_e, and another 224 GW_e is under construction (Hydropower & Dams, 2013). In 2012, 30 GW_e of additional capacity was installed – half of which was in China – and in 2013, an additional 30 GW_e is expected to come on line in China alone. For many countries, hydropower is a key source of renewable energy. Some countries, such as Austria, have already reached a roughly 70% share of hydro in their power sector. In Sri Lanka, which has utilised about 70% of its theoretical potential, hydropower contributes to 40% of the electricity generation mix. Other South Asian countries with resources for hydropower, such as Bhutan and Nepal, also plan to increase its use, but financial challenges currently limit utilising this potential. In 2012, Vietnam completed the construction of a 2.4 GW_e hydro plant in the Black River, the largest plant in Southeast Asia.

In Peru and Mexico, hydropower is planned to play an increasingly important role in supplying domestic power demand. Most countries in Africa are also seeing large investments in major hydropower projects: the Grand Inga Dam in the Democratic Republic of the Congo, currently only in planning stages, would upon completion of its nine phases have a total capacity of 40 GW_e, or nearly two times the capacity of the Three Gorges Dam on China's Yangtze River (22.5 GW_e) (Hydropower & Dams, 2013).

There is no single definition of what separates small hydropower from large, but typically all plants below 10 MW_e are considered to be small hydro. As a rule of thumb, around 10% of total hydropower potential stems from small hydro, which can play a crucial role in electrification. China alone has around 50 000 small hydro plants, which have played a key role in the electrification of the country.

The remaining potential for large hydropower is unevenly distributed. Around 600 GW_e of economic potential is located in the Amazon basin; the Himalayan foothills in China, India and Central Asia; sub-Saharan Africa; and Siberia. Nearly two-thirds of the global small hydro potential is in Asia, with global potential estimated at 173 GW_e, compared to the more than 75 GW_e of systems smaller than 10 MW_e currently installed (UNIDO/ICSHP, 2013).

Hydropower can be split into two types of systems: run-of-river plants and manmade reservoirs. Run-of-river plants depend on the river's flow rate, which often fluctuates seasonally. Reservoirs can be artificial lakes fed with water from natural streams or, increasingly, water pumped up from a lower level. When water is pumped in this matter, the main focus is power storage; when power prices are low, water is pumped into the higher reservoir and allowed to flow back through turbines to generate power when prices are high. Pumped storage is by far the most efficient, cheapest and most widely deployed form of electricity storage today, with around 150 GW_e of capacity currently installed worldwide[1].

Most pumped storage capacity today is in Asia. In 2012, about 2 GW_e of additional capacity was added in the region, with three-quarters of this in China. The European Commission recently addressed the increasing importance of energy storage in a working paper in its Energy Infrastructure (DG/ENER, 2013), as a large increase in medium and seasonal storage will be expected especially after 2025 (Hydropower & Dams, 2013). Europe has around 50 GW_e of installed capacity, and another 20 GW_e is expected to be installed in the next decade.

The main obstacles to further hydropower growth are environmental and social, as along with resource exhaustion.

In addition to conventional pumped storage, new technologies being developed include the variable-speed approach, which could support grid variability. The approach is more complex than conventional pumped storage units, but more than ten units are under construction today, and with technological learning, more can be gained from the technology in the near future (Henry *et al.*, 2013). As existing plants are redesigned, the share of pumped hydro is projected to rise. Pumped hydro will play an increasingly important role as backup for variable renewable energy technologies. If existing plants are adjusted for more balancing power, there would be less need for additional measures and technologies for this purpose.

5.1.6 Geothermal

Around 12 GW of geothermal power is currently installed worldwide. The United States is the leader, but the Philippines, New Zealand, Iceland, Indonesia and Mexico also have significant capacity. Virtually all established capacity is in locations with high-quality resources (volcanic areas). Important expansion plans exist in Kenya and Indonesia, and Africa's Rift Valley and the Pacific Rim offer other opportunities. Various islands have volcanic origins and can deploy geothermal – including St. Kitts and Nevis, Grenada, Dominica, the Azores, the Canary Islands, the Solomon Islands and Vanuatu. Japan also wants to expand geothermal use, following decades of stagnation because of concerns among environmentalists

1 The statistical treatment of pumped capacity is mixed; some countries include it with their hydropower but others do not. Notably, China, where most growth is foreseen (100 GW_e by 2030), does not include pumped hydro with its hydropower capacity data.

(the remaining resources are in protected areas) and spa owners worried about reduced hot water availability for their pools. The example of Iceland shows how spas and power generation can be combined.

Enhanced geothermal systems and deep geothermal are not widely deployed. Enhanced geothermal demonstrations have suffered from small earthquakes during fracking (Basel and St. Gallen, Switzerland), resulting in local opposition. A shallow geothermal project in nearby Staufen, Germany, also caused damage to local structures, slowing developments in the country. Thus, a better understanding of the geology of reservoirs and how to activate them without causing seismic activity is a priority. Deep geothermal resources are being developed in southern Germany and the UK, but the project size is generally small (<20 MW_e) and costs are high (>USD 20 cents per kWh). For the time being, the majority of capacity additions will occur where there are high-quality resources.

Geothermal plants can run continuously. For sustainable operation, the fluids used must be reinjected. The US capacity has suffered from initial projects without reinjection that never fully recovered their original rated capacity. A geothermal resource is natural but not infinite: after 3-4 decades of production, the resource could be depleted, and replenishment takes thousands of years.

Most of the cost of a geothermal project stems from drilling. Not every well is a success; it depends on the temperature and flow rate – and the latter can vary significantly. Drilling costs have gone up in recent years: in Indonesia, for example, they have risen from USD 6 million to USD 8 million per well. The risk of drilling has been identified as the main impediment for new geothermal capacity. Therefore, efforts focus on the establishment of financing facilities that mitigate drilling risk.

5.1.7 Solar CSP

In contrast to solar PV, which generates electrical current directly, with CSP a series of mirrors concentrates solar energy onto a heat medium, which is then used to drive a conventional turbine. Designs either concentrate to a few hundred degrees (Parabolic/Fresnel designs) or to a maximum temperature for steam power cycles in power tower designs (around 600 degrees Celsius (°C)). Because thermal heat can be easily stored, CSP is perhaps best thought of as solar power with an easy storage potential; specifically, when comparing the cost of CSP to solar PV, it is important to remember that CSP is dispatchable and can provide power even after the sun has gone down.

CSP works only in arid, sunny locations, such as northern Africa and the southwest United States. Today's installed capacity is nearly 3 GW_e worldwide. North America has about 0.5 GW_e of installed capacity and the remainder is in Spain, the world's leading market for CSP. In 2012, Spain added 803 MW_e for a total capacity of 1 954 MW_e and generated 5 138 gigawatt-hours (GWh) over the course of the year, according to the trade body Protermosolar (2013).

In concentrated solar power plants, mirrors concentrate solar rays onto a heat medium, driving a conventional turbine.

Of the 42 CSP plants installed worldwide as of 2012, 37 were parabolic trough plants, 3 were power towers and 2 use linear Fresnel collectors. Capacity additions included Termosolar's 22.5 MW_e Borges CSP facility, coupled to a biomass generator and running constantly, and Novatec's 30 MW_e Puerto Errado 2, currently the largest Fresnel plant in operation.

The year 2013 began well for the Spanish CSP market, with two 50 MW_e plants from NextEra Energy, Termosol 1 and 2, coming on line, bringing the nation past the 2 GW_e mark with 2 054 MW_e of total installed capacity. Six more parabolic trough plants are currently under construction, as well as three new plants using parabolic dish technology. But given the dead stop in the Spanish market after February's energy reform, CSP developers are now turning to other countries for new projects. Spain's largest developer, Abengoa, was a 20% owner of Abu Dhabi's 100 MW Shams 1 and is building a 150 MW_e plant in South Africa, a 280 MW_e plant in the United States and a 470 MW_e hybrid solar-gas plant in Mexico. Installations are ongoing in Morocco, including Ourzazate with a total capacity of 500 MW_e. Saudi Arabia plans to add 25 GW_e by 2032, making it the largest CSP market in the world.

Hybrid plants use heat generated in CSP plants for steam cycles in coal or gas plants. A coal plant retrofit is being installed in Australia (Kogan Creek), and various gas hybrid plants are operating in North Africa. Algeria's first solar tower power plant will also be solar-gas hybrid, with a total capacity of up to 7 MW_e; the technology is being developed in Germany. The technology can also be applied in other parts of North Africa. Generally, the share of solar in total power generation is below 10%. The fact that retrofits are possible may create opportunities, but space for a solar field will limit opportunities in many cases, although a market is also starting to develop in China. As of 2012, five CSP projects were approved in China with a total capacity of 340 MW_e, all with parabolic trough technology. Together with the projects planned in the region, China's installed CSP capacity by 2020 could reach more than 6 GW_e, exceeding the plans of the National Development and Reform Commission (ESTELA, 2012a).

Archimede CSP in Italy is the first plant to use molten salt as a heat-transfer fluid. More molten salt CSP projects are planned in Italy, China and Egypt, with a total capacity of nearly 300 MW. Novatec has started the construction of a demonstration plant in Spain with molten salt as a heat-transfer fluid used for the first time in a Fresnel collector plant. In the next decade, the global CSP market is expected to develop with a higher share of tower, Fresnel and dish collectors at the expense of trough (ESTELA, 2012a).

Earlier experiences showed that installation of a series of CSP plants in the United States in the 1980s was followed by two decades of inactivity. Future capacity expansion depends on to what extent CSP capital costs can be reduced, and this will depend on large-scale applications to achieve technology learning. CSP has suffered from the rapid cost decline for solar PV, as the LCOE of utility-scale PV is now a third that of CSP without storage, and the storage capacity is not properly valued. CSP plants also need more than 50 MW_e of capacity, whereas PV is a more scalable. According to ESTELA (2012a), a cost reduction of between 35 and 50% can be expected by 2020 compared to 2010 levels (mainly compared to the case of Spain). Despite its high costs today, a number of countries – such as Saudi Arabia, South Africa, India and Morocco – are pursuing CSP deployment for reasons such as energy security, and projects in these countries have already surpassed projections, according to ESTELA (2012a).

Plummeting solar photovoltaic prices have created price pressure in the solar market. Further price reductions critical for concentrated solar power.

Each CSP plant with a total capacity of 50 MW_e (with thermal storage) is equivalent to 2 250 jobs per year, and each running plant requires on average 50 persons a year for operation and maintenance (ESTELA, 2012a). Protermosolar (2013) reported that the total number of jobs in the sector was about 28 885 in 2011 and about 17 862 in 2012.

5.1.8 Ocean energy

Ocean energy technologies can be subdivided into five categories: ocean thermal energy conversion (OTEC), salinity gradient, wave energy, ocean current energy (tidal currents and permanent currents) and tidal head energy (tidal barrages). Within each category, the technologies can be further divided into onshore, near-shore and offshore devices. IRENA has developed four technology briefs describing the technologies in more detail (IRENA, 2014f-i).

With more than 300 EJ of global potential, ocean energy sources can potentially supply around three-quarters of global energy demand. Yet ocean energy is the least deployed of renewable energy sources, with only around 500 MW_e installed worldwide; more than 90% of this is from two tidal barrages in France (240 MW_e) and South Korea (254 MW_e).

Ocean energy sources are widespread. More than 98 countries can deploy OTEC technologies within their exclusive economic zone. Wave energy sources are available to most countries with a coastline; the best resources are found along west coasts, with an annual average energy content increasing with geographical latitudes. Equatorial regions generally experience less but much more constant incident wave power. Although tidal currents are observed around the world, the existence of hot spots due to geographical conditions (islands, bays, estuaries, etc.) limits the economical extraction of tidal currents in those areas.

Concentrated permanent currents are observed mainly along east coasts (*e.g.*, the Florida current). Permanent currents passing east coasts (*e.g.*, the Humboldt Current) are generally less concentrated due to the earth's rotation and hence are of lower interest for economic exploitation. Due to high water depths, the extraction of permanent currents is not yet a strong focus of development. The exploitation of permanent currents in principle, however, is economically interesting because it will require technologies which are developed for tidal current power and experience capacity factors up to three times as high due to its permanent nature.

Areas with high tidal head are generally near areas with high tidal flows and hence represent hot spots due to geographical conditions. Salinity gradient sources can be deployed at estuaries, ideally in areas where only a small amount of fresh water mixes with seawater in order to avoid large brackish water zones which limit energy content, but also inland in combination with waste water plants. Ocean energy technologies are of particular interest for island states, which are surrounded by ocean energy sources but so far have to rely on imported fuels to provide for their electricity, heat and water demand.

The ocean energy technology market is among the most embryonic and dynamic. Today, approximately 5 wave power technologies and 5-10 tidal current power technologies are close to market readiness, and numerous concepts are in earlier development stages. Generally speaking, tidal current technologies are some years closer to market readiness than wave power technologies. The first commercial tidal current arrays are expected to be grid connected before 2020, whereas the first wave power arrays might produce in the early 2020s. There are 4 existing tidal barrage plants today, but an additional 12 projects are in various stages of development. Similarly, around ten OTEC plants have been demonstrated so far, but at least another ten scaled-up projects are in various stages of development. Salinity gradient is the least-developed technology, with only two pilot projects existing today.

Ocean energy technologies are of particular interest for island states, which have relied until now on imported fuels.

The ocean energy technology market is also providing new opportunities for industry. Except for tidal barrage, which is basically conventional hydropower technology, most new technology development and deployment activities took place through small-scale entrepreneurial companies or university spin-offs. This has changed in the last three years. Large industrial manufacturers/utilities such as ABB, Andritz Hydro, DCNS, GDF/Suez, Lockheed-Martin, Statkraft, Siemens and Voith Hydro are entering the market, mainly by taking over start-up technologies and developing them to market readiness. At the same time, technological advances and expertise from the offshore oil, gas and wind industries are becoming available to ocean energy technologies. The deployment of salinity gradient and OTEC technologies is creating interesting synergies with the water management, water desalination and cooling sectors.

Growing interest from industry and policy makers – especially in Europe and Canada – has also spurred emerging interest from commercial and financial institutions. However, most of the projects are currently financed through public grants, national feed-in tariffs and equity money from technology developers. It is expected that the first project financing from development banks will be available after the first smaller arrays have been operating reliably for several years.

Despite the growing interest in ocean energy, these technologies do not feature prominently in most national energy plans. Only Japan and South Korea have plans to install around 1.5 GW_e of rated capacity. With a theoretical potential in the thousands of gigawatts, there are opportunities to explore further deployment of ocean energy technologies; fortunately, there are a large number of demonstration projects and ongoing feasibility studies for larger-scale deployment of these technologies.

For tidal barrage, the UK has discussed advanced plans for more than 9 GW_e of installed capacity, Russia has proposals for large-scale dams up to 100 GW_e, the Philippines has plans for more than 2 GW_e, and smaller projects have been proposed in South Korea. For tidal current, in which turbines similar to those used to convert wind energy utilise the flow of the sea to generate power, extensive plans are being developed, and a total global capacity of up to 6-12 GW_e by 2030 is technically feasible.

The first commercial wave energy plant – based on oscillating water column technology – was established successfully in Spain in 2012 with a capacity close to 300 kilowatt-electric (kW_e), and a 1 MW_e commercial plant is being constructed in South Australia. There are plans for close to 400 MW_e of capacity in Scotland and 250 MW_e in India. A large number of new devices is being tested, especially on the shores around the UK.

Because OTEC uses the temperature gap between cold deep seawater and surface water to generate electricity, it is particularly interesting for countries and island states in the Caribbean and Pacific. The earliest demonstration projects took place in the 1970s; installations up to 1 MW_e have been successfully demonstrated, and a 10 MW_e demonstration plant is planned for Hawaii. Numerous ongoing projects are exploring 10 MW_e OTEC plants (the minimum size for an economically viable plant) in China, the Bahamas and the French islands of Réunion and Martinique. The Marshall Islands and the Maldives also have expressed interest. Issues requiring attention include fish entrapment, water reinjection and a cold-water landing site for coastal plants. One of the great technological challenges for OTEC is developing the polyethylene pipes of up to 10 metres in diameter and more than 1 000 metres long that will be used at such sites. OTEC combined with water desalination (flash evaporation technology) and seawater cooling can make a project economically viable. Seawater cooling for hotel air conditioning is picking up in places such as Curaçao, French Polynesia (Bora Bora), the United States (Guam, Puerto Rico) and Zanzibar, and this technology uses similar water pipes and heat exchangers.

For salinity gradient, a 10 kW_e pilot plant exists, and a scale-up towards a 50 kW_e system has started. The technology can be used in estuaries where fresh water enters the ocean, or as a hybrid technology connected to a wastewater facility.

At the moment, the capital costs and LCOEs for most ocean energy technologies are higher than those of other renewable energy technologies. However, with continued technology development, increased learning/deployment and possible synergies with other offshore technology developments, the cost projections look attractive.

5.1.9 Mini-grids and off-grid systems

Interest in renewables-based mini-grid and off-grid systems is on the rise, both in developed and developing countries, as illustrated at the successful IRENA Off-grid Renewable Energy Conference (IOREC) in 2012 (IRENA, 2012f). Such systems cater to diverse loads for lighting, appliances and productive uses. In developed countries, they supply electricity to remote areas, military bases and businesses. In developing countries, mini-grids mainly provide electricity to rural and remote areas without grid access.

Solar PV-based off-grid systems are affordable and can be deployed rapidly. Solar PV lighting is the most widespread option. Solar light-emitting diode (LED) lamps cost less than USD 20 and are powered by batteries recharged during the day. Their life-cycle costs are considerably lower than for kerosene lamps. Somewhat larger systems of 50-100 watts can maintain small electronic equipment. There is no clear border between mini-grids and off-grid supply, but mini-grids typically have a capacity of at least 1 MW_e.

Solar home systems (SHS) have experienced sustained growth in developing countries, and worldwide installations now surpass 5.1 million. Bangladesh is the global leader, having deployed more than 2.4 million SHS and created jobs for an estimated 70 000 people along the SHS supply chain. Between 1996 and 2003, some 10 000 SHS were sold to Bangladeshi households. Installations have since grown rapidly under the Infrastructure Development Company Limited (IDCOL) SHS Programme, reaching a cumulative 455 000 at the end of 2009 and 2.6 million as of November 2013. The ongoing initiative aims to install 4 million systems by 2015, which would serve over 20 million beneficiaries or 12% of the total population (IRENA, 2013i).

The state-owned IDCOL achieves this outreach through more than 46 participating organisations, such as Grameen Shakti, which has built on the successful micro-lending experience of the Grameen Bank (IRENA, 2013i). The jobs in Bangladesh are mostly for young field assistants with basic technical and vocational skills to sell and install SHS, provide maintenance and collect monthly payments on solar loans as part of Bangladesh's microfinance network (Bimesdoerfer, Kantz and Siegel, 2011).

Despite some commercial success in Kenya – Africa's leader in SHS installations with 320 000 units installed in 2010 (Ondraczek, 2012) – its solar industry faces numerous challenges to growth and job creation. These include domestic financing (SHS primarily reach only the wealthiest rural populations), the quality of imported solar PV panels and a lack of technical training. Tanzania, too, has faced complications in enforcing quality control with SHS. These problems in Kenya and Tanzania are typical worldwide, and there are skill gaps in many developing countries, particularly for the key occupations of electrical engineers and technicians.

In lower-income rural communities, efforts to provide electricity access have tended to focus on small SHS. Currently, at least 5.1 million SHS are installed in developing countries (see Table 5.1), up from only an estimated 1.3 million in 2002 (Energypedia, 2011). Data gaps remain, however, in the availability and relevance of information, preventing reliable analysis of the number of SHS deployed globally.

Most distributed generation today is in the form of diesel generators, but recent growth rates and plans for solar PV systems in countries like Egypt, Ethiopia, Ghana, Kenya, Lesotho, Madagascar and Uganda show that renewables-based mini-grids are increasingly the first choice thanks mainly to plummeting PV prices. In most instances, a renewables supply option is cheaper than diesel power generation.

Mini-grids can run purely on renewables, but battery storage is needed if variable renewables are used. For example, solar PV with battery storage can be found on various island hotel resorts; Tokelau relies on solar PV for more than 90% of its electricity. Renewables can also be integrated in existing diesel mini-grids. Hybrid mini-grids solve the main problems with 100% diesel systems: high diesel prices and low fuel availability. There are several hundred island mini-grids, usually including diesel generators,

Table 5.1 Global status of solar home systems market

	Year	Number of systems
Bangladesh	2013 (June)	About 2 400 000
India	2012 (March)	861 654
China	2008	> 400 000
Kenya	2010	320 000
Indonesia	2010	264 000
Nepal	2012	229 000
South Africa	n.a.	150 000
Sri Lanka	2011	132 000
Morocco	n.a.	128 000
Zimbabwe	n.a.	113 000
Mexico	n.a.	80 000
Tanzania	n.a.	65 000
Total		5.1 million

Source: IRENA (2013i)

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typically in the 1-20 MW_e range. Increasingly, solar PV is being added, as are other renewable energy sources such as wind, geothermal, biomass and ocean energy, where available.

Since the 1950s, the Chinese have pursued the development of small hydropower plants, which first operated in stand-alone mode and were later connected to the national grid as it expanded (Peng and Pan, 2006). China has an estimated 60 000 such systems (mainly diesel and small hydro). As of 2001-02, there were 42 000 small hydro plants with a total capacity of about 28 GW_e.

Under the Township Electrification Programme (2003-2005), the Chinese government first focused on 100% renewable energy systems for village power. The programme built 721 solar PV and PV/wind hybrid systems along with 146 small hydro stations to provide electricity to 1.3 million people. The most recent initiative, the Village Electrification Programme (2005–2010), expanded the Township Electrification Programme's success by electrifying another 20 000 villages with renewable sources (targeting 3.5 million people). By the end of 2015, China aims to address the challenge of providing power to its 2.73 million people without electricity, including 1.54 million by grid extension and 1.19 million by independent solar PV power supply utilisation via a total of 583 projects.

Nepal, India, Vietnam and Sri Lanka, each have 100-1 000 mini-grids. Most projects use diesel or hydropower generation and are government run (GVEP, 2011).

Most hybrid mini-grids in operation today are essentially retrofit projects that cobble together existing legacy assets (diesel generators) and new technology (PV, storage units) through an overlay of controls. Smart, bi-directional islanding inverters are also an extremely important technology to enable distributed generation in mini-grids.

Mini-grids are beginning to move more into the mainstream, with a greater focus being placed on viable business models. The mini-grid market is thus much more robust than just five years ago. In the fourth quarter of 2013, Navigant (2013b) identified 4 148 MW_e of total mini-grid capacity throughout the world, up from 3 793 MW_e in the second quarter of 2013. According to that source, North America remains the world's leading market for mini-grids – with a planned, proposed and deployed capacity of 2 712 MW_e, or 65% of the global total, and an additional 34 projects and 207 MW_e since the second quarter of 2013. An estimated 1 503 MW_e of that total is currently on line, with another 224 MW_e planned, under development or proposed.

Use of mini-grids is growing rapidly worldwide.

Telecommunication towers represent an interesting niche market. There are some 650 000 such towers (averaging 3-5 kW_e and accounting for 1-3 GW_e of capacity in total) in India alone. Presently, some 40% of the power they need comes from the grid and 60% from diesel generators. PV battery systems are a viable alternative that is being developed (Tata, 2013).

Mining projects, which are often remote, represent another emerging market segment, as renewables can help to reduce diesel expenses. Such projects are being developed in Western Australia (15 TWh needed in the coming years), northern Chile and West Africa. A wind-diesel hybrid system has also been developed for a mine in Mauritania.

Another key market segment is the defence sector. More than 40 U.S. military bases now have operating mini-grids, or have planned mini-grids.

According to Navigant (2013b) global installed capacity of mini-grids will total over 15 GW_e by 2022; mini-grids are worth over USD 5 billion and are likely to reach up to USD 27 billion by 2022. The off-grid and mini-grid sectors will continue to grow at a higher annual growth rate for the next 5-6 years, while the hybrid market is expected to grow faster from 2012-2022.

Small-scale operation raises unit costs and results in high project development costs. Project operation and management costs per kWh are higher than for large projects. The power-supply cost of mini-utilities – diesel or renewables based – can exceed USD 1 per kWh. Mini-grids often close down after only a couple of years because financial sustainability is not achieved. Customised financing and business models are required to facilitate access to these systems in rural areas. Adequate standards and quality-assurance mechanisms need to be in place to avoid "market spoilage" (IRENA, 2013j).

As distributed generation grows, self-consumption reduces demand for grid electricity for those with grid connections, making centralised systems increasingly uneconomical. This phenomenon can, for example, be observed in South Australia. As the distribution cost per kWh rises, the incentive for people to produce their own electricity using renewables grows. This trend could result in a massive switch from centralised grids to mini-grids and off-grid solutions even in areas with grid connections.

5.1.10 Next steps for the power sector

This chapter provided detailed results for the power sector according to the bottom-up analysis of the 26 REmap countries as well as the latest information about the sector's most important renewable technologies. As opposed to end-use sectors, a wide range of technologies offer potential for the power sector to raise its renewable energy share. The biggest challenge, however, is to accommodate the increasing share of variable renewables in the existing grid system. Overcoming this challenge will require approaches to identify the required technology measures and policy needs which are specific to the countries, as grid characteristics, regulatory frameworks and existing infrastructure vary widely. By taking these differences into account, as well as the country needs which originate from REmap 2030, IRENA is preparing a roadmap in 2014/15 to support countries in transforming their power grid infrastructure.

To support such a power sector roadmap with further analysis, and also in order to validate REmap 2030 results with integrated system models, IRENA will continue to co-operate with the IEA-ETSAP national teams as well as other global modelling organisations. The focus of co-operation will be in the fields of power system modelling and renewable energy integration. This will also help national and regional governments to gain more insight into how current approaches to energy planning can be improved for target setting and to understand technology deployment and finance needs.

5.2 Buildings

5.2.1 Overview

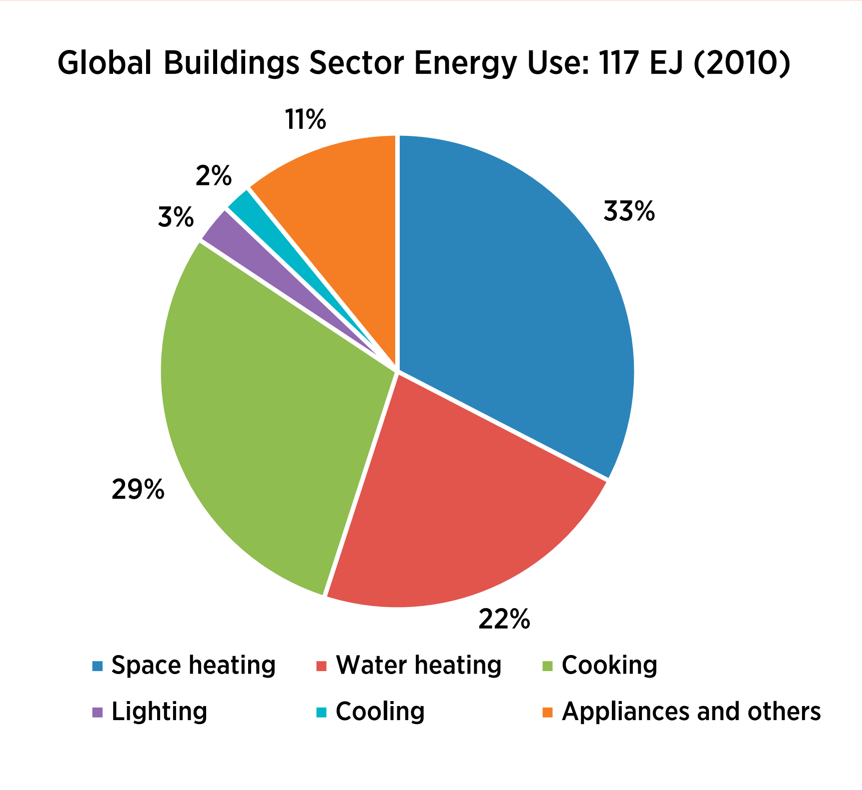
The building sector includes all energy consumed in residential and commercial buildings. Around one-third of global TFEC is consumed in buildings. The share of renewables can be significantly higher in combination with lower energy consumption, *i.e.*, increased efficiency. Nowhere is this relationship more salient than in buildings.

The sector's energy use worldwide reached 117 EJ in 2010. Space heating and cooking are the largest energy users in the sector (see Figure 5.9). The distribution provides an important message. In addition to space heating – the application which receives the most attention for renewable energy deployment – substitution of fossil fuel use for cooking and water heating is equally important to increase the sector's total renewable energy share.

A third of all energy consumption occurs in buildings.

Energy consumption in buildings can look quite different from one region to another. The main distinction is whether a building needs more cooling or more heating. In Europe, heating is the largest single energy end-use, making up approximately 50% of TFEC. An average home in Europe consumes 68% of its total energy demand for space heating and 14% for hot water, mainly in the winter and based largely on fossil fuel.

Figure 5.9 Global total final energy consumption of the building sector by application, 2010



Space heating, water heating, and cooking account for 84% of energy demand in buildings.

Source: IRENA analysis based on IEA (2010)

In contrast, where air conditioning is deployed for cooling, electricity consumption tends to be greater in the summer than in the winter. World-wide, at least 10% of electricity is consumed for cooling purposes; in the United States, cooling in buildings accounts for a sixth of total electricity generation. Likewise, air conditioning in the Gulf Cooperation Council (GCC) states accounts for 70% of annual peak electricity consumption. Such heavy cooling demand is expected to nearly triple by 2030. By then, the fuel needed to power air conditioning in the GCC will be the equivalent of 1.5 million barrels of oil per day, nearly 2% of global oil production. Apart from biomass, only solar water heaters (0.2 EJ per year) and geothermal heat (0.3 EJ per year) are deployed on a significant scale today.

Buildings offer a huge opportunity for transformation with renewable energy.

Table 5.2 provides a breakdown of the global building sector's energy use developments by energy carrier for the years 1990 and 2010. Since 1990, the potential of conservation in the building sector has been repeatedly demonstrated. One type of architecture is known as Passive House in Germany and Austria or as EnerPhit in Switzerland; in accordance with the EU's Buildings Directive, all new builds will have to comply with these

Table 5.2 Global building sector total final energy consumption by energy carrier, 1990-2030

	Reference Case			REmap 2030
	1990	2010	2030	
	EJ/year			
Coal	9	4	4	1
Oil	12	13	14	13
Gas	16	25	30	23
Electricity	16	33	53	55
Heat	2	6	7	7
Modern biomass	7	8	8	14
Traditional biomass	20	27	25	12
Other renewables	0	0	5	9
Total	83	117	147	134

Source: IEA (2012b) for 1990, 2010. IRENA estimates for 2030

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standards – collectively known as “nearly zero-energy buildings” – by 31 December 2020 (EC, 2010).

The most efficient new homes north of the Alps, where demand for heat dominates and air conditioners are rarely installed, have 1/20th the demand for heating energy of an average home built in the 1970s. Such buildings essentially make do with backup heaters without the need for central heating systems. But such buildings require proper orientation, generally with a south-facing façade. When the building has an east-west orientation, the potential to exploit solar energy “passively” is significantly reduced. Studies have shown, however, that the same type of architecture can be redesigned for hot countries to avoid the use of air conditioning (Chiras, 2002).

Energy-efficient architecture can cut demand for heat 20-fold, but only in new buildings.

Because most buildings already exist, retrofits are all the more important. Furthermore, because buildings have long service lives, retrofits must implement the highest standards today in order to be efficient decades later. But often, building owners make such investments, while tenants reap the benefits of lower heating bills. In addition, building owners may lack the expertise needed to properly assess what looks like a hefty investment in proper energy modernisation measures; they may then opt for more modest insulation with lower upfront costs.

Finally, certain types of retrofits are very costly, although the technology may make sense in new buildings. For instance, heat pumps provide temperatures too low for small radiators requiring high temperatures and are therefore used in combination with large-surface systems, such as underfloor heating – which is quite expensive for retrofits.

Table 5.2 also provides a breakdown for the year 2030 for the Reference Case and REmap 2030. The sector’s energy use will continue to grow in the next two decades to 147 EJ by 2030 according to the Reference Case, a slower rate than observed between 1990 and 2010 – mainly because of the developments in fuel choice and improved efficiency of heating, cooling and cooking devices. The share of electricity use is projected to continue increasing. Mainly traditional use of biomass and small quantities of each fossil fuel are substituted. The share of modern biomass remains the same at 5%, but the share of solar thermal and geothermal (covered under other renewables) increases to 4%.

In REmap 2030, the share of electricity use increases to 41%. The share of fossil fuels and traditional use of biomass decreases further. The share of modern biomass and other renewables reach a total of 18%.

Most industrialised countries are projected to have no or a very limited renewable energy share in their building sectors in the Reference Case. But REmap 2030 shows that a doubling can be achieved by 2030. The modern renewable share in buildings will increase from 15% to 91% in REmap 2030 (see Figure 5.10). In the building sector, countries from all different regions are estimated to have high renewable energy shares, such as 48% in Nigeria – a considerable increase compared to its very limited use of modern renewable energy in 2010.

The increase in biomass capacity for space and water heating is 130 gigawatt-thermal (GW_{th}) in the REmap Options, reaching a total of 600 GW_{th} in REmap 2030 (including CHP) for the 26 countries. Furthermore, 400 GW_{th} of additional modern biomass-fired cooking capacity will be installed in the 26 REmap countries. Assuming around 5 kilowatt-thermal (kW_{th}) of cooking capacity per household, worldwide at least 160 million households would get modern cook stoves. Worldwide biomass demand in the building sector would reach about 25 EJ if all REmap Options are deployed (including the district heat sector), compared to today’s total use of about 40 EJ biomass, of which 32 EJ is traditional use.

A projected 650 GW_{th} of solar thermal would be added in the building sector if all REmap Options are deployed in the 26 REmap countries, reaching a total installed capacity of nearly 1 900 GW_{th} worldwide in the building

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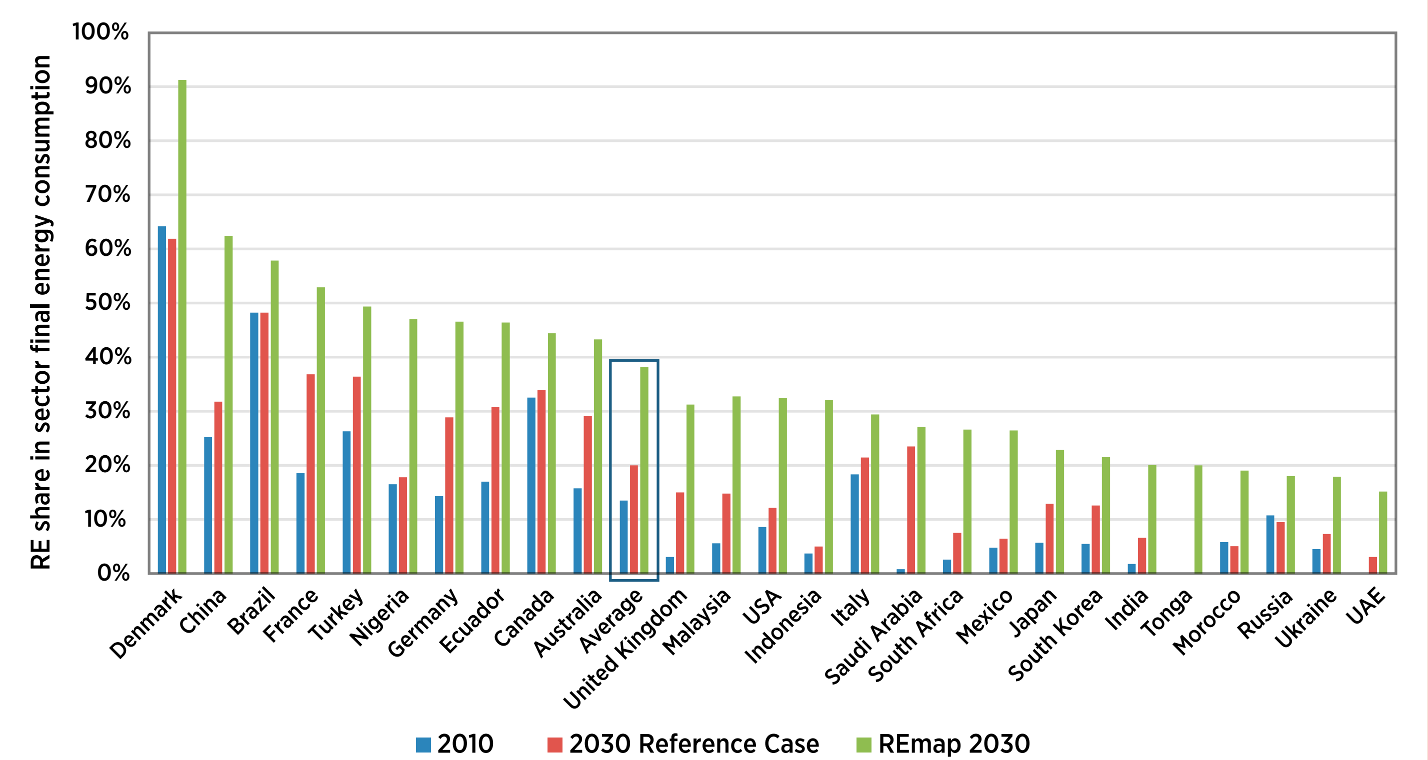
Figure 5.10 Current and projected share of renewable energy in building sector TFEC, by country, 2010-2030



The average share of renewables in building energy consumption is 38%, with the share in each country ranging from 15% to 91%.

Note: Results presented in this figure refers to renewable energy share of the sector's TFEC, thereby including the contribution of renewable electricity and district heat consumption (see Indicator 1 in Chapter 2.3).

sector. This is seven times higher than the installed capacity in 2012. In the past five years, solar thermal capacity has been growing by about 30 GW_{th} of net additions worldwide per year (AEE-Intec, 2007-2013). The Reference Case projection for the building sector is a somewhat higher continuation of this trend, at about 40 GW_{th} per year of additional capacity.

The growth if all REmap Options are implemented is on average 90 GW_{th} per year, or three times higher than what has been experienced so far. This growth is on the high side, but it is still realisable. Growth in China and parts of the EU (which account for 80% of today's installed solar thermal capacity) could continue to grow at about similar rates between today and 2030, and with implementation in other emerging markets (*e.g.*, the US, some economies in transition, Africa and developing Asia), such high rates can be achieved.

There is also a considerable market for the electrification of space heating and cooling. A total additional heat pump capacity of 310 GW_{th} exists according to the total of all REmap Options, mainly in the United States, Germany and China. An estimated 70% of the total installed capacity is air-to-air heat pumps; the remaining 30% is geothermal heat pumps. The total number of heat pumps reaches 40 million worldwide in REmap 2030 (excluding air conditioning systems).

5.2.2 The impact of urbanisation

It is expected that between 2010 and 2030, around 1.4 billion people will join the 3.5 billion people already living in cities (UN DESA, 2012).

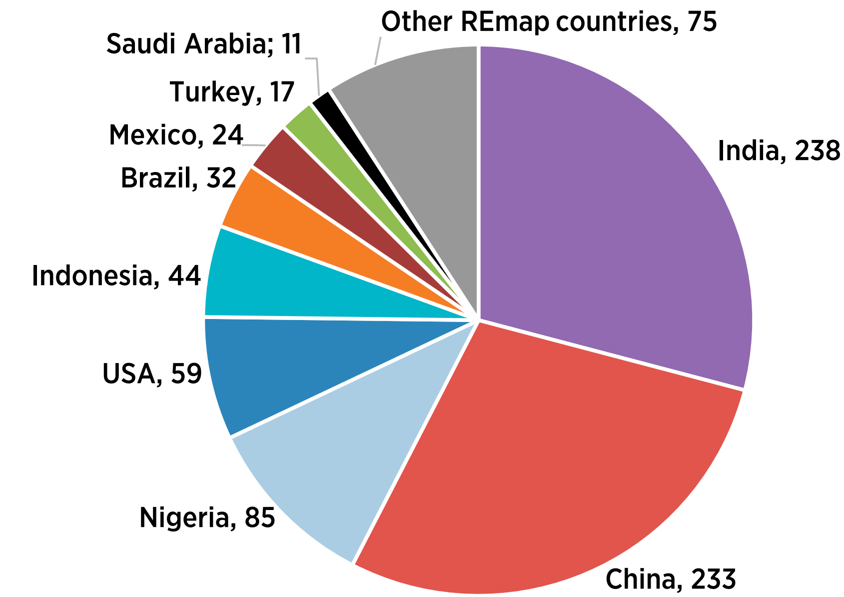
In other words, total population growth will occur primarily in cities. For the REmap countries, it is expected that almost 900 million people will be added to their cities, mostly in India (238 million), China (233 million), Nigeria (85 million) and the US (57 million) (see Figure 5.11). On a relative scale, the largest changes will take place in China, Nigeria, Morocco and Malaysia, where urbanisation rates will increase more than 10%.

The influx of almost 900 million people will have important impacts on energy consumption in the building, power and transport sectors. The Global Energy Assessment (GEA) City Energy Data Base suggests that urban dwellers in OECD countries, on average, consume one-third less than the national average, and that urban dwellers in non-OECD countries consume more (about twice) final energy per capita than their respective national averages. Per capita direct final energy use (which includes energy consumption due to economic activities) is on average around 100 GJ. The higher energy consumption in OECD countries is due to lower transport energy use and less energy-intensive service activities, while the higher energy consumption of urban dwellers in non-OECD countries is due to higher incomes relative to the national average, particularly in Asia (GEA, 2012).

However, these comparisons between urban and rural household consumption depend on the specific country and on the characteristics of the specific cities. In China, rural residential energy consumption is around 10-15 GJ per capita higher than the 5 GJ of final energy demand per capita in urban households, due mainly to the demand for solid fuels for cooking. It is projected that energy demand for urban households will increase to around 10 GJ per capita in 2030, due mainly to growth in electricity consumption (Krey *et al.*, 2012).

In the building sector, more than 200 million new dwellings need to be constructed in this time period – the energy efficiency of these buildings will have important impacts on future energy consumption. The expected decline in urban household size will exacerbate the need for more floor space. It is therefore very important that all new dwellings are constructed using the latest energy efficiency standards. The Global Buildings Performance Network provides a comparative overview of the latest energy efficiency policies for new buildings (GBPN, 2013).

Figure 5.11 Population growth in urban areas between 2010 and 2030, Number of additional urban inhabitants in million



Another important consideration is the level of income for these urban dwellers. Household energy consumption in Cape Town is around 3 000 kWh per year for low-income households, and 9 000 kWh per year for mid- to high-income households (Winkler, *et al.*, 2006). In this particular case, the major difference lies in space and water heating demand. As income in urban households increases, it is expected that electricity consumption will also increase. At the same time, and especially in developing countries, a large number of the new dwellers are low-income

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households. Many of these households will arrive in slums with limited infrastructure. In 2010, 10% of urban dwellers in developing countries still had no access to energy and 30% had no access to modern fuels.

For the transport sector, infrastructural design will be the decisive factor, with evidence suggesting that there is a clear correlation between population density and transport energy consumption (Dargay, Gately and Sommer, 2007; Stone 2008). Those countries with lower use of private motorised modes of transport will have substantially lower energy requirements. In general, the private use of motorised vehicles is below 40% if a city has an urban density higher than 50 persons per hectare (GEA, 2012).

5.2.3 Heat from biomass, solar and geothermal

Biomass has been used traditionally for heating, with applications ranging from open fireplaces to stoves. In more modern uses, biomass is combusted in efficient boilers and furnaces. Compared to traditional uses, however, modern use of biomass today is limited, with about 20% of total biomass use for heating in the building sector. The majority of biomass used for heating is solid biofuels, which include wood logs and twigs, wood chips and saw mill residues, and pellets. In some countries, agricultural residues, such as straw, are also used, especially in rural areas.

Combusting wood pellets, or wood chips, in efficient boilers could reach the efficiencies of natural gas or coal-based equivalents. In 2012, Europe accounted for about 60% of the global pellet demand, equivalent to 10 million tonnes of solid biomass. About half of the pellets in Europe were consumed in small heating appliances (boilers and stoves), with the other half going to the power sector and large-scale CHP plants. Germany's wood pellet production reached 2.25 million tonnes per year in 2012. Nearly 300 000 wood pellet heating units were installed in Germany, most of them smaller than 50 kW_{th} capacity (EUWID, 2014).

Pellet boilers are the primary heating equipment in small and mid-size installations, while pellet stoves are used as a complementary heating option. The number of pellet boilers installed is increasing; in the last decade around 200 000-300 000 boilers were sold per year. Stoves are also increasingly becoming important, with demand for pellets rising by between 0.5 and 1 million tonnes per year. Biomass-based heating demand in Europe alone is projected to increase to more than 20 million tonnes by 2020, a more than doubling compared to current use of biomass (Wood Markets, 2013).

In industrialised and developed countries outside of Europe, demand for modern forms of bioenergy is increasing as well. Projections show that total demand for wood pellets in North America, Japan and South Korea could reach more than 10 million tonnes by 2020 (Wood Markets, 2013). As a result of increasing energy demand, and the traditional use of biomass as one of the main energy sources in the building sectors of most developing countries, the demand for traditional use of biomass is projected to increase at similar rates observed in the past. China's wood pellet demand is projected to reach approximately 10 million tonnes per year by 2030 (Wood Markets, 2013).

According to global market data from the IEA Solar Heating and Cooling Programme, solar water heating capacity reached 234.6 GW_{th} (equivalent

Box 5.4 Modern bioenergy options for cooking

Perhaps more than any other substitution, the use of modern renewables in cooking – instead of traditional use of biomass or fossil fuels – considerably raises standards of living when people do not produce soot and smoke while preparing meals. Biogas can be directly used for cooking, as is still a common practice in China and India. It can also be upgraded and sold to the natural gas network, an emerging option in countries such as Germany.

Ethanol as a cooking fuel is an emerging option, although dedicated stoves are needed. In Africa, the first supply chain has been established in Mozambique. Advanced cooking stoves also fall in this category. Their uptake is still relatively low, but they can raise stove efficiency by a factor of two compared to traditional cooking. Modern solid fuels, such as briquettes, are promoted in Africa, but sustainable charcoal is controversial.

to 335.1 million m²) at the end of 2011; the net growth in 2012 was estimated at 33.5 GW_{th}, bringing the total to 268.1 GW_{th} (AEE-Intec, 2013). Solar can be used here both in combination with gas boilers or in purely solar units.

The use of solar hot water heaters in China has continued to increase, and accounting for over 65% of global installations (AEE-Intec, 2013). Around 40% of all new Chinese water heaters use solar. In addition to subsidies and obligations, this growth is driven in part by the cost competitiveness of solar water heaters with traditional energy sources. China added a total capacity of 44.7 GW_{th} in 2012. In contrast, the net increase was only 28.2 GW_{th} because the life span of installations is less than ten years (Frankfurt School-UNEP Centre/BNEF, 2013).

In contrast, the EU and Switzerland installed 2.6 GW_{th} of solar water heaters in 2011, a similar volume as in the preceding year. In Europe, the solar thermal market has grown by 9% a year on average over the last decade (ESTIF, 2013), although it contracted slightly in 2009-10 due to the financial crisis. Growth is likely to continue as China aims to boost the country's solar water heating capacity to 280 GW_{th} by 2015 and 560 GW_{th} by 2020.

Geothermal heat production capacity amounted to 48.5 GW_{th} in 2010, with 424 petajoules (PJ) of production which includes both ground-source heat pumps (or shallow geothermal, GSHP) and deep geothermal heat. Around 47% is used for ground source heat pumps, 26% for baths, 15% for space and district heating, 8% for industry, agricultural drying and greenhouses and 3% for fish farming (Lund , Freeston and Boyd, 2011). According to Lund, Freeston and Boyd (2010), GSHP accounted for approximately 70% of the worldwide installed capacity in 2010 (equivalent to 49% of the total global geothermal heat production from all sources). The remaining 30% of installed capacity is deep geothermal.

China, the United States, Sweden, Turkey and Japan are the leading countries accounting for more than 60% of the global installed capacity of GSHP and deep geothermal energy. While in the United States and Sweden, GSHP is the main use of the technology, in China, Japan and Turkey, geothermal heat is used for district heating and bathing. Most use in the United States is for peak cooling, which means they are oversized for heating. Over 600 schools in Texas now have GSHP, whose main purpose is cooling. In the United States, the GSHP market is growing at about 12.5% per year, and in Iceland almost 90% of space heating is from geothermal sources.

Navigant Research forecasts that installed geothermal heat production capacity will grow to about 127 GW_{th} worldwide in 2020 (Navigant, 2013c). Global cumulative installations of GSHP are expected to grow from 2.9 million in 2010 to 5.7 million in 2015, equivalent to an annual growth rate of 14%.

5.2.4 Heat pumps

Heat pumps essentially use electricity to provide heating or cooling to a building from the ground (see above for GSHP), the outdoor air or even nearby bodies of water. They are used for air conditioning, refrigeration, space heating, hot water supply, cold storage warehouses, and process heat and steam for industry.

Heat pumps are energy efficient, providing three to six units of useful heating/cooling energy for each unit of electricity consumed, compared to less than one unit of thermal energy for each unit of energy consumed by traditional heating systems. The coefficient of performance (COP) is the ratio of the energy output to the energy input. Today's best heat pumps offer COP values of as much as seven, as well as high reliability under a wide range of operating conditions. In particular, significant advances have been achieved for air-source heat pumps, mostly for air conditioning. Some models of air-source heat pumps provide indoor space heating even with outdoor air temperatures as low as -25 °C, while keeping COP values greater than one.

With capacities between 1 kW_{th} and 10 megawatt-thermal (MW_{th}), heat pumps can provide heating and cooling to single houses or to entire districts, next to industrial applications for temperatures from below -100 °C to above 100 °C. Although efficiency has improved substantially in the past decades, it is expected to continue improving by 20-50% between now and 2030.

Although the economics and market penetration of heat pumps have improved significantly, their contribution to space and water heating is still relatively modest except for some industrialised countries. Given the large share of heat demand for space heating/cooling and hot water supply in buildings, highly efficient heat pumps have a key role to play.

Furthermore, because heat pumps mostly use the renewable sources of heat and sinks (apart from electricity), they contribute significantly to the penetration of renewable energy. Heat pumps are considered a renewable energy technology in the EU, where they are expected to account for between 5% and 20% of the region's renewable energy target for 2020 (IRENA/IEA-ETSAP, 2013b). Several countries (*e.g.*, the US, the UK, Australia and Japan) grant tax reductions, subsidies or other benefits to facilitate its use.

Because significant differences exist in national standards and regulations to measure heat pump performance, their contribution to the penetration of renewable energy is not well captured in today's energy statistics. To support heat pump deployment, national standards should be harmonised, consumers should be fully informed of the efficiency of heat pumps, and the investment costs of heat pumps should be reduced.

Box 5.5 Refrigeration

Cold can be stored, for example in the form of ice. Here lies an opportunity to store solar energy.

Approximately 4 000 ice storage systems for air conditioning are in use in the United States, along with 8 000 worldwide. Buildings have installed massive ice-making tanks in their basements or on rooftops. Water is frozen at periods of low electricity prices to produce gigantic blocks of solid ice, which are melted when electricity is most expensive. The ice is used to chill air circulated throughout the building to help cool rooms. The relevance of this option for solar depends on the demand structure. It seems less relevant for office buildings with daytime peak demand, but may be more relevant for hotels or dwellings with an evening peak.

The total capacity of refrigerated warehouses is estimated at 460 million cubic metres (m^3) worldwide in 2012, an increase of roughly 10 million m^3 over 2010. The largest 25 companies account for about a quarter of this capacity. At 50 kWh per m^3 per year of total electricity demand, the total demand is 24 TWh – small on a global scale, but energy costs make up a significant share of total cost.

5.2.5 Renewable cooling

While air conditioning improves productivity, reduces mortality rates and is generally held to improve standards of living, it also poses a particular challenge as a part of a vicious cycle within climate change. As the climate warms up, demand for cooling will increase, thereby contributing to (fossil) energy consumption, which in turn speeds up climate change. Renewable cooling applications are therefore crucial. Because demand for cooling generally coincides with sunlight, countries with a high level of air conditioning will generally be able to get a larger share of their electricity from solar PV without storage.

The Dutch Environmental Assessment Agency estimates that energy demand for air conditioning could increase by 72% as a result of climate change between 2000 and 2100 (Isaac and van Vuuren, 2009). At present, the world consumes roughly 12 times more energy for heat than cooling, but those levels could equal out by 2070, and by 2100 the world might be consuming 60% more energy for air conditioning than heat. Worldwide, the energy consumed for air conditioning in the world outside the US would be 50 times greater than the current level in the United States if everyone had the same level of air conditioning services as Americans currently do (Sivak, 2013).

Globally, air conditioning will account for roughly 5 EJ of electricity demand in 2030 (nearly 10% of the sector's total electricity consumption). Nearly 100 million cooling units are currently sold each year, roughly half of which are room air conditioners. After a brief downturn during the economic crisis, the market has picked up again with 13% growth year-over-year in 2011. Overall, the market is currently worth nearly USD 100 billion annually.

Asia-Pacific is the largest production site and buyer's market, but North America has the largest installed base. In fact, the United States consumes more energy for air conditioning than the rest of the world combined, although other countries are closing the gap.

If the rest of the world used the same level of cooling in buildings as the US does, energy demand for air conditioning would be 50 times the current demand for cooling in the US.

In the UAE, air conditioning reaches up to 60% of total power demand. Sustainability-oriented building codes for Abu Dhabi (*i.e.*, Estidama) and Dubai were implemented recently but were not in force when the majority of the existing building stock was completed. Power consumption for space cooling accounts for 14.6% of total building energy consumption in the UAE, a figure based largely on data from commercial buildings. In reality, much of the load reported as "appliances" in residences is probably also air conditioning.

At present, some 87% of households in the United States have air conditioners (compared to 62% in China in 2003 – up from 1% in 1990), and the Chinese are adding some 50 million air-conditioning units per year. India is currently at quite a low level, with only 2% of households having air conditioning in 2007, but that market is growing by a double-digit percentage annually.

5.2.6 District heating

District heating networks distribute waste heat from a local power generator to nearby homes and businesses to provide space heating, hot water and, very seldom, process heat. However, most industrial processes generate their own process heat with boiler/CHP plants on-site. District heat is a necessity for the use of CHP, which is the most efficient way to use biomass for energy production. A high level of district heat supply for space heating is an efficient way of increasing renewable energy in space heating.

The energy source is often (92%) oil or gas, which is not renewable. The goal is then to increase the efficiency of finite resource consumption. Biomass accounted for most of the renewables (>7%), with geothermal and solar thermal making up the remainder. In Germany, one-third of Buesingen village in Konstanz is heated with solar thermal technology, accounting for about 15% of the annual heating demand. On winter days, biomass from the region is also used for heating (die Zeit, 2013).

Worldwide, 11.5 EJ of heat was delivered from district heating systems in 2011 – around a quarter of all low-temperature heat below 100 °C – including in Russia (around 7 EJ) and China (2.8 EJ). The share of renewable energy in district heat varies, with nearly 80% in Iceland (geothermal heat), 42% in Latvia, 32% in Norway and 20-25% in Austria, Denmark and Estonia (Euroheat & Power, 2013).

In the EU, 10% of all heat is supplied through district heat. In most of these countries, this heat is sold largely to the commercial and residential sectors. About 20% of it is generated with renewable resources (notably biomass and waste) (DHC Platform, 2012). In the United States, around 4% of all heat is supplied through district heating systems. In Commonwealth of Independent States (CIS) countries, district heat use is also widespread, but losses are significant because pipes are not well insulated.

Russia has the largest district heat sector worldwide, and Germany is the largest market in Europe (Euroheat & Power, 2013). The US and South Korea are the biggest producers among industrialised countries outside of Europe. District heat in China is also becoming more important. Experience in some EU countries (*e.g.*, Hungary and Poland) and in South Korea shows, however, that demand for district heat is declining due to improvements in the energy efficiency of buildings. Demand for district heat may also be limited because individual boilers or heat pumps could be a more cost-effective source of space heating.

In the Reference Case, district heat production is projected to increase by more than 50% between 2010 and 2030 to a total of 15 EJ. Together with the increase in the heat output of CHP plants (7 EJ, an increase of only 29%), total heat demand worldwide could reach 22 EJ. The largest increase is estimated for China, with a doubling of the total demand for heat from CHP and district heat plants. Demand for district heat will also at least double in Ukraine and Canada by 2030 compared to 2010.

In REmap 2030, Germany increases its district heat sector's renewable energy share the most, from 21% in 2010 to a total of 59% in 2030. A large increase in China could also be realised where the renewable energy share reaches 30% by 2030, mainly from biomass. Total biomass demand in the 26 REmap countries could reach 5 EJ in 2030 if all REmap Options are deployed.

5.2.7 District cooling

In district cooling, naturally chilled water is transferred through pipes. The energy source is either natural cooling from different water resources or waste heat. Electricity use for cooling purposes can account for a large share of the total electricity demand (up to 10%). In North America, developed Asia-Pacific and Middle East countries, cooling is common. Cooling demand is projected to grow in the coming decades, so district cooling is an important market for renewable energy and electricity conservation.

Worldwide, more than 30.6 TWh of cooling was delivered through 31.4 GW_{th} of district cooling systems in 2013, of which there is nearly 10 GW_{th} in the UAE and more than 16 GW_{th} in the United States. In Europe, 2% of all cooling is supplied through district cooling systems, a rapidly growing market segment (DHC Platform, 2012). So far, the use of solar absorption systems has been limited to demonstration plants, but the approach could in principle be combined with district cooling. The cost effectiveness of this solution must be compared with solar power generation combined with compression chillers.

5.2.8 Next steps for the building sector

This chapter provided detailed results for the building sector according to the bottom-up analysis of the 26 REmap countries as well as the latest information about the sector's most important renewable technologies. The most important applications where modern renewable energy technologies will play a role to substitute fossil fuels are space and water heating next to cooking. The sector is unique in terms of its traditional use

Box 5.6 Seasonal storage of heat and cold

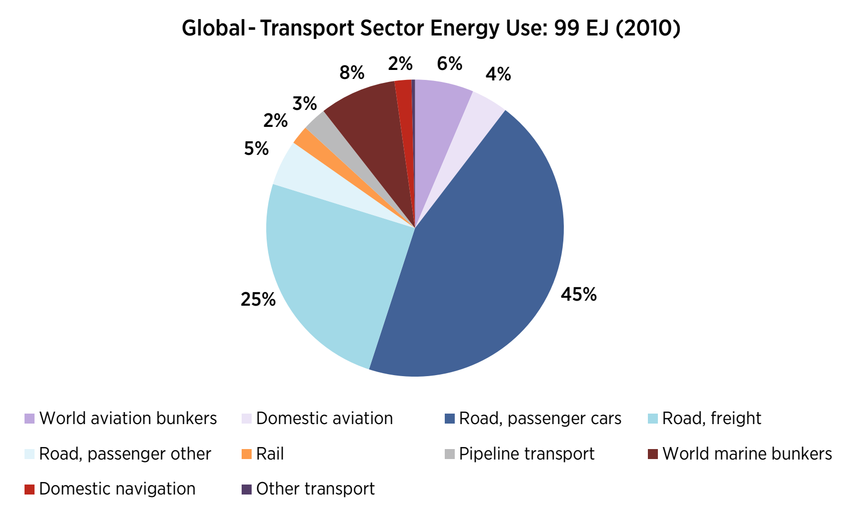
Seasonal storage is an emerging option. The campus of the Swiss Federal Institute of Technology in Zürich (ETH-Zürich) was heated with a 40 MW_{th} oil furnace, but in 2007 this was replaced with a modern geothermal seasonal storage system. The system cost CHF 38 million with an expected payback of only eight years. The system includes a set of 100 boreholes up to 500 metres deep, creating a natural heat reservoir of a million tonnes of soil and rock. With a storage capacity of 2.6 million kWh of heat, the innovative system deployed specially designed flow tubes in the boreholes as a means of reducing costs significantly. These boreholes use less-expensive flexible tubes and membranes instead of tubes cast in concrete.

Along with a heat pump (with a COP as high as 10 on the coldest winter days) and a low temperature heating system with a 28 °C inlet temperature, the system generates heat extremely efficiently. The system is "charged" in summer while providing cooling, and the heat is used in winter. New technology would also allow deeper boreholes where higher temperatures would be accessible. The cost of drilling is constant per metre down to 500 metres depth. The temperature profile in the ETH soil is 3 °C per 100 metres of depth. A temperature of 26 °C at 500 metres depth allows recovery at 17 °C at the surface (ETH Zürich, 2013).

of biomass in developing countries, and its substitution will be increasingly important in the next decades. Substitution is of particular challenge because traditional use of biomass for cooking or heating is part of the lifestyle in most developing countries and also because the energy demand for building will continue to increase. For a better understanding of the challenge ahead, the actual consumption volumes need to be known, which are currently subject to large uncertainty.

Next to improving energy access, improving energy efficiency of the sector will be key in order to attain the objective for renewable energy. The sector has tremendous potential to improve energy efficiency through passive houses and other options (*e.g.*, heat pumps), but the realistic potential needs to be better understood. In 2014/15, IRENA will expand its work to identify synergies and develop strategies for renewable energy, energy efficiency and energy access nexus.

Figure 5.12 Global total final energy consumption of the transport sector by mode, 2010



Road travel makes up 75% of energy use in transport, much of which could be electric.

Source: IEA (2012b) and IRENA analysis

5.3 Transport

5.3.1 Overview

The transport sector deals with the energy use of all transport modes: road, rail, aviation and navigation. Transportation accounts for around 30% of global TFEC and is dominated by road transportation (passenger cars and freight transport), which accounted for three-quarters of the sector's TFEC in 2010 (see Figure 5.12). Total light vehicle production in 2012 reached 81.5 million, of which 66.7 million were passenger cars and the remainder were primarily light trucks (Renner and Gardezi, 2013). Aviation (including aviation bunker fuels) accounted for 11% of TFEC in the transport sector in 2010, and sea transport (including marine bunker fuels) accounted for around 10%.

Table 5.3 provides a breakdown of the global transport sector's energy use by energy carrier for 1990 and 2010. The sector's TFEC has increased

Table 5.3 Global transport sector total final energy consumption by energy carrier, 1990-2030

	Reference Case			REmap 2030
	1990	2010	2030	
	(EJ/yr)			
Oil – Ships and planes	14	21	25	25
Oil – Road and rail	48	71	94	75
Electricity	1	1	2	5
Biofuels	0	2	6	16
Other fuels	3	4	5	5
Total	66	99	132	123

Source: IEA (2012b) for 1990, 2010. IRENA estimates for 2030

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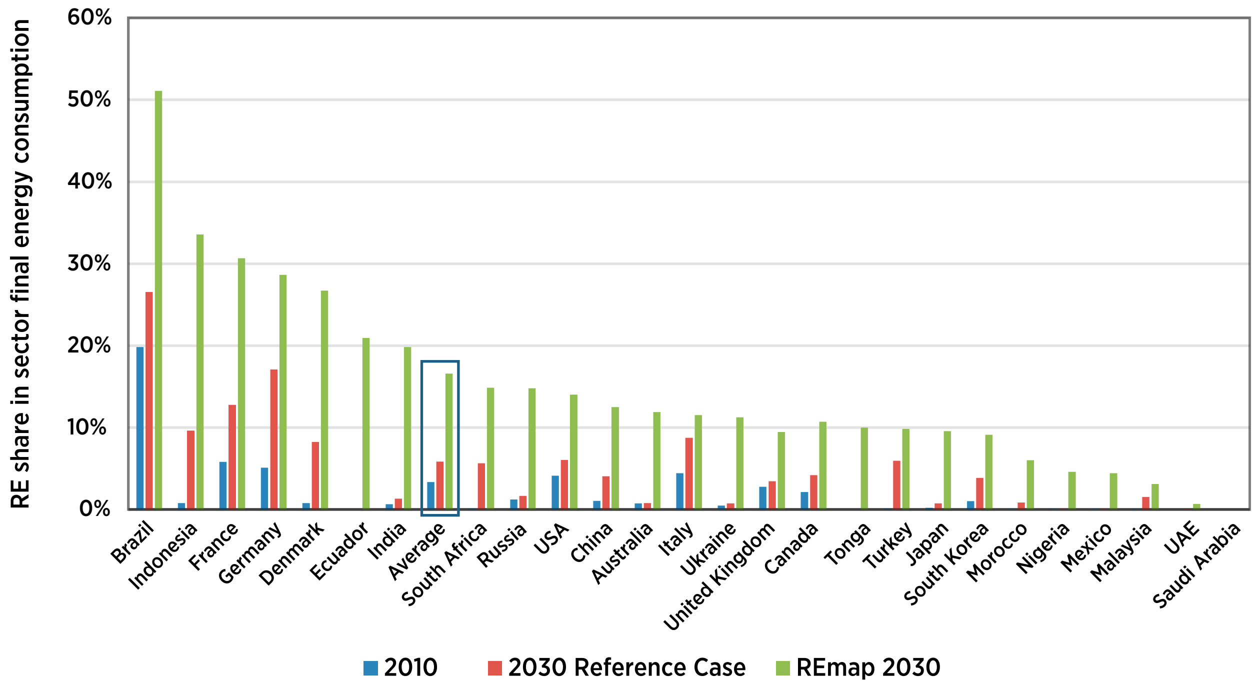
Figure 5.13 Current and projected share of renewable energy in the transportation sector, by country, 2010-2030



With REmap Options, the average country renewable energy share ranges from 0% to 51% in 2030.

Note: Results presented in this figure refer to the renewable energy share of the sector's TFEC, thereby including the contribution of renewable electricity consumption (see Indicator 1 in Chapter 2.3).

by 50%, from 66 EJ in 1990 to 99 EJ in 2010, but the breakdown by carrier has changed little. Oil products account for about 93% of the sector's TFEC, mainly for road transportation. The share of electricity (1%) and other fuels (*e.g.*, natural gas) (4%) remained the same in the entire period. Biofuels have gained a market share of 2% in 2010 from no use in 1990. All of the growth in electricity consumption in transport came from the rail sector.

Table 5.3 also provides a breakdown for the year 2030 for the Reference Case and REmap 2030. The sector's energy use will continue to grow at similar rates in the next two decades, from 99 EJ in 2010 to 132 EJ by 2030, according to the Reference Case. The use of oil products for road and rail transportation will account for 71% of the sector's TFEC by 2030. The share of biofuels will more than double to 5% by 2030 to a total of 6 EJ, whereas the share of electricity will remain the same.

In REmap 2030, biofuels use nearly triples to 16 EJ and electricity use reaches 5 EJ. Liquid biofuels and electric vehicles (including trains) substitute mainly the use of oil products for road and rail transport.

The transport sector is where renewable energy has made the least progress – and where biomass can quickly reach the limits of its sustainability. A larger share of renewables in the transport sector will almost certainly entail a modal shift – from individual, fossil-powered mobility to electric and hybrid vehicles with greater public transport. A shift to renewables in transport thus depends not only on technological advances, but also on behavioural and societal changes. The best part is that the public could view these tremendous gains in environmentally friendly energy as progress – as an improvement in the standard of living, not as a luxury that has to be foregone for the sake of the planet.

Figure 5.13 shows developments in the sector's renewable energy share for the 26 REmap countries and by country. The renewable energy share in the transport sector will increase from 3% to 17% in REmap 2030, mainly from increased use of liquid biofuels. The transport sectors of a number of countries exceed a 20% renewable energy share. Demand for liquid biofuels will originate from all countries; however, since feedstock availability is distributed unevenly, the trade of liquid biofuels will increase. Likewise, innovation will play a key role in the development of more efficient technologies to utilise primary biomass for biofuels, as resources are constrained.

With all Remap Options deployed advanced biofuels will cover 37% of demand for bioenergy liquids by 2030.

In the 26 REmap countries, about 8.2 EJ of additional biofuels could be added by 2030 according to the REmap Options, roughly half of which is advanced biofuels, which brings total biofuel demand to approximately 13 EJ. About 8 EJ of bioethanol demand will be first generation; another 3 EJ, second generation. Biodiesel use is projected to reach 2 EJ. Total liquid biofuels demand is equivalent to 16 EJ, or 650 billion litres, worldwide in REmap 2030 – six times more than in 2010.

Compared to scenario estimates of different organisations which yield a range of 5-19 EJ for liquid biofuels demand in 2030 (IRENA, 2014j), REmap 2030 is found to be plausible. The demand for liquid biofuels is equivalent to a growth of 11% per year between today and 2030. This may be lower than the growth between 2000 and 2012 of about 19% per year, but it is still considerable especially given the slowdown in biofuels production in the past years and the investments in key regions such as Brazil. Realising the high share of renewable energy from liquid biofuels in the transport sector will therefore require special attention from policy makers and the energy industry to develop cost-competitive and sustainable advanced biofuels in the coming years.

The transport sector could double its share of electricity use if all REmap Options are deployed. Most structural changes towards electrification (such as high-speed trains instead of busses) are taken into account in the Reference Case. The additional electrification potential lies in increased use of plug-in hybrids and battery-electric passenger vehicles. In the REmap Options, up to 900 PJ of additional electricity will be used by these vehicles. About 80% of the consumption will be related to passenger road vehicles, with the remaining 20% for light-freight vehicles. Worldwide, the total number of battery-electric vehicles and plug-in hybrids in operation is estimated to reach 160 million in REmap 2030, or approximately 10% of the total passenger car stock[2].

5.3.2 Conventional and liquid biofuels

Biofuels consumption for land transport grew from around 417 PJ in 2000 to 2 410 PJ in 2010. Bioethanol consumption grew from 272 PJ in 2000 to 1 426 PJ in 2010, an annual growth rate of 18%. The growth in biodiesel was even faster in percentage terms, from just 18 PJ in 2000 to 616 PJ in 2010, an increase of 42% per year. Other liquid biofuels also grew, but at a rather modest rate of 11% per year from 126 PJ in 2000 to 368 PJ in 2010. Biofuels demand is expected to grow further from 120 billion litres in 2013 to around 190 billion litres by 2022, according to recent research from Navigant (2014a) – an annual growth rate of 5.2% per year.

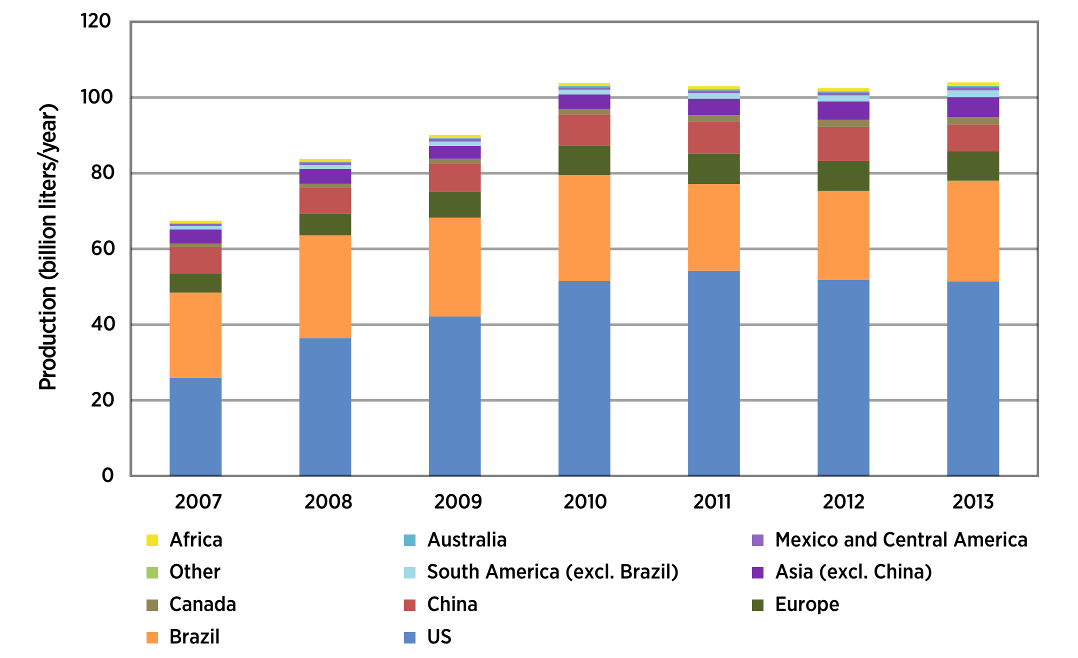
In 2010, some 84 million tonnes of conventional biofuels based on crops containing starch, sugar or vegetable oil were delivered, representing some 104 billion litres (85 billion litres of bioethanol and 19 billion litres of biodiesel) – enough to cover 2.7% of global transportation fuels demand. Production grew from 1.83 million barrels per day in 2010 to 1.87 million barrels per day in 2011 and 2012. The outlook for 2013 is for total liquid biofuels production to grow to 2.02 million barrels per day (IEA, 2013b). Finally, biogas is starting to be more widely deployed in countries such as Germany, Finland and Sweden, with a few hundred refuelling stations to date.

2 This refers to the total number of EVs if all were to operate with 100% electricity (total renewable electricity consumption of approximately 3 EJ). In reality, EVs would consume a mix of renewable and fossil fuel-based electricity from the grid, and in REmap 2030 the share of renewable electricity is 44%. Accounting for the share of power originating from fossil fuels, total electricity demand of EVs would be equivalent to 6.8 EJ and would translate to as much as 360 million EVs in REmap 2030. This is more than 20% of the global passenger car stock.

The largest producers of bioethanol are the United States and Brazil (see Figure 5.14). The United States produced around 60% of the global total in 2012, with Brazil accounting for around a quarter. Other major producers are Canada, China and Europe. In contrast, Europe, the third largest producer, accounts for only around 5% of global production. Production of bioethanol in the United States is based almost exclusively on corn as a feedstock, whereas in Brazil sugar cane is used. Global cane production amounted to 1 794 million tonnes in 2012. Brazil accounts for around 41% of global sugarcane production, followed by India (19%). Around a quarter of sugar cane is used for bioethanol production, with the rest devoted to sugar production. A five-fold increase of sugarcane ethanol production would require another 125 million hectares, equal to 1% of agricultural land in Brazil.

The use of bioethanol is limited because it can corrode fuel tubes. Stainless steel tubes add little cost and solve the problem but are not yet applied universally. This limits the share of bioethanol to around 10% of the blend. On the other hand, bioethanol is a more stable chemical compound than petrol, which allows a higher compression ratio during combustion to yield a higher conversion efficiency. Flex-fuel vehicles have been designed to operate on a variable mix and adjust the compression ratio depending on the mix. In Brazil, the majority of cars sold are flex-fuel vehicles, but this practice is not the rule worldwide.

Figure 5.14 Global ethanol production, by country and region, 2007-2013



Growth in bioethanol production has stalled since 2010.

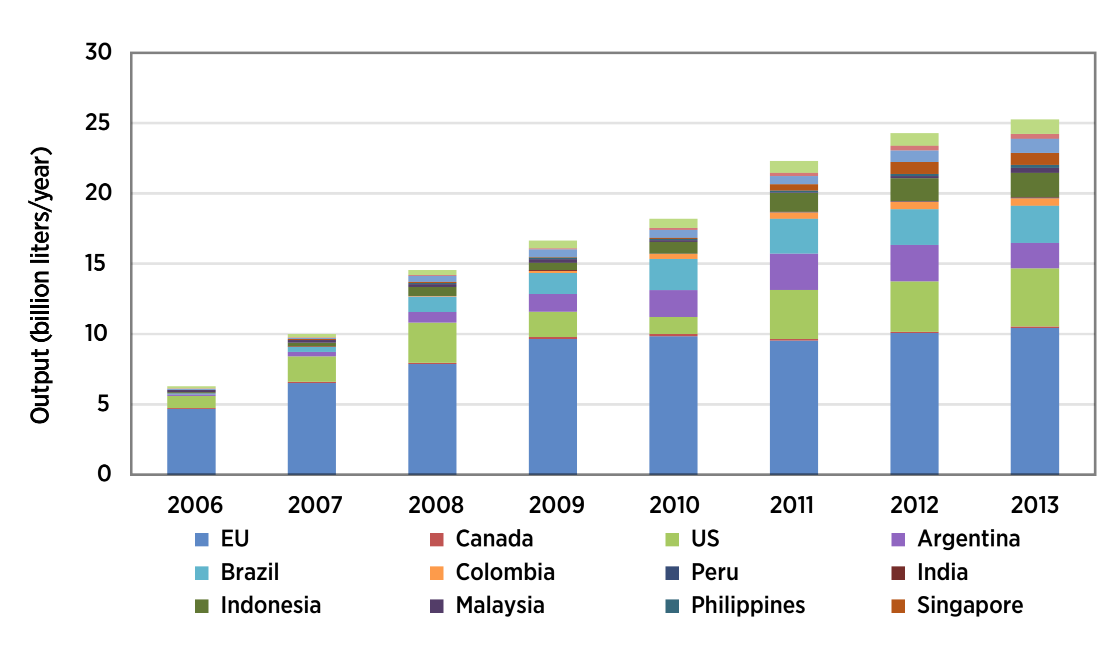
Note: Data for 2012 for Africa, Australia, Mexico and Central America, and "Other" are not available.

Source: F.O. Lichts (2013a) Includes the production of both fuel and non-fuel ethanol

Global biodiesel production grew 47-fold between 2000 and 2013 (see Figure 5.15). Europe, where biodiesel production grew from 17 PJ to 378 PJ (around 10 million tonnes) in the same period, has led the growth. The rapid growth in biodiesel has been driven by the biofuels mandate; also, the large share of diesel light-duty vehicles in Europe means that any mandate for biofuels requires a greater proportion to be biodiesel. Brazil increased its production of biodiesel from zero in 2005 to 2.5 million tonnes in 2013 to become the world's second largest biodiesel producer, thanks to a mandate that sales of diesel should include 5% biodiesel.

Biodiesel production in Europe, around 327 PJ in 2011, was around 5% lower than in 2010, with production facilities running at only around 39% of capacity in 2011 (IEA, 2012b; EBB, 2013). Production is influenced strongly by policy and the relative economics of domestic production (influenced heavily by variations in feedstock costs) and the cost of imports. For instance, the German biodiesel market collapsed overnight when tax exemptions were revoked.

Figure 5.15 Global biodiesel production, by country and region, 2006-2013



Strong growth in biodiesel is occurring increasingly outside the European Union.

Source: F.O. Lichts (2013b)

Likewise, biodiesel production in North America fell by around 39% in 2010 compared to 2009 after the expiration of the biodiesel tax credit (IEA, 2012b; US EIA, 2012). However, the retrospective reinstatement of the credit at the end of 2010 saw biodiesel production in the United States in 2013 dramatically reverse this decline, and production increased to around 139 PJ in 2013, 3.4 times the 2010 level.

Stop-and-go policy support has hampered biofuels growth.

Rapeseed is the feedstock for more than half of global biodiesel production. In 2009, rapeseed was used as the feedstock for around two-thirds of biodiesel in the EU, with 13% from imported palm oil, 10% from soybeans, 4% from refined vegetable oils and 3% each from sunflowers and tallow (Hamelinck *et al.*, 2012). Argentina and Brazil also produce significant quantities of biodiesel, predominantly from soybeans. In the United States, biodiesel production in 2012 was based primarily on soybean oil, although significant quantities of canola oil, corn oil, tallow, and white and yellow grease were also used (US EIA, 2013). Thailand, Malaysia, Colombia, Indonesia and Singapore all produce biodiesel from palm oil.

The biofuels described above are controversial because they rely on food crops. Advanced biofuels based on lignocellulosic crops (wood and straw) produce ethanol and diesel substitutes from the woody parts of existing food crops (*i.e.*, the parts not eaten) and from other crops that thrive on land not suitable for food crops (such as switchgrass and jatropha).

Production of advanced biofuels is just taking off, with only a few plants in operation worldwide. Advanced biofuels accounted for around 0.2% of total biofuel production in 2012. As of late 2012, 230 million litres of cellulosic biofuels capacity was available worldwide, more than twice as much as in the previous year. The United States has a capacity of 120 million litres, including the biomass-to-liquids plant completed by KiOR and Ineos at the cellulosic bioethanol plant in Florida.

Elsewhere, Borregaard has 20 million litres of cellulosic bioethanol capacity in Norway; Beta Renewables has 75 million litres of capacity from agricultural waste in Italy; and Brazil has an installed capacity of 40 million litres from sugarcane bagasse and straw (operation starting in the beginning of 2014). Another five plants in the United States with an average capacity of 75 million litres per year per plant will process a

5

variety of feedstocks to produce cellulosic bioethanol, with production starting in 2014 (Sheridan, 2013). At present, the investment costs for a cellulosic bioethanol plant are more than three times greater than for a corn-based plant. Although feedstock costs are lower, the cost of cellulosic bioethanol is still considerably higher than for first-generation bioethanol (IRENA, 2013c).

It is projected that global production capacity for advanced biofuels will grow to more than 1.2 billion litres in 2015. The bulk of the growth will take place in the United States, but advanced biofuels still account for only around 1% of global biofuel production. Some sources estimate that biofuel production could triple to more than 300 billion litres in 2030 (Novozymes, 2012). At that point, 20% of agricultural residues would be used as feedstock. This should be considered a high estimate for advanced biofuels production.

Advanced biodiesel could be produced from a variety of feedstocks including wood, waste or jatropha through a combination of gasification and biomass-to-liquids routes. Higher-quality biodiesel can be obtained (*e.g.*, NExBTL biodiesel) compared to conventional biodiesel. This allows for higher blending, with fewer or no problems in the logistics of fuels or in automobile engines. Another possible route for biodiesel production is the hydrotreatment (or refining) of non-food oils, although also including animal fats. Technology is already fully commercialised for the hydrotreatment of vegetable oils, with two plants in Finland and two others in Singapore and the Netherlands in operation (four plants with a total capacity of 2 million tonnes per year). Another wood-based biorefinery is expected to start operation in 2014 in Finland to produce biodiesel with a total capacity of 0.1 million tonnes per year (UPM, 2012). A commercial-scale plant in the Netherlands is producing bio-methanol from glycerin with a total installed capacity of 0.2 million tonnes per year.

Another liquid biofuel which has potential for both diesel and petrol engines is biomass-based dimethyl ether (DME). The first bio-DME plant in the world running with black liquor gasification located in Sweden has a total production capacity of 4 tonnes per day. Total field test mileage reached at the end of 2012 was approximately 825 000 kilometres with a maximum truck mileage of 183 588 kilometres. The field test target for June 2014 is to reach 1 475 000 kilometres, with a single truck reaching 300 000 kilometres (BioDME, 2013).

5.3.3 Electric mobility

Electricity can play an important role as a clean energy source without local air pollution and greenhouse gas emissions. EVs are 2-3 times more efficient than those with internal combustion engines (ICE). As the share of renewables rises in electricity production, EVs will facilitate the switch to renewable energy in overall supply. In return, the greater the share of renewables in power supply, the more environmentally friendly our electric mobility becomes.

Electric vehicles are 2-3 times more efficient than conventional cars.

A vehicle that relies completely on electricity for motive power is referred to as an EV or sometimes a battery-electric vehicle (BEV). An EV has no internal combustion engine; a battery pack supplies electricity to an electric motor (or motors), which convert the electricity into mechanical energy. The battery also provides all the auxiliary power required (for lights, air conditioning, etc.). The battery is recharged from an electricity source and from regenerative braking.

Hybrid-electric vehicles (HEVs) combine a battery with an electric motor and an internal combustion engine, usually running on petrol, but a diesel motor is also possible. The internal combustion engine can then be switched off at idle and low speeds, when the vehicle runs purely on electricity; alternatively, the electric motor can provide additional power to complement the internal combustion engine when required. The battery is recharged via regenerative breaking or by the internal combustion engine.

The first HEVs were optimised to achieve fuel economy improvements, so the battery and power trains were not designed for pure electric operation in all driving conditions. Their batteries therefore do not have to go through deep discharge/charge cycles, and battery life can be optimised. The new generation of HEVs is designed to offer all-electric driving and can be plugged into the grid, which is why they are called plug-in hybrid-electric vehicles (PHEVs).

More than 90% of the world's electric bicycles are in China.

PHEVs have sufficient battery storage and powertrain designs to allow for purely electric operation over a certain distance, with the on-board internal combustion engine acting as a "range extender" by providing power when the battery is exhausted or when more power is needed. With significant deep discharging and charging, the batteries need to be more robust than "light" HEV configurations, and prolonging battery life becomes a very important consideration. This type of vehicle configuration will often allow a majority of driving to be done on electricity from the battery alone, while the retention of an internal combustion engine means that the total range of the vehicle on electricity and liquid fuels is comparable to today's internal combustion engine vehicles.

In the 2013 "greenest" vehicles list of the American Council for an Energy Efficiency Economy, the majority of the cars topping the list were hybrid, plug-in hybrid or all-electric vehicles, showing that they perform much better in their life-cycle greenhouse gas and pollutant emissions compared to conventional vehicles (ACEEE, 2013,2014).

Electrification is also an option for delivery trucks and urban busses. However, it is less suited for long-distance transportation, including the bulk of freight transportation.

EV sales amounted to 180 000 in 2012, or 0.3% of total car sales. About half were plug-in and half were battery-electric vehicles. It is projected that PHEVs will grow to 1-3% of the global car market by 2020 (Navigant, 2013d). In comparison, hybrid-electric vehicles accounted for 3.2% of global car sales in June 2013 (Electrification Coalition, 2013). EV sales reached 10% of total passenger car sales in 2013 in Norway. In 2014, global PHEV sales are projected to reach nearly 350 000 cars, raising the number of EVs in the vehicle stock to 700 000, according to Navigant Research (Navigant, 2014b). Increasing production of batteries contributes to the reduction in the price of batteries. Compared to McKinsey estimates for 2020 of USD 200 per kWh, current costs are USD 238 per kWh. This level was not expected until the end of 2013 and also highlights that McKinsey's 2020 projections will likely be reached much earlier (GoingElectric, 2013).

Box 5.7 Renewable solutions for aviation and shipping

The International Air Transport Association (IATA) aims for 6% biofuels by 2020. Tests show that this goal is technically feasible with biofuels commercially available today, with mixtures of kerosene currently containing up to 50% biodiesel. However, availability and cost pose major obstacles. No other solutions have been identified so far.

Ships use diesel and heavy fuel oil (bunker oil). These engines can also use biodiesel and to some extent raw vegetable oil. But here too, availability and cost pose major obstacles. Maersk and the U.S. Navy, the two largest fleet owners in the world, are exploring algae biofuels and aim for a 50% reduction of oil use by 2020 (Maersk, 2011). UAE-based Etihad Airways will soon offer flights powered with 100% biofuels.

Biokerosene could be produced from halophytes, but researchers are also looking into possibilities of using agricultural waste and palm leaves. Halophytes are crops which can be irrigated with salt water and can grow in the desert. The development of this raw material has been researched by a consortium of Boeing, Etihad Airways, Masdar Institute and Honeywell.

To some extent, solutions such as kites and wind energy can help. Based on Wang and Lutsey (2013), we estimate that wind power (kites and Flettner rotors) can contribute 5% and solar can provide 0.2% of total demand by 2030.

Electric two-wheelers (e-bicycles, e-scooters and e-motorcycles) are rapidly gaining ground. Sales in Asia-Pacific reached 44 million in 2012, more than 90% of them in China (Pike Research, 2013). E-bicycles account for more than three-quarters of the market for electric two-wheelers. Pike Research forecasts that global annual sales of e-motorcycles and e-scooters will reach 18.6 million by 2018.

By 2018, China will have 355 million electric two-wheelers – or one vehicle for every four persons. To some extent, e-bikes can replace cars. Sales in the region are projected to more than double by 2030. Elsewhere, sales of electric bikes are also picking up. Roughly a quarter of Germans, for instance, plan to purchase an e-bike.

The greatest benefits here will come from a modal shift – when people switch from cars to electric bikes for local commuting. Because of the support from the electric motor, more people will ride bikes to work without having to shower when they get there. And of course, eliminating a car altogether will save money, so this transition can also produce financial benefits.

5.3.4 Next steps for the transport sector

This chapter provided detailed results for the transport sector according to the bottom-up analysis of the 26 REmap countries as well as the latest information about the sector's most important renewable technologies. Liquid biofuels for road transportation are key for the sector to raise its renewable energy share; however, a six-fold increase in their use is needed to achieve a considerable increase, according to REmap 2030. In view of the slowdown in liquid biofuels use in recent years and the need for sustainable sourcing of biomass feedstocks, reaching these levels will be challenging with today's conventional biofuels. Development and deployment of advanced biofuels in the next years will be essential. The commercialisation of advanced biofuels will also be very important for the aviation and shipping sector where no other alternatives were found.

EVs and modal shifts present other opportunities. Yet even with a high EV share in the passenger vehicle stock, the increase in the renewable energy share is limited. This is because EV potentials is limited to road passenger transportation, and only a part of the power grid is renewable. Potentials for modal shifts needs to be better understood for expanding the portfolio of options in the sector, in particular for freight transportation. In 2014/15, IRENA will develop action teams for the transport sector through the cooperation with experts of the interested countries and other stakeholders with the aim of identifying opportunities for advanced biofuel and electrification technologies and gain more insight into their potentials and costs as well as identify policy needs to accelerate their deployment.

5.4 Industry

5.4.1 Overview

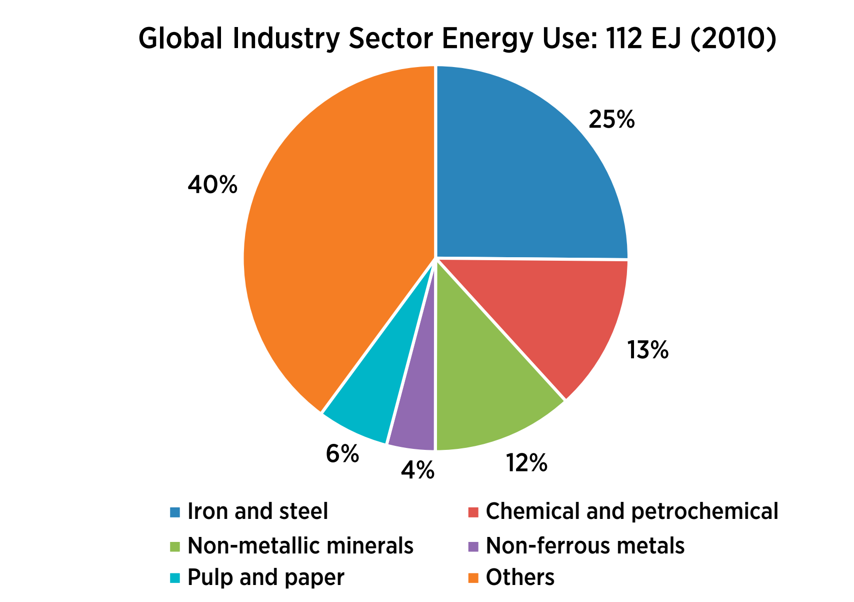
This chapter is a shortened version of IRENA's detailed roadmap looking at the potentials of renewable energy in the manufacturing industry sector which can be found online.

Manufacturing industry deals with the production of bulk materials (*e.g.*, cement, aluminium), food, textiles, wood products and other goods. It excludes the energy mining and energy transformation (*e.g.*, oil refineries) sectors. The global industry sector's TFEC reached 112 EJ in 2010 (see Figure 5.16). Energy-intensive sub-sectors account for 60% of the sector's TFEC, while the remaining 40% is made up of less energy-intensive sub-sectors.

The industry sector is often overlooked in discussions about renewables, even though it accounts for a third of energy consumption.

Industry consumes a great deal of energy, most of it as heat. Worldwide, a total of 73 EJ of fuels were used to generate process heat via steam and

Figure 5.16 Global total final energy consumption of the industry sector by sub-sectors, 2010



Source: IEA (2012b)

direct heat, with another 9 EJ used by blast furnaces and coke ovens[3] for iron and steel production (together referred to as process energy).

Electricity demand in industry reached 25 EJ in total, approximately two-thirds of which is related to motor systems (including compressors, fans, blowers and pumps; based on data from the US and EU) (IPCC, 2007c). The remaining one-third is for primary aluminium production, metals recycling, electrolysis and other auxiliary use. The share of electricity in TFEC has nearly doubled in both the industrialised and the developing countries and economies in transition, from approximately 15% to 25-30% in the past four decades.

Most fuels are used for combustion in boilers, furnaces, kilns or heaters to generate process heat at varying temperatures. Process heat is used for different industrial processes such as drying, washing (food industry), dyeing, bleaching (textile), distillation and evaporation (chemicals).

Low-temperature processes (<150 °C) exist in sectors such as food and beverages or textiles. Medium-temperature processes (150-400 °C) are found mostly in chemical and petrochemical processes, pulp and paper, and non-ferrous metals (alumina manufacturing). Kiln

3 According to the IEA's Energy Statistics, blast furnaces and coke ovens are part of the energy transformation sector. Therefore their energy use is not reported together with the iron and steel sector, whereas in reality they are often integrated in steel mills. Coke ovens transform metallurgical coal into coke, which is required for iron production; blast furnaces subsequently produce iron from iron ore with a coal and coke mixture as fuel input. In order to provide a complete picture, the rest of this analysis takes into account their energy use together with the industry sector.

Table 5.4 Global industry sector total final energy consumption by energy carrier, 1990-2030

	Reference Case			REmap 2030
	1990	2010	2030	
	EJ/yr			
Coal	27	39	59	53
Oil	14	14	20	20
Gas	15	19	43	36
Electricity	16	27	53	54
Heat	6	5	6	6
Bioenergy	5	8	12	21
Other renewables	0	0	0	3
Total	83	112	194	193

Note: Includes blast furnaces and coke ovens, but excludes non-energy use.
Source: IEA (2012c) for 1990, 2010. IRENA estimates for 2030

operations in the non-metallic minerals sector and blast furnaces in the iron and steel sector for iron production operate at high temperatures (>400 °C).

Table 5.4 provides a breakdown of the global industry sector's energy use by energy carrier for 1990 and 2010. The sector's TFEC increased by 35% between 1990 and 2010 to 112 EJ, and fossil fuel use has seen some changes although it continues to account for two-thirds of TFEC. The share of coal use has increased at the expense of oil and natural gas use, mainly because of increased production in China. The share of electricity use has also increased from 19% to 24% between 1990 and 2010. Biomass use remained stable at 7%. The importance of district heat has decreased as the sectors produced more of their own process heat. Energy use of industrialised countries decreased by about 10-15% in this period, whilst developing countries and economies in transition would increase their energy use by 15-20%.

Table 5.4 also provides a breakdown for the Reference Case in 2030 and REmap 2030. The sector's energy use will grow at higher rates in the next two decades, from 112 EJ in 2010 to 194 EJ by 2030 in the Reference Case. It will account for nearly 40% of global TFEC by 2030, compared to approximately one-third in 2010, highlighting the increasing importance of its potential, which has so far received limited attention. Natural gas (22%) and electricity (27%) use will account for an increasing share of the sector's TFEC by 2030, with the share of coal decreasing. Renewables' share will remain at 6%.

In comparison, the share of bioenergy increases to 11% and the share of other renewables to 2% in REmap 2030. Coal and natural gas are mainly substituted, with their total share decreasing from 53% in the Reference Case to 46% in REmap 2030.

The renewable share in industry could increase from 11% to 26% if all the REmap Options are implemented (see Figure 5.17). The global industry sector currently has only a limited renewable energy share in most countries (on average 10%).

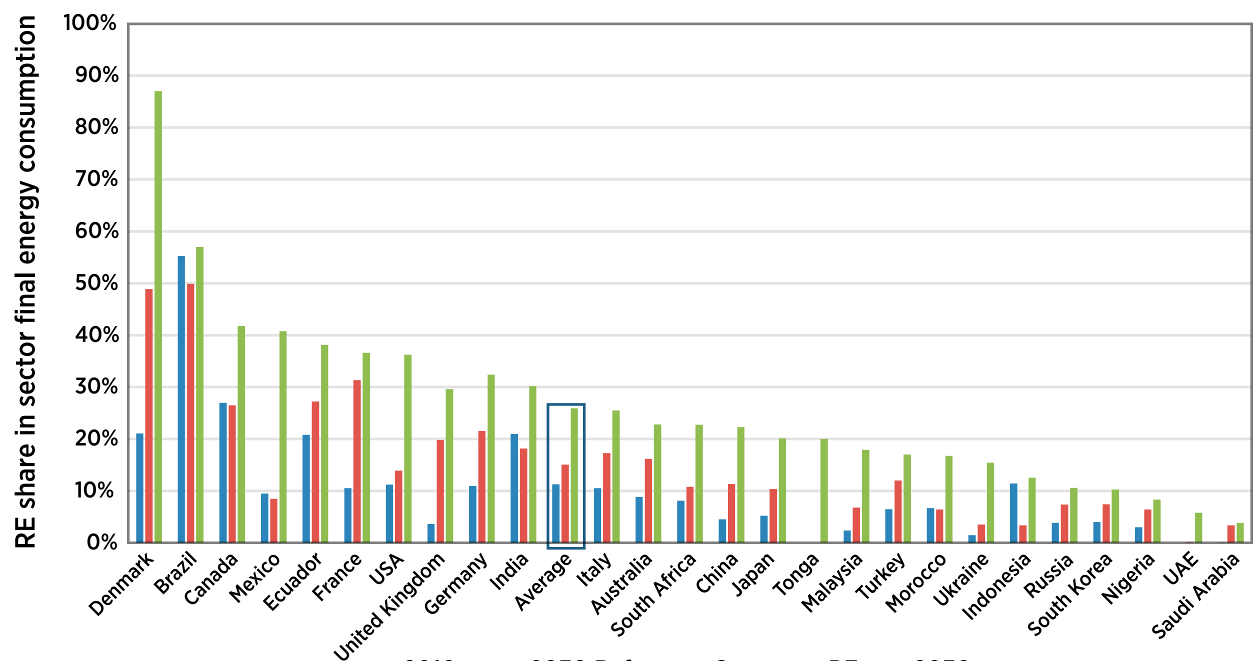
Unlike the traditional use of biomass in the building sector, biomass use in the industrial sectors of developing countries and economies in transition is regarded as modern. Brazil and India therefore already have high renewable energy shares in their industry sectors compared to the world average and could even go beyond these levels with additional biomass and solar thermal in REmap 2030.

Fossil fuel demand for process heat generation can be substituted with biomass and other technologies such as solar thermal systems and heat pumps. A higher share of renewable energy in the power sector, on-site power generation from renewable energy sources and biomass-fired CHP plants can increase the share of renewable electricity in industry. Biomass could play a key role for high-temperature heat applications, mainly in the non-metallic minerals sectors where other renewable technologies do not provide an alternative.

Biomass capacity in the industry sector could increase to 780 GW_{th} in the 26 REmap countries, according to REmap 2030. Total demand for biomass in the industry sector would reach 21 EJ if all REmap Options are deployed by 2030. This is a slightly slower continuation of the past trend between 1990 and 2010 (4% per year compared to about 3% per year).

Total solar thermal capacity in the 26 REmap countries could reach 700 GW_{th} if all REmap Options are deployed. Today, there is very small solar thermal capacity in the industry sector installed worldwide (<1 GW_{th}). Hence, reaching REmap 2030 would require substantial growth. However, suitable solar thermal technologies in industrial production plants are similar to those in the building sector, and this creates benefits for transferring the technological experiences easily to process heat generation. Furthermore, most of this capacity would be installed in low-temperature heat using processes of small-scale sectors, which are growing in number in developing countries and can integrate solar thermal plants to their systems when new plants are designed. With the right policies in place that consider these aspects, such growth would be realisable.

Figure 5.17 Current and projected share of renewable energy in the manufacturing industry sector, by country, 2010-2030



With the right policies, the renewable share of energy use by industry could more than double to 26%, by 2030, based on technologies now available.

Note: Results presented in this figure refer to the renewable energy share of the sector's TFEC, thereby including the contribution of renewable electricity and district heat consumption (see Indicator 1 in Chapter 2.3).

Compared to other end-use sectors, access to a continuous energy supply is essential as most industrial plants operate for three-quarters of the year. The cost-competitiveness of technologies is the second most important factor. Most industry sectors are already located in regions where cheap and reliable raw material and energy supply are provided. Industry will increasingly relocate to areas with low energy prices. Efficient technologies with low capital costs running on cheap energy sources will determine the extent to which renewable energy will be deployed in the sector.

5.4.2 Biomass

Today, most renewable energy is biomass and waste (~7.8 EJ). In the production of bricks, tiles and other ceramics, different forms of biomass are used in Asian countries. Coconut shells, rice husk and different forms of biomass are combusted either for steam generation or direct heat. In Europe, waste fuels are used in cement kilns and to an extent in lime production, but the shares are generally low, although some kilns run at 100%. Wood chips and wood pellets have also gained market share in other industry sectors in Europe and are combusted in efficient boiler systems like their fossil fuel-based equivalents.

As in Brazil today, charcoal can be used in other countries to substitute coke input and coal injection in blast furnaces and sinter ovens for high-temperature applications above 1 000 °C. With technological developments to enhance the mechanical stability of charcoal, it can be used in more regions and at a higher substitution rate. The substitution rates of coal by charcoal in iron making can be very high: 100% for coal injection and 20% as a coke-making blending component (Norgate *et al.*, 2011,2012).

Technically, all fossil fuel use in cement kilns can be substituted with biomass. Two limiting factors are the calorific value of the fuels used and the

Box 5.8 Action areas for SMEs

While energy-intensive industry makes up more than 60% of the industry sector's TFEC, small and medium-sized enterprises (SMEs) account for over 90% of the world's businesses and provide jobs for more than half of the working population. Raising the share of renewable energy in the industry sector requires a separate focus on energy-intensive sectors (large energy users) and SMEs to optimally allocate resources and accelerate technology deployment.

Bioenergy could technically provide process heat for all sectors, but support for other technologies not yet deployed is needed. It is also important to prioritise investments to sectors requiring the least modifications in production processes because industrial plants run for several decades, often exceeding their technical lifetimes. Their processes are mostly integrated in terms of material and energy flows, which limit the penetration of new fuel systems.

SMEs are estimated to account for 15-30% of current total final industrial energy use (Banerjee *et al*., 2012). Energy costs often form a substantial part of overall production costs, and fossil fuel price volatility has a serious impact on their profitability. Furthermore, production capacity is – especially in developing countries – often based on aging, inefficient equipment, thereby increasing the energy demand of process heat generation. Replacing inefficient equipment with new capacity and integrating renewable energy in new capacity are two key areas that can benefit SMEs.

Overcoming barriers against new technology uptake: Lack of awareness is a major barrier for renewables deployment. Few SMEs know how they can reduce their dependence on expensive fossil fuels or have the technical skills or dedicated energy managers to focus on the integration of renewables in existing processes. There are also limited reference projects that SMEs can learn from. Additionally, few companies cater to renewables deployment in smaller companies. To realise the many opportunities for SMEs, these barriers need to be eliminated.

SME clusters: One strategy to break the vicious circle of unfamiliarity with renewables deployment is clusters and cluster leaders. Many SMEs operate in clusters organised around a specific set of industrial operations. The proximity of multiple SMEs with similar operations and energy demand structures makes SME clusters a way of promoting renewable energy deployment. Specific knowledge-management centres could be employed to collect and provide data on renewable energy applications for these clusters.

Mix of renewable energy technologies: Although the absolute energy demand per SME is often relatively low, the potential to provide a significant share of the energy consumption per plant is much higher than in large companies. A portfolio of renewable energy technologies consisting of biomass, solar thermal systems, geothermal and heat pumps can be deployed to cater to a range of heat requirements and provide flexibility to SMEs towards reducing their dependency on fossil fuels.

temperature level of the process. Direct combustion of biomass at the precalciner is easier because the temperatures are lower in this part of the process. Biomass gasification is another alternative where synthetic gas can be combusted, but experience with gasification technology in kilns is limited (Seboka, Getahun and Haile-Meskel, 2009). Roughly 60% of the total fuels used in cement production are used at the precalciner, which is the technical potential of biomass use in the process. Without any additional investments, 20% of the fuels can be substituted with biomass (Chinyama, 2011). Cement Sustainability Initiative (CSI, 2009) estimates that by 2030, 10-30% substitution in developing countries and up to 50-60% in industrialised countries is viable. Higher substitution rates change the operation dynamics of the plants significantly.

Biomass-based steam generation is particularly interesting for the chemical and petrochemical sectors, food and beverages, and textile sectors, where most production processes operate with steam. Low- and medium-temperature process steam used in the production processes of these sectors can be provided by boilers or CHP plants. Combusting biogas in CHP plants is another option already pursued in northern European countries, especially in the food and beverage sector, where food waste and process residues can be digested anaerobically to produce biogas.

Worldwide, biomass is estimated to contribute to more than 80% of the renewable energy potentials of all technologies in industry, with about three-quarters of the total biomass-based heat demand originating from CHP; hence, it is the most important technology for the sector to contribute to a doubling of the global renewable energy share in 2030. A number of practical constraints could limit the potential of biomass. In addition to the limited availability of biomass, the price of feedstock will increase as the limits of supply approach, and demand for large volumes will increase transport, thereby raising costs further. Continuous energy supply is another issue, and large storage areas for biomass will be required, especially in plants with high absolute demand.

Real-world constraints, such as storage space for biomass, limit the potential of renewables in industry.

Finally, there are such mundane considerations as the need to store biomass locally. In addition to costs, space availability on-site is the most important barrier limiting the deployment of the technology. Energy-intensive plants may require too much energy per unit area, whereas SMEs could have lower demand per plant. SME plants worldwide could therefore be the starting point for the implementation of solar thermal – which requires little storage area – in the industry sector.

While biomass, solar thermal, geothermal and heat pumps can provide low- and medium-temperature process heat, biomass is the only alternative for high temperatures.

5.4.3 Solar thermal

The share of solar thermal for process heat is currently very low but growing. One of the first large-scale systems was installed in the US at a plant producing food products to generate medium temperature steam (2.4 MW_{th} of capacity from a total of 384 collectors) (Sun & Wind Energy, 2009). A few pilot projects have been implemented in Europe (ESTIF, 2013). In the countries with the largest solar thermal capacity, less than 10% of the total capacity installed in 2010 was related to process heat and space heating, low-temperature process heat, water treatment, and refrigeration and cooling in industrial buildings (Weiss, 2013).

Although new initiatives focus mostly on the residential sector, installed solar thermal capacity in industry may also increase. For example, by 2020 China aims to reach 300 million m^2 of solar thermal capacity in operation, with about 35% related to industrial applications and other large-scale projects (Koldehoff, 2012). Industry sectors may benefit from the progress achieved in the building sector, especially because the technologies used for low-temperature process heat applications are similar: flat-plate panels and evacuated tubes.

New solar-process heat technologies are also being developed. For example, CSP has potential to provide process heat in enhanced oil recovery (EOR) operations. Although the related energy use is outside the manufacturing industry's TFEC (and thereby the scope of REmap 2030), technology can be applied in industrial production plants. Currently, two enhanced oil recovery plants in the US state of California, one in Coalinga and the other in McKittrick, produce pressurised steam for the process (capacities of 29 MW_{th} and 7 MW_{th}).

The IEA *Solar Heating and Cooling Roadmap* (IEA, 2012e) projects that up to 3 EJ of solar heat can be deployed in the global industry sector by 2030.

There is a broad range of applications for solar thermal technology, including industrial cooling. The technology will gain more importance as cooling demand in the food and beverage sectors increases in regions subject to stricter hygiene and health standards.

Solar drying is already applied in southern Asian countries and in south-eastern Europe. Various agricultural products (such as tomatoes, tea, meat and fish) use modern preservation and drying techniques. If the drying time of solar drying were shorter, the process would be employed more often in the food and beverage sector. The cost of solar drying is already relatively low.

5.4.4 Heat pumps and geothermal heat

For low-temperature process heat applications, heat pumps (air-source or ground-source) and deep geothermal heat are two other options. So far, heat pumps have played only a negligible role. In contrast, deep geothermal heat is used in some industrialised countries as well as in China, but its share is still less than 1% of the sector's TFEC.

Temperature lift – the difference between the temperature of ambient air and process heat – determines the COP of heat pumps. Besides COP, electricity prices determine a heat pump's economic viability.

Geothermal heat requires a short distance between the source and the consumer. It is currently applied in the pulp and paper sector and for drying, evaporation, distillation or washing applications in various other sectors. In Iceland, for example, geothermal heat is typically used to dry fish (Arason, 2003). Similarly, tomatoes are dried with geothermal heat in Greece (EGEC, n.d.).

Geothermal resources in China are abundant and are already used for heating purposes. The resources are widely distributed throughout China. Similarly, Turkey has one of the largest geothermal resource potentials worldwide with an estimated technical potential of 31.5 GW_{th}. Most of the potential is located in Western Anatolia, where most industry is found and a number of industrial-scale units exist for drying figs and apricots.

SMEs, which account for more than 95% of the number of industrial plants worldwide, have low absolute energy demand per plant compared to large plants in the energy-intensive sectors. As with solar thermal, SMEs are a good starting point for heat pumps and geothermal as they offer great potential in small plants for food or textiles production. In light of their limited deployment so far, both technologies will require policy support to complement biomass technologies so that they can collectively achieve a greater share of renewable energy in the industry sector.

Box 5.9 Electrification in industry

Industry gets a large share of its electricity from the grid but also produces electricity in off-grid plants and cogeneration units. Plants can either directly consume the power they produce or sell part of it to the grid.

In some power-intensive sectors (such as aluminium smelters and cement factories), on-site generation is common as it ensures a continuous supply of cheap electricity. Fossil fuel use in plants with on-site generation can also be substituted with renewable energy. In particular, new plants can be located next to renewable energy resources to increase the share of renewable electricity in the industry sector.

The electrification of production processes is another option if electricity is generated from renewable energy sources. Industrial production processes typically operate based on fossil fuel technologies, with the exception of a few processes, such as smelting and electrolysis. Some heat-based production processes can also operate via novel process routes running on electricity.

For example, in Iceland hydrogen is produced from water via electrolysis and subsequently combined with CO_2 to produce bio-methanol (IRENA/IEA-ETSAP, 2013c). This process substitutes the fossil fuel-based steam reforming or partial oxidation process. However, since electrolysis is an electricity-intensive process, such transition is only possible where electricity is cheap.

As historical developments show, the share of electricity is increasing. In REmap 2030, the share of electricity use in Asian, African and Latin American countries could increase by about 50% compared to current levels. These regions will account for two-thirds of the industrial power demand worldwide by 2030. Hence, increasing the share of renewable energy in the power sector is key to increasing the share of renewable energy in the industry sector.

5.4.5 Next steps for the industry sector

This chapter provided detailed results for the industry sector according to the bottom-up analysis of the 26 REmap countries as well as the latest information about the sector's most important renewable technologies.

Biomass will be the key for this sector to generate medium- and high-temperature process heat, as no other technology provides an alternative. The analysis shows that for low-temperature process heat supply, solar thermal, geothermal and heat pumps are the other alternatives next to biomass. Policy makers need to realise this portfolio of options and develop targets for limiting fossil fuel use for low-temperature process heat generation in national plans. This will be an important first step for this sector, as its renewable energy potentials are so far neglected. To close this knowledge gap, IRENA has prepared a detailed roadmap specific to the sector, which is available online, providing the opportunities and next steps beyond what is shown in this chapter at the regional level.

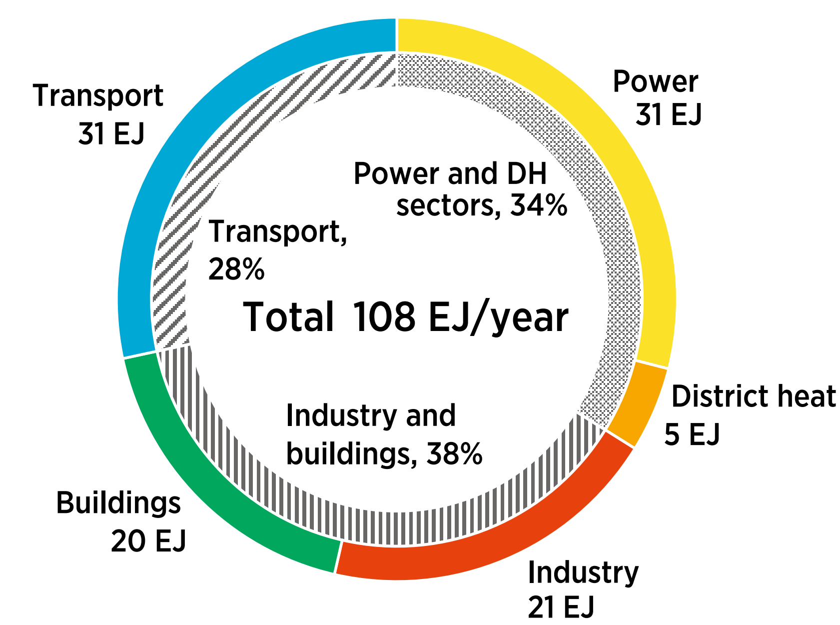
While the global average supply cost of primary biomass in 2030 is estimated at USD 8.3 per GJ supply costs in each country generally range from USD 2 to USD 18 per GJ.

The competition for biomass from other sectors – as fuel for heat and power generation, and as motor fuel – poses a particular challenge, as the industry sector will need to rely heavily on biomass if it aims to raise its renewable energy share. The portfolio of renewable energy technologies should be expanded with electrification alternatives for industrial processes. More insight into the costs and performance of these technology options will be essential. As for the building sector, the synergies between improving energy efficiency in industrial production processes and renewable energy will need to be understood better, given that the growth in the sector's energy demand between today and 2030 is projected to be the largest among all end-use sectors.

5.5 Biomass prospects

REmap 2030 shows that biomass would need to be the key resource if all REmap Options are to be deployed by 2030 and would dominate total use in all end-use sectors. However, affordability, supply security and sustainable sourcing are major concerns. In view of the importance of biomass, IRENA has prepared a working paper which is published along with this report. This working paper provides detailed findings about: 1) sustainable biomass availability by 2030, 2) supply cost and future price of biomass, 3) rate of biomass supply expansion, 4) optimal use of biomass, 5) key uncertainties for biomass prospects, and 6) governments role to strengthen biomass deployment. This working paper can be found online (IRENA, 2014j).

Figure 5.18 Global primary bioenergy demand by sector with REmap Options, 2030

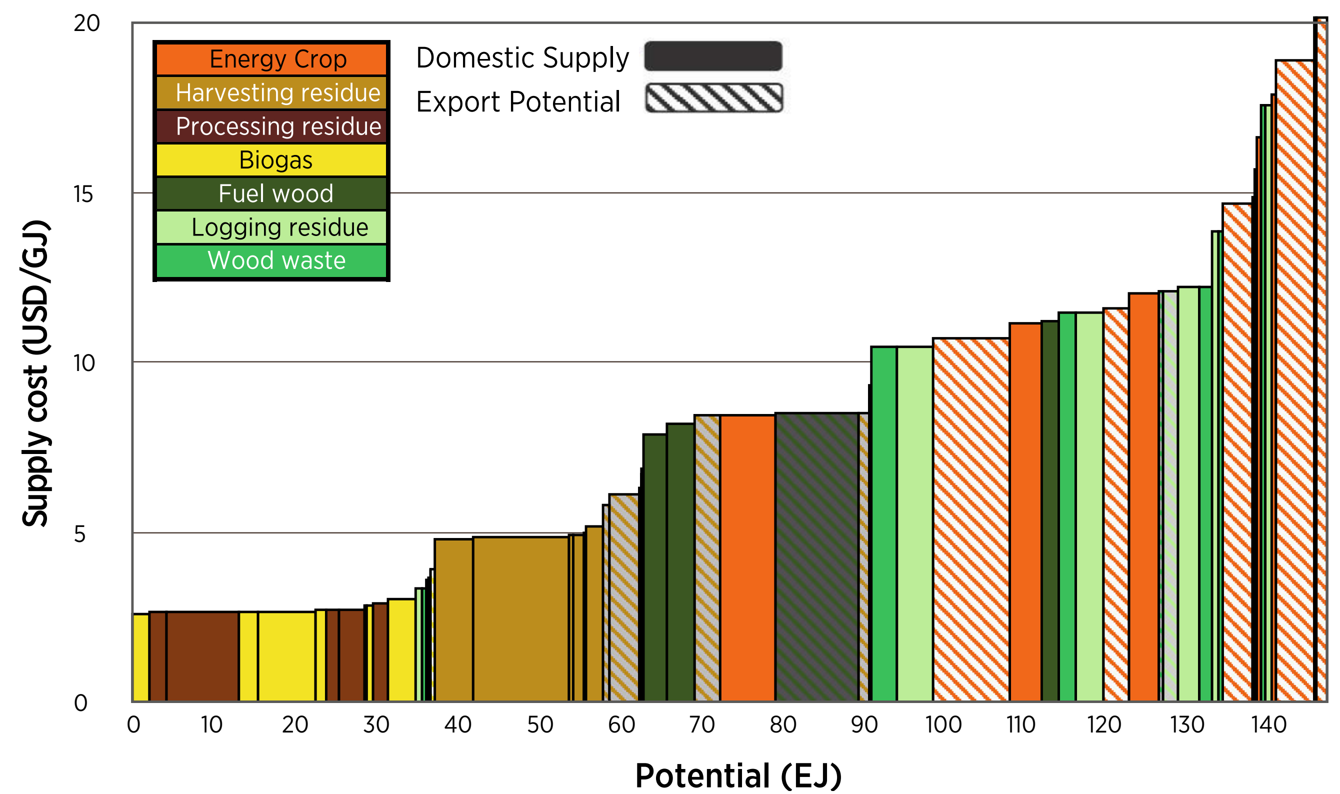


Biomass is versatile and can be used to provide power, transport and heat.

5

Figure 5.18 shows how biomass consumption is spread across the three end-use sectors of industry, transport and buildings, as well as the power and district heat sector, by 2030, when the additional REmap Options are implemented (in primary energy terms). It is assumed that the biofuels are produced from solid biomass with a conversion efficiency of 50%; hence, 1 GJ of biofuel (in final energy terms) requires 2 GJ of raw biomass (in primary energy terms)[4]. IRENA finds that demand for solid biomass will grow at an annual rate of 1.9% to 2030, far higher than projected in the Reference Case and in the historical increase of 1.3% per year between 1990 and 2010.

Figure 5.19 Global supply curve for primary biomass, 2030



The growth is far greater for liquid biofuels, which in the Reference Case increase by a factor of only 2.7 from 2010 to 2030, compared to six-fold growth in REmap 2030. From 2000 to 2010, annual liquid biofuels growth averaged 19%, although it flattened at the end of the decade, in part because of the EU's hesitation to increase its mandate for liquid biofuels. IRENA believes, however, that advanced biofuels will become competitive well before 2030 (IRENA, 2013c).

Figure 5.19 shows the supply potential for primary biomass in EJ along with the price by type/region. IRENA estimates that up to 25% of the total global biomass supply potential of 95-145 EJ is exportable surplus, meaning that biomass is largely a resource to be consumed locally. Traded biomass products will be mainly liquid biofuels, pellets and chips. Note also that global biomass demand is expected to increase to 108 EJ in 2030 with implementation of the additional REmap Options, close to the lower

4 The way IRENA expresses primary energy use of biomass is different than the method applied by IEA and most other studies. The difference relates to liquid biofuels of the transport sector. In other studies, primary energy of liquid biofuels is equivalent to their total energy content and does not refer to the raw biomass used to produce them. To ensure compatibility between the results presented here and other studies, one would therefore need to account for a conversion efficiency of 50% (on an energy basis) to convert raw biomass to liquid biofuels.

Box 5.10 Impacts of increased biomass demand on carbon balance and greenhouse gas emissions

Plants convert CO_2 from the atmosphere into biomass. Carbon stored in biomass is called biogenic carbon. Some of this carbon stays above ground and some in the ground. When plants die, decomposition starts. As plant material decays, carbon stored is released as CO_2 back to the atmosphere. If the amount of carbon released in biomass plantation and forests equals the amount of carbon sequestered, then the biomass carbon cycle is in balance. There are also circumstances where some of the carbon is stored in the ground. Carbon stored is huge, for example in the case of peatland.

When biomass is combusted before a plant decays, biogenic carbon is also released to the atmosphere. If the total biogenic carbon released during biomass decay and/or combustion is sequestered, the system continues to be in balance. As a result, CO_2 in the atmosphere does not increase. This is much different than the CO_2 emissions from fossil fuel combustion, which take millions of years to be sequestered; therefore, their combustion increases the CO_2 emissions in the atmosphere.

The carbon cycle could, however, change in different ways when large amounts of bioenergy are used as fuel. If bioenergy substitutes fossil fuel, there is a positive effect because fossil fuel CO_2 emissions are avoided. With increasing bioenergy use, carbon stored in living plants and soil may also change, but the dynamics in soil carbon are not well understood. So this may have a positive or a negative effect.

When short-rotation energy crops or agricultural residues are used as fuel, they result in a balanced carbon cycle because they grow annually. In comparison, rapid expansion of palm oil plantations in Indonesia and Malaysia, for example, has led to major problems associated with bioenergy. Logging rain forest on peat bogs for palm oil plantations has a negative effect. Plantations which were partly on carbon-rich peat soils in the region resulted in drainage. The subsequent oxidation of peat and natural or anthropogenic fires results in substantial CO_2 emissions. Peat digging also has a negative effect which results in an increase in CO_2 emissions in the atmosphere.

The use of forest residues could result in a positive or negative effect. The rate of carbon sequestration into biomass or soil through the decomposition of residues is slower than the rates of forest residue combustion. Harvesting forest residues could therefore result in accumulation of CO_2 emissions in the atmosphere. Through increased use of forest residues via thinning and other sustainable forest management strategies, forest growth can be accelerated, and fires also could be prevented, reducing overall CO_2 emissions.

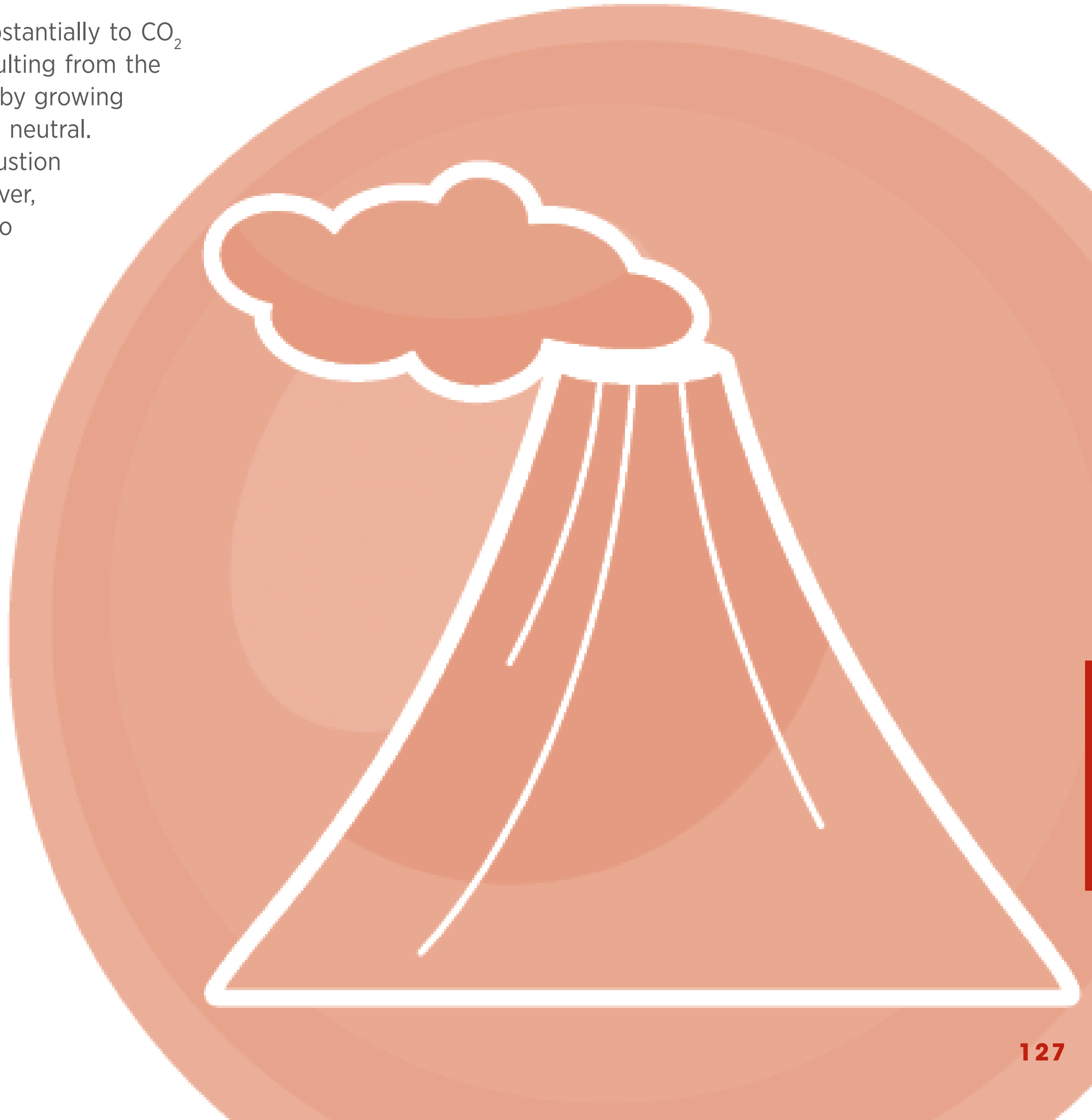
There could also be indirect effects of bioenergy use. Indirect land use change, which is the expansion of farmland elsewhere to continue producing crops or livestock to meet the demand as a result of conversion of farmland for bioenergy production, could result in an increase in CO_2 emissions.

As IRENA's analysis showed, residues have large supply potential. Increased recovery of residues may have positive or negative effects on the biomass carbon cycle, but if they are sustainably sourced, they can contribute significantly to CO_2 emission reductions. Energy crops would also contribute to emission reductions if they are cultivated sustainably on surplus land. Transforming forests into agricultural area for bioenergy crops which would store less carbon, or just combusting beyond surplus forest growth levels, result in a substantial volume of additional CO_2 emissions.

end of the total supply potential. While these are very ambitious biomass use growth estimates, concerns about its sustainability will gain further importance as the limits of biomass supply are reached. This outcome also points to the importance of innovation and the development of new technologies. With the commercialisation of more efficient and emerging renewable energy technologies, the portfolio can be widened and dependence on biomass can be reduced.

Supply costs are lowest for agricultural residues and biogas from food waste and animal manure, and highest for energy crops. IRENA's biomass supply estimate for 2030 compares well with World Bioenergy Association (WBA) estimates (Kopetz, 2013), which suggest that up to 153 EJ of biomass can be supplied by 2035, with more than 80% of this originating from forest products (wood fuel, residues and waste) (70 EJ) and agricultural residue and waste (62 EJ). The remaining 12% is energy crops (18 EJ). IRENA's estimates for agricultural residues and food waste are similar, at 39-66 EJ, although its estimates for forestry products are lower, at 25-42 EJ. In comparison, IRENA estimates a higher potential for energy crops of about 31-37 EJ, explained mainly by the difference in land availability assumed.

If biomass is sourced sustainably, it can contribute substantially to CO_2 emission reductions. This is because biogenic CO_2, resulting from the combustion of biomass, is assumed to be sequestered by growing biomass in the next season; hence, it could be carbon neutral. When life-cycle stages of bioenergy other than combustion are considered (*e.g.*, harvesting and recovery), however, bioenergy may have higher GHG emissions compared to fossil fuels, and also when emissions related to direct and indirect land use change are accounted for. Strategies to ensure the sustainability of biomass include improving agricultural yields, managing the land and other resources sustainably, and increasing the use of agricultural and forest residues while not exceeding the limits posed by, for example, soil organic matter.



Key points

- Five key areas for national policy action have been identified to accelerate renewable energy deployment: 1) establishing transition pathways for renewable energy, 2) creating an enabling business environment, 3) integrating renewable energy, 4) managing knowledge, and 5) unleashing innovation.

- *Realistic and ambitious transition pathways* must be developed with overarching long-term strategies based on credible and attainable targets. Policy attention which is currently focusing mainly on the power sector should be extended to cover end-use sectors as well.

- An *enabling business environment* for renewables needs to be created by creating access to finance and a level playing field, reducing the risk on investors and streamlining planning procedures. Externalities need to be endogenised, and fossil fuel subsidies need to be removed.

- Governments need to facilitate together with the private sector the rollout of the infrastructure needed to *integrate renewables* into the energy system – such as electricity transmission grids and biomass supply chains.

- *Increasing and managing knowledge* about renewables related to, for example, their costs and resource availability, and also avoiding misconceptions based on inaccurate data will be important for increasing social acceptance and increasing awareness of the potential of renewable energy technologies.

- *Innovation* in existing and mature technologies as well as in breakthroughs is required to continue raising the share of renewables beyond a doubling. Innovation is also needed in financing and policy frameworks.

- REmap 2030 results point to a number of areas with opportunities for international co-operation, including interconnectors (trade and grid stability), harmonised standards, capacity building, exchange of best policy practices and pre-commercial research for innovation.

- As the renewable energy hub of the Sustainable Energy for All (SE4ALL) initiative, important areas of future work for International Renewable Energy Agency (IRENA) include co-operation with other hubs to identify nexus issues on renewable energy, energy efficiency and modern energy access; and with other organisations in the context of high-impact opportunities.

This chapter discusses how REmap can be operationalised (**Chapter 6.1**). Roadmaps specific to the 26 REmap countries can be found online in the 26 REmap country briefs. **Chapter 6.2** discusses the existing policies and the specific characteristics of the 26 REmap countries in terms of renewable energy policy, strategy and technology development. **Chapter 6.3** identifies national policy action items, and **Chapter 6.4** explores how international co-operation can benefit both individual countries as well as help to achieve the global doubling objective.

6.1 Transition roadmap for doubling the global renewable energy share

Who needs to do what by when? Change is needed in physical terms (for example, in gigawatt capacity and tonnes of fuel) but also in terms of policy frameworks (for example, in energy pricing, market structure and planning). This chapter explores the physical changes that need to happen between today and 2030 and puts the change into perspective with the developments of the past decade.

The technology options for 2030 according to REmap 2030 and the RE+ Options can be broken down into four main strategic categories:

1. *Renewables for power generation* (representing around 40% of total modern renewable energy use in REmap 2030), including one-third hydro, one-third wind, one-tenth solar and the remainder other renewable energy sources. This includes:

- Large-scale power generation projects (large hydropower, wind farms, concentrated solar power (CSP), etc.) and
- Small-scale power generation projects (rooftop solar photovoltaics (PV), small hydro, wind power, etc.).

2. *Renewable substitutes for fossil fuels in end-use sectors* (representing around 60% of modern renewable energy use), with buildings accounting for 38%, industry for 38% and transport for 24%. This includes:

- Modern biomass for thermal applications (representing around 25% of renewable energy potential), excluding the replacement of traditional use of biomass.
- Access to modern energy through renewables, notably the replacement of traditional use of biomass with modern cook stoves and modern solid and liquid biomass fuels (representing around 20% of the renewable energy potential).
- Solar thermal solutions for hot water and space heating and for industrial process heat (representing around 5% of renewable energy potential).
- Liquid and gaseous biofuels and electric vehicles (EVs) for transportation.

3. *Other technology options*, including:

- Electrification as a strategy to enable more renewable energy power use (representing around 2-3% of renewable energy use).
- A doubling of energy efficiency improvement rates (makes a 15% difference for the renewable energy share in 2030).
- Structural changes, such as modal shifts.
- Emerging technology options (such as ocean power, algae).

4. *Enabling infrastructure measures and technologies*, such as grid and storage infrastructure, recharging stations, biomass supply and logistics.

As REmap 2030 illustrates, with additional REmap Options, modern renewable energy use worldwide could increase by at least 50% between today and 2020, and could nearly quadruple in the 2010-2030 period in absolute terms, doubling the global renewable energy share. According to REmap 2030, about one-third of the additional modern renewable energy potential – on top of the Reference Case – exists in the power sector, and the remaining two-thirds is found in the three end-use sectors of industry, buildings and transport.

Table 6.1 provides an overview of REmap 2030 based on three groups of indicators: technological indicators, financial indicators and the share of renewable energy.

Table 6.1 REmap 2030: An overview

	Units	2000	2012	REmap 2020	REmap 2030	Reference case 2030	REmap / Reference (%)	CAGR: 2000-2012 (%/y)	CAGR: 2012-2030 (%/year)	Indicators for REmap 2030
Technology indicators										
Hydropower (excl. pumped storage)	(GW_e)	689	1 004	1 350	1 600	1 508	6	3.2	2.6	
Pumped hydro	(GW_e)		150	225	325	306	6	N/A	4.4	
Wind onshore	(GW_e)	17	283	600	1 404	900	56	26.4	9.3	300 000 of 5 MW_e plants
Wind offshore	(GW_e)		6	50	231	68	242	N/A	22.5	
Solar PV	(GW_e)	8	100	400	1 250	441	184	23.5	15.1	12.5 million of 100 kW_e plants
CSP	(GW_e)	0	3	15	83	52	62	7.6	21.5	830 of 100 MW_e plants
Biomass power	(GW_e)	35	83	139	390	170	129	6.7	8.9	
Geothermal	(GW_e)	8	11	25	67	26	162	3.1	10.6	
Ocean	(GW_e)	-	1	3	9	2	519	-	17.3	
Biomass, traditional	(EJ/yr)	28	27	20	12	29	-58	-0.0	-4.3	
Biomass, advanced for cooking	(EJ/yr)		1	4	4	2	88	10.4	8.4	270 million 5 kW_{th} cookstoves
Biomass heat from cogen for ind/DH	(EJ/yr)	1	3	4	14	6	129	10.2	9.8	
Biomass pellets for heating	(EJ/yr)	0,1	1	2	3	2	49	48.6	5.8	16 million 20 kW_{th} household boilers
Biomass chips logs etc. for heating buildings	(EJ/yr)		5	5	6	4	49	6.4	1.0	31 million 20 kW_{th} household boilers
Biomass boilers industry incl. biogas	(EJ/yr)	4	4	5	7	7	0	-1.0	3.4	0.7 million 1 MW_{th} industrial boilers
Biofuels transport	(billion litres/yr)	18	105	214	650	287	127	15.9	10.7	15% of global transport fuel use
Biomass use, total	(EJ/yr)	43	51	61	108	79	37	1.4	4.3	20% of total primary energy supply
Solar thermal area (2005 data)	(million m^2)	157	446	1,162	4,029	1,532	163	11.3	13.0	
Share in buildings	(%)	100	99	91	67	97	-31	-	10.5	
Share in industry	(%)	-	1	9	33	3	968	-	41.8	
Geothermal heat	(EJ/yr)	0.2	0.5	0.7	1.2	0.6	86	9.6	4.3	
Heat Pump	(GW_{th})	N/A	50	177	474	300	58	N/A	13.3	
Number of heat pumps	(mln)	N/A	4	15	40	25	58	N/A	13.3	
Battery storage	(GW_e)	N/A	2.0	25	150	73	105	N/A	27.1	5% of total variable renewables capacity
EV, PHEV	(mln)	N/A	0.2	25	160	69	133	N/A	45.8	10% of the total passenger car fleet
Financial indicators										
Net incremental system cost	(billion USD/yr)				133	0.9%	of 2011 gross fixed capital formation (15.5 trillion)			
Net incremental investment needs	(billion USD/yr)				265	1.7%				
Subsidy need	(billion USD/yr)		101		315	58%	of 2012 fossil fuel subsidies (of 544 billion)			
Fossil fuel subsidies	(billion USD/yr)		544							
Regional indicators (based on REmap 2030)										
Global - Modern RE (excl. Trad. Biomass)	(%)		9		27	13				
Global – Modern + Access	(%)				30					
Global – Modern + Access + EE	(%)				34					
Global – Modern + Access + EE + "RE+"	(%)				>36					

Note: Transition indicators for technology deployment, investment and regional deployment, and renewable energy shares provided in the policy indicators refer to REmap 2030, thereby excluding the full implementation of SE4ALL objectives of doubling the energy efficiency improvements and modern energy access.

In the first group, technological indicators, biomass is found to be a key resource. Total biomass use grows from around 50 exajoules (EJ) to 108 EJ per year (in primary energy terms) – a more than doubling, or a growth rate of 4% per year, significantly faster than the growth during the last two decades of around 35%, or 1.5% per year. More than 50 EJ additional biomass to be used by 2030 equals around 4 billion tonnes, or a queue of trucks that would circle the world 25 times. Up to half of the supply potential would originate from Asia and Europe (including Russia). It is critical that the biomass supply is sustainable, including through reduced life-cycle greenhouse gas (GHG) emissions.

The share of modern renewable energy could increase by at least 50% by 2020 if action starts today.

Modern solid biomass use would increase by four times, and liquid biomass use would increase by six times, between 2010 and 2030. About 63% of the total demand for biomass liquids is estimated to be for conventional biofuels, with the remaining 37% being for advanced biofuels. Cane ethanol accounts for the bulk of conventional biofuel growth – equivalent to five-fold growth in sugar cane for biofuel production. The production of liquid biofuels from cane could be located in regions where cheap feedstocks are available, such as Africa and Latin America. Asia, Europe and North America could concentrate on supplying agricultural and forestry residues for various applications.

If additional REmap Options are implemented, the largest liquid biofuel users could be in Brazil, China, India, Indonesia and the United States (US). These five countries could more than double their biofuels demand beyond their national plans by 2030 and make up at least half of the total global biofuel market in REmap 2030.

Achieving the goal of modern energy access requires the substitution of traditional use of biomass for cooking and space heating. If all REmap Options are implemented, the installed capacity of advanced cooking technologies would increase more than four-fold, particularly between today and 2020, mainly in Africa and parts of Asia. A core part of the transition is the provision of more than 1 billion clean cook stoves.

In the next seven years (from 2014 to 2020), all renewable power sector technologies will need to grow substantially in order to implement all additional REmap Options by 2030. Different technologies would grow at different rates, however, with wind and solar PV increasing at least 5- and 12-fold, adding about 70 and 60 gigawatt-electric (GW_e), respectively, of new wind and PV capacity on average each year between today and 2030.

Early planning requirements for grids and systems in the power sector will be crucial as the share of variable renewables approaches 20% in REmap 2030. Today, four countries (Germany, Italy, China and the US) account for approximately 60% of total installed solar PV (around 100 GW_e) and wind (around 300 GW_e) capacities worldwide. According to additional REmap Options, all other countries would invest in new capacity along with their national plans and beyond. With all REmap Options to be implemented by 2030, India, Japan, Mexico and the United Kingdom (UK) could reach a total installed wind capacity of at least 300 GW_e, nearly 20% of the global potential. Similarly, China, India, Indonesia, Japan, South Africa and the US would together add another 500 GW_e of solar PV capacity by 2030.

Our most pressing challenges for 2020 are ramping up new technologies for renewable power, boosting energy storage and electrifying the transport sector.

The US, Indonesia and Japan are the main countries which will contribute to the global deployment of geothermal power technology. For CSP, the main countries are Saudi Arabia, the United Arab Emirates (UAE) and India.

There are currently some 200 000 EVs worldwide, and an expansion to 160 million EVs and PHEVs would represent approximately 10% of the global passenger car fleet. Infrastructure needs to be developed in parallel to accommodate this shift in vehicle type. The contribution of six countries (the US, China, Japan, the UK, Germany and Canada) is crucial, as they would account for at least 60% of the EV market in REmap 2030. As this roadmap shows, realising the full technology potential requires the contribution of all countries – from industrialised to developing and emerging economies.

Countries of every size and economic type have a part to play in order to double the global renewable energy share by 2030.

Furthermore, the policy needs vary by technology category. First, technologies are in different stages of their life cycle. Second, the technology characteristics vary. Biomass solutions require feedstock supply and may involve trade. EVs require refuelling infrastructure and battery development. Emerging technologies require more research, development and deployment (RD&D). Governments should first assess the applicable technology solutions and then develop the policy framework needed to support the transition, based on sector and technology characteristics.

The second group of indicators in Table 6.1 is investment needs in order to realise all REmap Options. Net incremental investment needs (above the Reference Case) for doubling the renewable energy share by 2030 amount to US Dollars (USD) 265 billion per year worldwide. More than 60% is in the power sector, with 10% in the industry sector and the remaining 30% in the building sector (the transport sector requires no additional investments). When the net fuel-cost savings are also accounted for (USD 130 billion per year), the net incremental system costs worldwide are estimated at USD 133 billion per year[1]. These incremental costs are relatively modest, as the average cost of substitution in the REmap Options is USD 2.5 per GJ.

The technologies with the greatest scale-up potential by 2030 are onshore wind, solar photovoltaics, transport biofuels, solar thermal, heat pumps and electric vehicles.

The subsidy needs are estimated to triple to USD 315 billion in 2030 if all REmap Options are implemented. This is a market correction for the fact that carbon dioxide (CO_2) and health costs of fossil fuels are not fully priced. Subsidies per unit of modern renewable energy continue to fall during this period due to technology learning and rising fossil fuel costs[2]. The largest subsidy needs are for the power sector (two-thirds of the total), with solar PV and wind accounting for 65% of the sector's total. The transport sector's subsidy needs are largely for electrification and advanced biofuels. In comparison, global subsidies for fossil fuels amounted to USD 544 billion in 2012 (IEA, 2013a).

Lastly, Table 6.1 shows renewable energy shares for different sets of energy policy goals. The Reference Case takes the global modern renewables share from 9% to 14% between 2010 and 2030, an increase of approximately 5 percentage points. When all REmap Options are implemented, the additional increase is 13 percentage points, to 27%. This roadmap suggests that policy ambition needs to increase so that the global renewable energy share can be doubled.

1 The incremental system costs are added to the Reference Case system costs. They do not consider a drop in fossil fuel prices because of lower demand. If fossil fuel prices would drop by 10% due to a 15-26% reduction in demand, the savings amount to USD 450 billion per year, which exceeds the system costs increase by more than a factor of three.

2 The subsidy needs in 2030 represent an upper estimate. For example, if one tonne of CO_2 is priced around USD 35 in 2030, the subsidy needs would drop from USD 315 per year to zero.

6.2 Existing renewable energy targets and country highlights

Elaborate policy frameworks exist but their scope and characteristics vary widely from country to country. In a majority of the 26 REmap countries, there is an official Reference Case or scenario analysis available (see online Annex). Some of these countries have a renewable energy target as a share in TFEC. About half of the 26 REmap countries have targets which are specific for TFEC, but the reference year varies from 2015 to 2050[3].

Analysis of existing renewable energy targets demonstrates the difference in set commitments across the different sectors. 22 of the 26 REmap Countries have adopted a national renewable energy target in their power sectors with a timeframe ranging from 2010 to 2050; most targets are to be met by 2020. In some cases, the target is general for the renewable energy share in total power generation; in others, it is technology specific. Some countries have no targets, while others have multiple targets for different time horizons, so the reference years vary. Technology-specific targets differ based on the deployment level, experience with technology and resource availability.

For the transport sector, biofuel and EV targets exist only in some countries. Most REmap countries have adopted biofuel blending mandates ranging from 2% to 10%. Some of the European Union (EU) countries are far from achieving the 10% renewable energy target of the transport sector, explained in part by the low confidence in biofuels. Several countries (Japan, India, China and Germany) have EV targets for their national vehicle fleets. China has announced a target of 5 million EV and plug-in electric vehicles (PHEV) by 2015, but as of 2012, only 4% of this had been met (Yue, 2013).

3 A comprehensive overview of the renewable energy targets that have been introduced in the 26 REmap countries can be found online. These targets represent the commitments of these countries in increasing the share of renewable energy in their national energy mix.

There are conventional and advanced biofuel mandates for the EU countries and the US, and some governments are directing more support to advanced biofuels – such as Australia, Brazil, China and India.

Finally, buildings and industry (heating, cooking, etc.) have targets mainly for solar water heating and biomass use. Fewer countries have targets for end-use sectors as opposed to the case of the power sector. There is a need to strengthen efforts in the end-use sectors.

With policy efforts focus mainly on the power sector, the industrial sector and heat and cooling for buildings require more attention.

In general, targets for the building sector are not expressed as a percentage of TFEC, but rather in terms of specific technology capacity for heating or cooling or as an implicit objective to increase the share of renewables. Renewable energy is promoted through government incentives and rebate programs in space and water heating applications (solar water heaters, heat pumps and biomass boilers). For example, China, India, Morocco and Italy aim to achieve a certain gigawatt volume of heating capacity or m^2 area of solar thermal. In contrast, Japan has an absolute amount of renewable energy supply required if buildings have a floor surface area above 2 000 m^2.

In recent years, governments have identified the urgency of eliminating traditional biomass, which is a common cause for premature deaths due to indoor air pollution. Numerous global initiatives and partnerships, such as the Global Alliance for Clean Cookstoves, the Clean Stove Initiative, have been launched with the aim to educate the masses about clean and sustainable cooking practices. In order to accelerate the uptake, especially in less-developed countries, a market for modern cook stoves needs to be created which allows consumers to access affordable and reliable equipment.

Renewable energy targets have not been adopted widely in industry; however, governments increasingly allocate funds for industrial CHP efficiency. Furthermore, as the overall heating and cooling targets do not specify sectors, in principle some of these targets could also be deployed through increased renewable energy use in industry for process-heat generation.

The experience of different countries in setting renewable energy targets for the different sectors and in adopting measures to ensure that they are met, provides important opportunities for learning and exchange of best practices. Countries which are at an early stage of development and/or deployment of particular renewable energy options can learn from the experiences already acquired and the assessments already taking place in others. At the same time, governments can benefit from each other's experience in addressing some of the traditional barriers that impede renewable energy deployment. Avenues for cooperation include best practice analysis and documentation of conducive and credible policy frameworks, including streamlined planning frameworks, targets and deployment policies to strengthen existing national plans.

International co-operation can bridge gaps in countries' existing policy frameworks.

Based on the 26 REmap country analyses, renewable energy highlights of the 26 REmap countries were prepared which address country-specific policies and technologies. Country briefs which include country-specific transition pathway tables and country summaries will be made available online in the first half of 2014.

Australia: Renewable energy can comprise more than one-fifth of the country's TFEC by 2030, with a mix of solar PV (half rooftops, half utility), onshore wind and biomass (half biofuels, half heat applications). Uptake of renewables in the power sector is progressing faster than planned, particularly in rooftop PV. Renewable energy policy is under revision with the change of government in September 2013. Important policy initiatives also exist on the state level.

Brazil: Today, Brazil has the highest renewable energy share among the large economies. According to national plans, the country's renewable energy share will remain at the current level of 40% of TFEC, but with REmap Options it can go beyond 50%. Brazil would account for one-fifth of the global liquid biofuels demand, and its power generation would be almost 100% renewables. Very-low-cost wind has been added in recent years through a successful auctioning scheme.

Canada: Canada has abundant renewable energy resources, and renewables can account for one-third of Canada's TFEC by 2030. Biomass-fired industrial CHP plants can double the sector's renewable energy share, and a wide portfolio of renewable energy technologies would account for three-quarters of the country's total power generation. Important policy initiatives exist on the state level.

China: China would account for 20% of total global renewable energy use if all REmap Options worldwide were implemented, and for a similar magnitude of the total installed capacity of the different renewable energy technologies. China's engagement is critical in order to meet the doubling of the global renewable energy share objective. Objectives for solar PV and wind capacity additions have been raised recently to 10 GW and 15 GW per year, respectively. Air pollution is a major driver, along with industrial development policy and rising oil import dependency.

Denmark: Denmark represents the best practice in renewable energy deployment, in terms of both its policy environment and target setting. The country aims to reach a 100% renewables share by 2050 with renewable electricity combined with district heating, liquid fuels and gas, and complemented by extensive energy savings. Over the shorter term, the conversion of coal CHP to biomass CHP is a unique feature of the Danish transition.

Ecuador: Already, renewable energy accounts for more than 70% of Ecuador's power generation. The sector's renewable share could near 85%, mainly with additional hydropower and other renewable energy technologies. With a higher share of electricity use in the end-use sectors, the country's share of renewable energy in TFEC could be raised further.

France: France already has an ambitious goal for 2020: to reach a 23% share of renewables in its gross final energy consumption. This means building 840 PJ of renewable capacity in both the heating and power sectors. France is also the second-largest producer of bioethanol and biodiesel in Europe. Looking further ahead, after a national debate on energy transition, the French government is preparing a new long-term energy bill, to be adopted by the end of 2014. The precise trajectories and scenarios will be determined afterwards, also taking into account the future, post-2020 European energy and climate framework.

Germany: Germany's Energiewende ("Energy Transition") initiative has a long term target of achieving an ambitious share of 60% renewable energy in final energy consumption by 2050. The country plans to achieve this target with aggressive renewable energy deployment in the power and district heat sectors, including novel uses of solar thermal and heat pumps in district heat generation. Along with Denmark, it will be one of the major countries to deploy offshore wind capacity.

India: India is one of the main countries that relies heavily on traditional use of biomass and where a transition to modern energy services has yet to be achieved. It is also a big net importer of fossil fuels, and all end-use sectors could take up renewables. In industry, some biomass-fired technologies are already deployed (*e.g.*, gasification) and could be used more widely along with other medium- and high-temperature process heat technologies such as CSP. Solar PV, CSP and biogas power are being rolled out to meet rapidly rising electricity demand, with remarkably low costs being achieved in some projects.

Indonesia: Because of Indonesia's large size and hundreds of islands, a significant share of the country still lacks access to modern energy, including electricity. Electricity demand is projected to grow more than five-fold between now and 2030. Important efforts exist to electrify remote communities and islands using renewables. Expansion of geothermal power is being pursued, but additional efforts are needed to meet targets. Uptake of solar PV is just starting. Indonesia is already the largest producer of palm oil worldwide, and biomass offers opportunities for all sectors of the country, provided that it is sustainably sourced. Abatement of high energy subsidies is a policy priority.

Italy: Already in 2011, Italy surpassed its EU binding target of 26% renewable energy in final energy consumption within the power sector and in 2012 the renewable energy share was 27.1%. On June 2013, for two hours, the cost of energy in the Italian Energy Market has reached the quote of ZERO in the whole territory of the country. Renewable energies covered entirely the energy demand all over Italy, cutting down the cost of energy until the quote of zero was reached. The country is developing a number of innovative smart grid solutions to support even higher shares of variable renewables into the power sector.

Japan: Given uncertain nuclear plant prospects and high gas prices, Japan has put in place an ambitious renewable energy policy. This policy is delivering. In addition, as of July 2013 more than 4 GW_e of new renewable power was in operation. In order to accelerate growth, Japan will continue to steadily implement this policy, together with efforts for deregulations and grid enhancements.

Malaysia: The government is already pushing for increased use of renewable energy through targets and by establishing an organisational structure to facilitate the targeted growth. To a large extent, these targets can be fulfilled by the large biomass resource of the country. A feed-in tariff scheme has been put in place, but high energy subsidies present an obstacle for renewable energy uptake.

Mexico: The country's energy policy was fundamentally re-designed at the end of 2013, and a progressive policy has been put in place to accelerate renewable energy growth in the power sector.

Morocco: Morocco is one of the most energy import-dependent countries in the region. To reduce this dependency and benefit from socio-economic aspects of renewables, the country has ambitious plans for the year 2020 to use CSP, solar PV and wind technologies. Future export of renewable power to Europe could be hindered by transmission capacity limitations.

Nigeria: Nigeria today meets nearly 65% of its energy demand from traditional use of biomass. It is one of the most challenging countries in terms of meeting the objective of modern energy access, in particular because energy demand is growing very fast. The developments and experiences which are being achieved in Nigeria will be important examples for the greater Africa region, in terms of both modern energy services and the uptake of renewable energy.

Russia: Russia has a wide range of renewable energy resources, such as biomass and geothermal, but the country's tremendous land area creates difficulties in deploying these potentials. Coal and natural gas use in Russia's large district heat sector could be substituted with biomass, and additional sectors could benefit from the large biomass resources available, raising the country's renewable energy share further. The country's first renewable energy power auction was held in 2013, and exports of biomass commodities such as pellets are growing. Important initiatives are taking place on a regional level that supplement national efforts.

Saudi Arabia: the Kingdom's dynamic economic and population growth have spurred the local demand for electrical power. Historically, the Kingdom has satisfied local power and desalinated water demands through the use of its plentiful, but non-renewable, hydrocarbon resources. The Kingdom has begun an ambitious all-encompassing approach towards a sustainable energy mix that emphasizes education, research, global collaboration, local integration, commercialization and social benefit. This ambitious strategy positions the Kingdom to not only implement the world's largest renewable energy projects but to also export the resulting expertise and developed technologies globally.

South Africa: Although South Africa is a major coal producer and consumer, the power supply crunch in recent years has served as a wake-up call, and the country has rolled out an ambitious renewable energy policy. This includes wind and solar power investments, as well as hydro imports. In combination with solar thermal for water heating and different forms of biomass and waste (including landfill gas), these measures have the potential to nearly triple the renewable energy share by 2030.

South Korea: South Korea imports 96% of its energy, and industry is a key player in the country's economy, accounting for 61% of total energy consumption. To enhance energy security and reduce GHG emissions, South Korea has not only been increasing deployment of renewable energy, but also developing renewable energy industry as a new economic growth engine. As a result, the Korean manufacturing sector is producing innovative renewable energy technologies and is planning to become one of the largest exporters of green technologies in the world. Korea will be releasing a new national renewable energy plan in 2014.

Tonga: The Tonga Energy Road Map (TERM) is a proven framework for energy transition. In other Pacific islands, the recent price slide of solar PV has resulted in a pipeline of new projects, and grid stability and electricity storage have come to the forefront as renewable energy integration issues.

Turkey: The country aims to raise its solar, wind, biomass and geothermal capacity and also to deploy its technical hydro potentials in its power sector to ensure energy security. A considerable share of its building stock will be renewed within the next two decades, which creates a large potential for integrating renewables; in general, however, new renewable energy policies are required to increase renewables use in end-use sectors.

Ukraine: Ukraine is dependent on natural gas imports, and its energy intensity is higher than in most other economically developed countries. The country could be an interesting illustration of how SE4ALL objectives for both energy efficiency and renewables can be met, as potentials for both are large. For renewables in particular, biomass, solar thermal and wind offer potentials for both end-use and power and district heat sectors.

United Arab Emirates: The UAE foresees abundant renewable energy potentials of mainly solar and can considerably increase the renewable energy share in its energy mix. For example CSP can be used to generate industrial process heat (including in petroleum refining) and for power generation. The UAE is a leader through funding, development and operation of projects globally, using MASDAR and Abu Dhabi Fund for Development (ADFD). The UAE hosts the IRENA headquarters.

United Kingdom: The UK has some of the best wind and marine energy resources in the world and is promoting the deployment of these technologies through a range of innovative policies. Biomass is imported on a significant scale and used for co-combustion, with Drax being the largest plant of this type in the world. The UK has clear plans to support future biomass deployment. The UK is well placed to meet EU renewable energy targets, and has a robust package of financial support and other policy measures in place to help ensure its achievement.

United States: The US has tremendous renewable energy potentials, but these vary greatly by region given the size of the country. It has one of the largest geothermal and wind resources and also is developing novel forms of hydro that have low environmental impact. The US is also a test-bed for transport sector technologies, such as hydrogen, battery electric and hybrid systems, and has innovative projects for advanced biofuels. Policies at the state level, rather than the federal level, are driving renewables deployment, and some states are world leaders in renewable energy deployment.

6.3 National actions for accelerated renewables deployment: policy opportunities

Although deployment of some renewable energy technologies is growing at a faster rate than many governments realise, governments will continue to play an instrumental role in supporting the further development and deployment of renewable energy technologies across all sectors. If the share of renewables is to be doubled in the global energy mix, deployment should not simply be left up to markets and existing players. Indeed, meeting the objective of doubling the share of renewable energy by 2030 requires action by both the public and private sectors.

Boosting renewable energy share requires action, not only from the private sector, but also from policy makers.

As renewables evolve, they require a specific mix of targeted incentives at each stage, from basic science and research and development (R&D) to commercial deployment. Renewable energy deployment policies, in particular, have been instrumental in stimulating market development. Such policies can be categorised broadly into:

- fiscal incentives (tax credits, grants, rebates, etc.);
- public financing (guarantees, low-interest loans, etc.);
- regulations (quotas, feed-in tariffs, auction mechanisms, etc.);
- enabling policies (capacity building, knowledge, etc.).

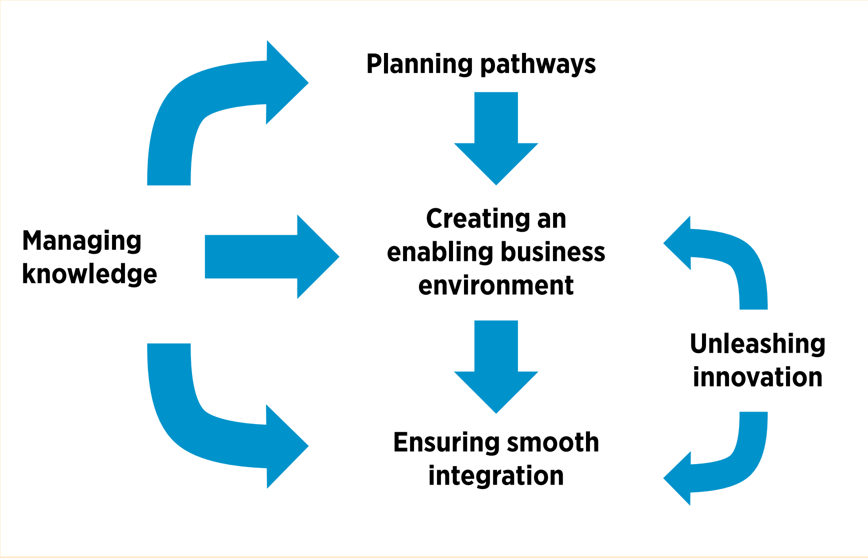
Various deployment policies have been adopted globally at the regional, national and state/provincial levels. As the previous chapter showed, renewable energy targets – and as a consequence policies – have focused mainly on the electricity sector. There is already a trend towards greater adoption of policies for the heating/cooling and transportation sectors, but further attention will be required for the end-use sectors (Mitchell *et al.*, 2011). Adoption of relevant policies across all end-use sectors will be crucial not only for the realisation of REmap Options, but also to bring about the necessary step-change beyond the electricity sector.

The success of REmap Options will also depend on a broad range of complementary policies, including trade and investment, R&D and education. In this context, adequate measures and planning will be required. For instance, the deployment of REmap Options will result in additional jobs in the renewable energy sector. These jobs will need to be filled with a suitably skilled and trained labour force, requiring an appropriate policy environment to meet the employment needs of a growing renewable energy sector (IRENA, 2013i).

Establishing the right mix of policies also has the potential to generate new economic activities and maximise value creation. This will depend on existing industrial capacities, regional and global market developments and the current competitiveness of each market. Governments can support value creation through a variety of measures, including programmes to strengthen technology transfer through cluster development, implementation of local content requirements, and product development through public and private co-operation in the field of research and innovation (IRENA and CEM, 2014). IRENA's econValue project analyses value creation from renewable energy deployment and provides recommendations for policy design options to optimise such benefits.

The 26 REmap country analyses present national policy actions needed to overcome existing barriers that are often technology, sector and country-specific. Supported by consultations with national experts, five areas of national policy action areas are identified (illustrated in Figure 6.1). Each policy action area is characterised by a context-specific mix of enabling policies and is stand alone, but they have a direct impact on the effectiveness of the other action areas. As such, they represent the phases of the renewable energy policy life-cycle starting with **planning pathways**, which includes more insight into the base-year situation and the development of national plans and targets. This is followed by **creating an enabling business environment** with extended policy support, long-term commitment and interim measures to improve the economic viability of renewable energy technologies (*e.g.*, risk guarantees). With increasing renewable energy use, the **integration** of renewables into the system and improvements in infrastructure will be needed. Each of these phases needs to be supported with **up-to-date and well-managed knowledge** about renewables (including skills and capacity building). **Innovation** in new and existing technologies as well as in policies and finance schemes will need to support market creation and the integration of renewables to the system.

Figure 6.1 Policy action areas to accelerate renewable energy deployment



Doubling the share of renewable energy in the global energy mix by 2030 is not an end point. As national plans improve and become successful for doubling the global renewable energy share in 2030, the policy action phases start again to review and adapt policy frameworks and targets, improve technology level and reach even higher levels of renewable energy.

The national policy action areas defined earlier are each accompanied by specific proposals in order to ensure that renewable energy deployment is adequately supported along its development stages. Table 6.2 provides an overview of these policy proposals for each of the national policy action areas; this is not exhaustive list. Most action will be national, but international co-operation can help to accelerate an energy transition, which is further discussed in the next chapter. As such, there is no "one size fits all" solution for policy frameworks. Actions and policies will need to be tailored to account for the specific needs of regions, sectors and technologies and involve multiple stakeholders (World Bank, 2013d). The existing physical, legal and regulatory structure of energy supply and demand, renewable resource endowment, the age profile of capital stock, demand growth prospects, and social and cultural factors all play a role and determine the optimal design of renewables policies. The rest of this chapter further elaborates on the specific proposals highlighted in Table 6.2.

6.3.1 Planning transition pathways

The implementation of policies to support the growth of renewable energy deployment can benefit from an overarching long-term strategy based on credible and attainable targets.

Proposal #1: Assess the base-year situation and Reference Case trends for renewable energy for 2030 on a country basis.

As discussed earlier in Chapter 6.2, the availability of energy data for the current situation and for the period to 2030 differs across countries. Some of them do not have reliable statistics about how much energy is consumed, such as Nigeria, and reported traditional biomass use data is subject to further uncertainty. Others have targets, although of varying quality and detail. Many EU Member States have targets for 2020, but roughly half are not on course to meet them. Other countries do not even monitor progress; however, a few have quite detailed roadmaps for 2030, with goals even for 2050.

The REmap analysis is based on country Reference Cases. In general, all countries have scenario modelling within universities or other organisations, but these are not necessarily linked to government studies and are not used for official projections. Therefore, not all countries had an official Reference Case to share with IRENA for the REmap analysis. Half of the 26 REmap countries provided a Reference Case with projection end-years varying between 2025 (*e.g.*, Mexico) and 2050 (*e.g.*, France). For others, external sources such as the IEA's *World Energy Outlook* 2012 were used.

Proposal #2: Develop a national roadmap to meet renewable energy targets. Monitor progress and re-evaluate targets and framework effectiveness and efficiency regularly.

While developing Reference Case trends that are consistent with national development agendas is vital, it is equally important to set national renewable energy targets and ensure that they are pursued. In addition, it should be recognised that change in the energy sector is gradual, usually spanning many years. During the course of this transition, it is crucial to ensure that the certainty and reliability of policies is maintained. One of the successful approaches, as experienced in Denmark, has been to achieve an agreement between the main stakeholders, including political parties, to formulate a long-term goal for renewable energy market development. There is also a need for periodic review and adaptation of policies as markets and technologies evolve, so that support schemes remain effective and efficient, while sufficient certainty is maintained in the investment environment (IRENA, 2012g).

Many countries have energy mix projections and renewable energy targets, but not all countries enforce them. Planning and project-approval procedures can be too lengthy, feed-in tariffs too low or difficult to obtain, and there is a perceived risk of sudden policy changes.

On the positive side, some countries exceed their targets. China and India have both surpassed their previous renewable energy targets, and their Five-Year Plans have been reviewed to include higher renewable energy targets for forthcoming years.

Proposal #3: Ensure human and institutional capacity to develop and sustain the transition.

Accelerated renewable energy deployment requires that a range of human and institutional capacity needs are met. Governments need to provide a supportive policy, planning and regulatory framework; the private sector has a key role to play in deploying new technologies. An enabling framework is needed including market structures, energy supply and use capital stock, and the availability of investment capital; finally, training

Table 6.2 Policy action areas and proposals to accelerate renewable energy deployment

Action Area	Proposals	Countries/Actors
Planning transition pathways	#1 Assess the base-year situation and Reference Case trends for renewable energy for 2030 on a country basis.	All
	#2 Develop a national roadmap to meet renewable energy targets. Monitor progress and re-evaluate targets and framework effectiveness and efficiency regularly.	All
	#3 Ensure human and institutional capacity to develop and sustain the transition.	All
	#4 Streamline planning processes and ensure their consistency and inclusiveness on different levels, including municipal, national and regional planning.	All
Creating an enabling business environment	#5 Invest in new capacity and develop risk-minimising measures to reduce the cost of capital and levelised cost of renewable energy generation and use.	All, developing countries
	#6 Consider increased renewable energy deployment as an alternative to fossil fuel subsidies.	Countries which subsidize fossil fuels
	#7 Ensure fair market access and phase out negative price distortions.	Countries with monopolies/oligopolies
	#8 Account for external effects in the pricing of fossil fuel energy supply and use.	Countries with high air pollution levels
	#9 Ensure quality of products through standards and regulations, and find the country balance for local content requirements in the light of market access for cost reductions and innovation.	All
	#10 Through country-dialogue and community engagement, establish a set of credible and predictable policy frameworks that can be maintained over longer periods.	All
	#11 Reduce the duration of project implementation by improving the planning and regulatory framework	All
Ensuring smooth integration into the existing infrastructure	#12 Build enabling infrastructure such as transmission grids, interconnectors and electric vehicle charging stations.	For example, countries where resource/demand centres are apart
	#13 Facilitate sustainable biomass supply and consider the nexus in the development of renewable energy strategies and policies, notably land, energy, water, agriculture, trade and infrastructure.	All
	#14 Develop market for affordable and reliable equipment for modern energy access.	Developing countries
Creating and managing knowledge	#15 Build a strong, publicly accessible knowledge base on renewable energy technology costs, potential and technology options.	All
	#16 Expand project development knowledge for bankable project proposals.	All
	#17 Collect and report best-practice information on technology and policies.	Countries with best practices
	#18 Establish and improve programmes to increase awareness and strengthen the capacity of manufacturers, installers and users.	All
	#19 Design renewable energy technologies from the point of view of product and service life-cycle environmental and sustainability impacts.	Countries with R&D and manufacturing base
Unleashing innovation	#20 Develop targeted policies that support the technology life cycle.	All
	#21 Review energy applications of high relevance and low renewable energy potential and develop programmes to fill the gap with new technology.	Countries with such applications

Box 6.1 The German Energiewende

Germany deserves special attention. As the world's fourth largest economy, it has retained its manufacturing industry base even as it pursues an ambitious transition to renewables, the phase-out of nuclear energy and reduced energy consumption. Most saliently, the German transition is a democratic movement, with most investments having been made by citizens, small businesses and communities. Germany's four biggest power providers, which collectively make up three-quarters of the market, are responsible for only 5% of all investments in renewables as of 2012 (Böll Foundation, 2012-2014).

Efforts began two decades ago, and the share of renewable energy in the power sector has since risen from around 3% to 25% in 2013. Policy-makers have acknowledged that the activities in the power sectors as part of the energy transition ("Energiewende") need to be complemented by further efforts in transport and heating.

In February 2014, roughly 36 GW of PV, 33 GW of onshore wind, 7 GW of biomass capacity had been installed resulting in a net electricity production of 30 TWh for solar, 53.4 TWh for wind and 42.6 TWh for biomass energy over the year 2013. Total installed renewables capacity is at 83 GW, compared to 105 GW of fossil and nuclear capacity. Electricity demand is stable or declining, and the daily peak averages around 60-70 GW, with an annual peak of 80 GW. Renewable power now regularly peaks at levels close to a third of total demand.

Because baseload power plants are inflexible, wholesale prices sometimes fall below zero, and exports to neighbouring countries are skyrocketing – up around 50% in 2013, and 2012 was itself a record year of power exports for Germany. Average wholesale prices have fallen for four years in a row, and utilities face losses, in part because they failed to understand the consequences of the transition for them. But to be fair, almost everyone expected wholesale power prices to go up this decade (DLR/IWES/IFNE, 2012). After the shutdown of 8 of the country's 17 nuclear plants in the spring of 2011, some feared a shortfall of generating capacity, so the outcome – a huge power export surplus and record-low wholesale prices – is the opposite of what was expected.

Electricity surcharges related to feed-in tariffs have grown significantly and accounts for more than a fifth of consumer electricity prices. Preventing further growth of this surcharge is a policy priority. According to German utility association Bundesverband der Energie- und Wasserwirtschaft, solar PV alone made up some 53% of the renewables surcharge in 2013, although it provided only 20% of all renewable electricity in 2012. This experience cannot be transferred to other countries, however; Germany invested in PV heavily during the last decade, when the technology was quite expensive, financing the steep learning curve. The technology now costs only a third as much, and prices continue to fall. Onshore wind remains the least expensive source of renewable electricity, making up only 16% of the renewables surcharge in 2013 although it accounted for a third of all renewable power. Future support levels for new wind and PV capacities will be similar to projected kWh-costs for new conventional capacities.

Biofuels have raised concerns in Germany because of the conflict between food and energy crops, but German car manufacturers are warming to the idea of electric vehicles. In the building sector, strict efficiency standards exist for new buildings, but the large inefficient existing stock is a challenge. Oil is used widely as heating fuel, although biomass pellets are often cheaper. Support for heat pumps and solar water heating has been wavering, with funding based in part on lower-than-expected revenue from carbon emission allowances. There are interesting demonstration projects for seasonal heating and cooling. So far, too little attention has been paid to renewables in heavy industry.

Major policy changes are expected in 2014 with the reform of the Renewable Energies Act (EEG). It is the intention of the government to focus on the most cost efficient sources of renewable energy, namely onshore wind and PV. In addition the FIT framework will continue to support the deployment of offshore wind capacity. The deployment targets are set at 6.5 GW until 2020 and 15 GW until 2030. The average FIT for all RE installations built until the end of 2013 was 17ct/kWh (in euro cent). This average is supposed to fall to 12 ct/kWh for new capacities. The new government has proposed binding deployment corridors for new wind and PV capacity in which the steady reduction of the FIT in coming years depends on the capacity addition of the previous year. This is supposed to keep capacity additions around 2,5 GW for each onshore wind and PV as well as to provide a greater planning security. The market premium (a fixed premium on top of wholesale market prices) that was optional in the past (80% of wind capacity participated) will now become mandatory improving the market responsiveness of renewable capacities. The amendment of the EEG is to enter into force on 1 August 2014. It also seems possible that Germany will implement a capacity payment for dispatchable electricity generation within the near future. Clearly, the ability of renewables to be built quickly and in large quantities has disrupted the traditional power market in Germany.

The macroeconomic benefits include an estimated 377 000 jobs in the renewables sector in 2012 and reduced energy imports. The benefit for the world may be even greater: in fact German power consumers are paying a large part of the bill for the global learning curve in wind and solar power.

and education institution need to ensure that there is the human capacity the sector requires. Therefore institution building and renewable energy education and training are critical in the transition to renewable-based energy systems.

Proposal #4: Streamline planning processes and ensure their consistency and inclusiveness on different levels, including municipal, national and regional planning.

Energy planning includes different stages: basic statistical data collection, establishing demand projections, analysis of options and strategies, enforcement and regular monitoring, and reporting and verification as a basis for policy adjustments. While these stages are in place in most countries for the power sector, this is less common for other sectors (IRENA, 2013k).

Even within a single country, local and national plans often do not match. German state-level renewable energy plans collectively exceed national targets, and there is a similar lack of co-ordination between federal and state governments in Nigeria, Canada, Russia and the United States. Municipal plans are all too often not well co-ordinated with national objectives.

6.3.2 Creating an enabling business environment

According to this roadmap, most renewable technologies will have an economic case by 2030 compared to conventional fuel equivalents. Although renewables are becoming increasingly cost competitive compared with conventional energy, this is not yet the case in all parts of the world. Reaching economic viability cannot be left to markets alone since, in some regions, markets are distorted due to subsidies on fossil fuels; in others, the risks for investing in renewable energy are high, which raise the costs. Benefits of renewable energy related to improved human health or climate change mitigation are also not accounted for. Policy makers need to act today in order to ensure cost competitiveness of renewables in the future. Establishing a market where renewables are cost competitive requires time. The time required needs to be shortened with new policies and interim measures.

Proposal #5: Invest in new capacity and develop risk-minimising measures to reduce the cost of capital and levelised cost of renewable energy generation and use.

The risk profile of renewable energy projects is, in many cases, different from that of conventional energy projects. Typically, the bulk of renewable project costs are upfront investments with low ongoing operating and fuel costs. Therefore, the required return on investment plays a critical role in overall project viability, more so than for competing fossil fuel projects. The cost of capital (or the discount rate) can vary widely and is a sensitive issue. In Africa, project developers and investors routinely demand a 20% return on capital. In industrialised countries, pension funds and other large investors may require only a 5% return for investments in utilities and transmission companies – a big difference for the viability of renewables projects. The difference in the cost of capital is related in part to the general characteristics of economies, but also in part to uncertainty about renewables policies. Reducing these uncertainties lowers the cost of capital. In addition, more-convenient debt requirements and longer debt terms would help to reduce the cost of capital. Mitigating risks for investors, for example through guarantee schemes and insurances, will accelerate the deployment of renewables. In general, a better understanding of risks, real and perceived, is necessary in order to effectively mitigate their impact.

The levelised cost of renewable energy is sensitive to the cost of capital, which increases with higher market risk.

Like the conventional energy sector, banks deal with large renewable energy projects. Yet the project size of the distributed renewables or rooftop solar PV could be quite small and makes an important difference. In the UK, for instance, only a few banks lend to projects smaller than

20 MW in size, making financing for new projects both more difficult and more expensive (REG Windpower, 2013). Many banks are not willing to lend below USD 20 million – quite a large amount for typical distributed renewable energy projects.

The cost of financing low-volume investments is higher because some transaction charges are fixed. There is a need to develop project-aggregation mechanisms that can be certified for investments from larger investors. Small-scale projects face additional challenges compared to large-scale projects in terms of obtaining market intelligence, training and retraining skilled staff and purchasing the small amounts of professional services needed to inform project development. Dedicated funds and government financing schemes such as guarantees, low-interest loans or green bonds are needed for this purpose (SE4ALL, 2013).

Funding the transition to renewables depends on private sector engagement. Developing countries face challenges in mobilising long-term financing for energy and green infrastructure, and the challenges are compounded by the need for regulatory reform, uncertainty about the global outlook and the resultant private sector risk aversion.

Strategies need to be developed for the financing of small-scale renewable energy projects.

The issue of constraints to scaling up financing flows for infrastructure in general – and clean energy in particular – has been widely studied. The following are the most frequently mentioned challenges (SE4ALL, 2013):

- Increasing the financial and human resources dedicated to project preparation;
- Bringing mainstream investors into emerging markets;
- Increasing leverage of attractive but limited development bank resources;

Box 6.2 Risk assessments for renewable energy investments

Investors in energy technologies primarily look at a trade-off between risk and return. The higher the risk, the higher the expected return. The level of risk relates to the size of the initial investment, current and future operating costs, the maturity of the market, the political environment, carbon prices, the ease and rates at which capital can be borrowed, etc. The return depends on the rate at which benefits start to be generated once the technology begins operation. For energy technologies, the return is often relative to the price of the electricity or energy sold.

Investors may see a relatively high risk for investing in renewables if they have no experience in the field, which could be the case if the policy environment does not provide sufficient investor confidence or if technology development is uncertain. For renewable energy technologies, if there are risks originating from the maturity of technology or the policy environment, high discount rates (or weighted average cost of capital, WACC) could result in high annualised capital costs. The upfront risks for investments in conventional technologies are lower, but fuel prices which contribute to a large share of the levelised cost of electricity/heat may fluctuate.

The time dimension for both risks and returns is an important element for investors. The choice of the right discount rate to assess the economic feasibility of technologies is becoming increasingly important. An analysis prepared for the Committee on Climate Change in 2011 found that low discount rates are assigned to projects with an overall low risk perception (such as solar PV, onshore wind, run-of-river hydro and biogas). Medium-high discount rates are used for biomass and offshore wind, whereas high discount rates apply for tidal and wave technologies. For conventional technologies, combined-cycle gas turbine (CCGT) plants are perceived to be low risk; new nuclear is perceived to be medium risk; and coal- and gas-fired power plants combined with carbon capture and storage (CCS) are perceived to be high risk.

In the REmap 2030 analysis, the discount rates are adjusted per country but not per technology. If discount rates were adjusted per technology, the cost comparison between new nuclear and onshore wind would be more beneficial for onshore wind. Similarly, the cost comparison between CCGT and offshore wind would be more beneficial for CCGT. A more detailed analysis of the impact of discount factors – including policy opportunities to reduce the cost of financing – is planned for the coming years.

- Improving the policy environment for private investments in energy; and
- Aggregating small-scale projects to meet minimum financing thresholds.

Development banks remain one of the main sources of concessional and/or long-term finance available for funding infrastructure. However, the contribution of development banks in the order of USD 60 billion per year in renewable energy is very modest in relation to the needs for financial scale-up. On average, the leverage factors are still comparatively low. A new paradigm is needed whereby development banks achieve a much higher leverage with a focus on project preparation and commercial financing is expanded at the same time.

Successful mitigation measures have included: lowering transaction costs, investment and production tax credits, subsidies, grants or rebates, soft loans, preferential treatment (priority grid access, parking and bus lane usage rights for electric vehicles, etc.), raising standards and implementing quality-control mechanisms. More-uniform international application of such measures will increase competition, increase market size and strengthen national deployment efforts.

In addition to investment support measures, policies for renewable power generation such as fixed price and premium feed-in-tariffs, portfolio standards and auctions are known to be effective for capacity development. However, such market policies need to be designed carefully to ensure that innovation and investments are continuous and that they remain effective and efficient. Finally, these interim measures should be removed when markets do not require them any further.

Proposal #6: Consider increased renewable energy deployment as an alternative to fossil fuel subsidies.

Resource availability, policy and economic factors determine the variations in energy prices across countries as well as the taxes and subsidies imposed. Countries facing energy security issues and importing nations generally have policies which promote the efficient use of energy, such as different forms of taxes, and switch to fuels which are locally abundant.

Countries with large fossil resources are generally also the energy exporters. They commonly also subsidise the domestic use of fossil fuels by granting inexpensive access to oil-based products, electricity and cooking fuels. As discussed in Chapter 4.2, pre-tax consumer fossil fuel and electricity subsidies reached more than USD 544 billion in 2012. A few countries make up most of the total, with primarily the Middle East (Iran and Saudi Arabia) and North Africa (Egypt) representing 50% and emerging and developing Asia (India, China, and Indonesia) representing 20% of this amount. Furthermore, some countries subsidise electricity as well (for example India and some African countries). These subsidies act as a barrier for uptake of renewables. They generally make for ineffective poverty alleviation policies, as the majority of the subsidies end up with those using most of the energy – *i.e.*, the rich. Renewables are increasingly seen as a viable solution for reduced government subsidies.

New financing approaches are needed to mobilise significant financial capital.

Nearly half of the total subsidies are for petroleum products, with 30% for electricity and a quarter for natural gas. Total fossil fuel and electricity subsidies are six times more than the renewable energy support of USD 88 billion (USD 55 billion for power from renewable resources and USD 33 billion for biofuels). On the one hand, governments intervene in markets in a positive way by providing subsidies to renewable energy. On the other hand, fossil fuel subsidies provide limited incentive for increased renewable energy use. Only few countries intervene in both ways at the same time but on a global scale both types of interventions pull in different directions. While it is often politically difficult to phase out subsidies government are encouraged to review the effectiveness of such subsidy schemes and consider accelerated renewables deployment in combination with higher energy efficiency as a way to reduce fossil fuel subsidies.

Proposal #7:
Ensure fair market access and phase out negative price distortions.

A greater share of renewable energy can produce greater economic growth for the national economy. Central-station power plants with large capacity require big corporations and banks, but distributed renewables open up the market to more small and medium-size enterprises, individuals and small investors. In Germany, individuals and citizen-owned energy co-operatives held 79% of the renewable power generation capacity in 2012 (Böll Foundation, 2013b). This diversification of ownership structures within the energy sector has the potential to stimulate local job creation as new small and medium-sized enterprises (SMEs) emerge within the sector. Indeed, this has also led to increasing competition with incumbents – who, naturally, cannot be expected to fully promote such diversification. Therefore policy makers must ensure a fair playing field for everyone. Greater market competition can benefit consumers and create jobs. The local benefits of renewable energy such as jobs, ownership of energy systems need to be communicated with the public.

Indeed, in some countries, utilities set the price paid to independent renewable power suppliers – their competitors. Not surprisingly, the prices offered are not always attractive. In other countries, incumbent utilities own the power grid. Unsurprisingly, grid access for renewables suppliers in such cases is often bureaucratic and costly.

Proposal #8:
Account for external effects in the pricing of fossil fuel energy supply and use.

The cost and benefits of renewable energy are not valued adequately in current market frameworks. As discussed in Chapter 4.2, if external costs that currently are not taken into account in the market – such as those for health care, climate change and environmental impacts – are taken into account, most of the conventional energy technologies would become more expensive than renewables. External costs need to be internalised by policy measures, as they are inherently ignored if left to market solutions.

Proposal #9: Ensure quality of products through standards and regulations, and find the country balance for local content requirements in the light of market access for cost reductions and innovation.

The need for international co-ordination in planning, standardisation and quality control is rising. Standardisation and quality control are essential for ensuring the safety, performance and long-term durability of products, in particular in an increasingly globalized renewable energy market. These are also important to support renewable energy technology deployment and increase investment and public acceptance, in particular for technologies newly entering the market. Support for demonstration projects is needed as well as for the creation of research, development and test facilities for new technologies.

For instance, the EU is currently focussing more on international grid expansion to lower costs and the need for upgrades. In the standardisation and quality-control fields, about 570 international standards have been identified, but their deployment is not as widespread as needed (IRENA, 2013l).

To increase local benefits, such as creating jobs or economic development, from renewable energy technology investments, governments are mandating the use of equipment and technologies which are produced domestically. However, there is also a risk for investors not to be able to implement the most innovative and cost-effective equipment due to local content requirements. The balance between local content requirements and international trade of technologies should be found for the deployment of affordable and best technologies.

Proposal #10: Through country dialogue and community engagement, establish a set of credible and predictable policy frameworks that can be maintained over long periods.

A long-term strategy that is adequately supported by an appropriate policy framework can play an important role in attracting investments into the renewable energy sector, as such frameworks reduce the investment uncertainty.

Box 6.3 Transition management

REmap is supporting policy makers by identifying realisable options to transition towards a renewables-based energy system. These technology options need to be supported by specific policy interventions between today and 2030. However, policy makers will also need to consider and engage stakeholders to ensure that these physical changes will be realised. These stakeholder groups include organisations that historically have dominated the energy sector – such as utility companies and oil companies, or car manufacturers in the transport sector – but also newer stakeholder groups like biochemical firms, electric car manufacturers, the offshore industry or local community groups.

One possible model for governing a transition towards a renewables-based energy system is "transition management". The idea behind transition management is that a physical transition also requires a fundamental change in the socio-economic system and cultural settings that govern the energy sector – including the attitudes and behaviours of consumers. Guiding principles for transition management are long-term goals, strategic innovation networks to support newcomers, experimentation and avoid lock-in, a recognition of the role of incumbent stakeholders that may want to protect their position, and the need to align different policy domains.

The relevance of transition management increases as the transition towards renewables deepens. In other words, for policy makers in countries with the highest renewable energy shares in the power and end-use sectors, it will be important to consider the different stakeholder roles, create space for newcomers and actively manage the transition. Similarly, countries that are looking at more innovative ways of integrating renewables into their systems will need to ensure that there are opportunities for continuous experimentation and learning. Finally, transition management provides a relevant framework to consider activities beyond 2030, as the transition towards renewables will require even deeper and more disruptive changes in the energy system (Rotmans, Kemp and van Asselt, 2001; Bosman *et al.*, 2013).

A number of countries have successfully included renewable energy in their energy plans. Germany is one prominent example. The country's target for 2050 is at least 60% renewable energy by 2050, with at least 80% renewable energy in the power supply. The country is also a global leader in wind and solar power growth through long-term policy commitments and stable incentives. Renewable energy has relatively high acceptance among political parties, developers, and society, and much has been done to strengthen Germany's capacity building at a research and technical level.

Denmark goes even further than Germany, with the Danish 2050 Strategy aiming to achieve 100% independence from fossil fuels in the national energy supply (electricity, heat, industry and transport) by mid-century. Denmark's government has helped the country become the world leader in wind energy through policy mechanisms guided by national energy plans with long-term targets. The government has several energy policy milestones: half of traditional consumption of electricity from wind power in 2020, a phase out of coal and oil burners by 2030, and electricity and heat supply covered by renewable energy by 2035.

Proposal #11: Reduce the duration of project implementation by improving the planning and regulatory framework

Planning procedures are a problem in many countries because of the time and cost involved. Japan is an extreme case, with the average development time of nine years for a wind project because of very strict environmental planning procedures. In France, the planning for a utility-scale solar PV project typically takes two years. Streamlined planning procedures reduce "soft costs" (permitting, paperwork, etc.). In Germany, it sometimes takes only a week to get approval for a small solar PV project.

6.3.3 Ensuring smooth integration into the existing infrastructure

The integration of large amounts of variable renewables – mostly solar and wind – into the power sector calls for particular attention. REmap 2030 analysis showed that a number of countries could achieve a more than 40% share of variable renewable energy in their power generation capacities if all REmap Options are implemented. Electricity transmission networks need to be expanded to connect centres of supply and demand in a way that is socially, technically and economically acceptable. More decentralised electricity production requires an improved distribution network, as opposed to high-voltage transmission lines; likewise, electric vehicles and bioenergy supply chains require new infrastructure.

Proposal #12: Build enabling infrastructure such as transmission grids, interconnectors and electric vehicle charging stations.

Grid infrastructure is key for supplying power from remote renewable energy resources to population centres. The Scandinavian Nord Pool power exchange is a best-practice example of how interconnection can help renewables. Power pools are market systems which complement physical interconnectors. If Denmark needs more power, it can look on the exchange for the cheapest producer that can ramp up production within the next 30 minutes – and that entity may be in Finland, a country with which Denmark shares no physical border. That flexibility is key as Denmark expands its use of wind energy. Likewise, Germany and Austria are now both closely intermeshed on the Phelix power exchange, and ELIX adds France and Switzerland to that pool.

In many European countries, transmission grid extension and reinforcement requires long administrative authorisation processes. Similarly, the UK lacks clear planning measures to support distributed electricity. As the share of renewable power continues to rise, sufficient power planning must ensure that intermittency is balanced through improved flexibility in generation, transmission and distribution planning, demand-side management and smart grids.

Infrastructure also includes the supply of biomass. The analysis showed that bioenergy demand would more than double between today and 2030, and international bioenergy trade could be 20-35% of total global biomass demand if all REmap Options are implemented. This will require substantial investment in logistics, road infrastructure to access residues and forest biomass resources, higher efficiency agriculture, the supply of fertilisers and other productivity-enhancing resources, and the efficient transport of its products to markets. Increased agricultural productivity could contribute to the use of less resources for the production of the same amount of food. Higher yields may reduce land expansion for food production and make available resources for energy crops in a world with rising food demand.

Electric vehicles require recharging infrastructure. Such infrastructure is currently being rolled out in various countries. Governments have to ensure uniformity of connectors and geographic spread as to facilitate acceptance.

Proposal #13: Facilitate sustainable biomass supply and consider the nexus in the development of renewable energy strategies and policies, notably land, energy, water, agriculture, trade and infrastructure.

Bioenergy trading (biofuel and solid biomass) has already grown immensely since 2000, driven in part by the EU's renewable energy targets and increasing demand from East Asian countries. If the security of feedstock supply is ignored, the biomass sector will not take off. Exploration of primary biomass imposes a burden on land and water resources. These resources are also required for food and feed production, and this demand will continue to increase along with population and economic growth. The use of agricultural residues can limit land expansion for biomass growth, but high removal rates could limit soil fertility and result in further environmental impacts.

Given these concerns, biomass needs to be sourced sustainably and utilised effectively. The incentives in an integrated policy framework need to target the sustainable use of forest resources and to limit the use of resources also required for food production. Innovation is also key for improving crop yields and cost reductions as well as for the development of less resource-intensive bioenergy commodities. As for bioenergy, other renewable energy policies do not stand on their own. The analysis has shown the importance of simultaneously improving energy access and energy efficiency in order to attain the objective for renewables. At the same time, renewable energy expansion needs to take place in a sustainable way, so deployment has to be undertaken in a holistic manner that takes into account the overall context, including the use of land and water.

In fact, under specific circumstances, some renewable energy technologies, in particular PV and wind, offer significant comparative advantages over conventional fossil-fuel based generation in terms of impact on resources (water and land) when seen from a qualitative and a quantitative perspective. These factors should be taken into account by governments in developing national energy sector strategies.

Proposal #14: Develop markets for affordable and reliable equipment for modern energy access.

Achieving modern energy access to substitute traditional biomass use for cooking as proposed by REmap 2030 represents another challenge. The priority to overcome this challenge is to establish a global market structure for the sales of cook stoves and fuels. Efficient cook-stove technologies which can use a range of fuel options need to be developed which also fulfil international standards and quality controls. Biogas, liquid biofuels and renewable electricity all can play a role but need economies of scale to be affordable and sustainable in economic and technical terms.

6.3.4 Creating and managing knowledge

Proposal #15: Build a strong, publicly accessible knowledge base on renewable energy technology costs, resource potential and technology options.

While a great interest exists to invest in renewable energy projects, reliable information about renewable energy technologies remains scarce. Existing technologies are developing fast and innovation leads to the development of new technologies. At the same time, new capacity is being rapidly added in different countries. Given the rapidity with which the sector is evolving, the debate on renewables is all too often fuelled by misconceptions and inaccurate data (*e.g.* installed capacity, costs, efficiency, etc.). This calls for greater efforts are needed to improve the knowledge base.

Credible plans take resource assessments, costs, energy demand data and other factors into account. Banks require even more detailed resource assessments. Governments need to understand the quality of project proposals, the track record of project developers and the key issues related to the technology solutions proposed. Legal and regulatory best practices must be understood, for example for power purchase agreements.

Proposal #16: Expand project development knowledge for bankable project proposals.

Many developing countries lack the capacity to develop bankable project proposals, which reduces deployment and raises project cost. In Germany, reliable feed-in tariffs mean that solar investors can pick up a two-page form to apply for a loan from their local savings bank. The national development bank KfW backs the loan, with the local bank serving as the conduit. Similar programmes exist, for example, in Brazil through the Brazilian Development Bank (BNDES). Countries that reduce risk and facilitate financing have seen a much stronger uptake of renewable energy than those relying on market forces which raise transaction costs for renewables.

In order to prepare bankable project proposals, the phases of project development such as timeline and steps, estimating finance needs and understanding the communication and co-ordination structure need to be better understood by investors, financers and governments. A better understanding supported by case studies and best practices will help project developers in the successful implementation of renewable energy technology projects and will help reduce costs and chances of failure.

Proposal #17: Collect and report best-practice information on technology and policies.

Governments, investors and other stakeholders need to be aware of the latest information on best practices in renewable energy technologies and policies. This will help to set technology benchmarks, enhance improvements in the deployment and implementation of the renewable energy technologies and also contribute to the evaluation and adaptation of existing policies. Sharing best practices and learning from each other also creates opportunities for international co-operation.

Proposal #18: Establish and improve programmes to increase awareness and strengthen the capacity of manufacturers, installers and users.

Societal acceptance and global awareness of renewable energy options will create increased focus and pressure on outside actors to push for the systematic integration of renewables. Societal and political will, nurtured by international co-operation and facilitation, can create an environment in which the mistakes and successes of all contribute to building a stronger, cleaner future for all. IRENA has proposed a multi-stakeholder global coalition for a concerted and innovative effort to develop clear messaging to improve social acceptance of renewable energy.

Training in renewable energy equipment use is an important issue, in part to increase awareness of renewable energy technologies. After implementation, people often need to be trained to use devices. The success of solar hot water and cook stoves has been slower than necessary because this education step was sometimes overlooked.

In the building sector, consumers do not know which heating systems are the best and which financial incentives are offered. In South Africa and India, where solar water heater targets exist, the lack of awareness is the biggest challenge in renewable energy deployment for heating.

Quality control matters for small and large projects. For example, solar PV projects in India using identical equipment in the same location show up to 20% difference in performance because of the design and installation quality. Deployment of international standards and guidelines can facilitate markets and help to maintain quality.

Proposal #19: Design renewable energy technologies from the point of view of product and service life-cycle environmental and sustainability impacts.

Introducing new technologies to the market has both environmental and societal impacts. The sustainability of existing and emerging renewable energy technologies requires assessment and comparison among other renewable energy technologies as well as with their conventional equivalents. For example, depending on feedstock type, land use and region, the greenhouse gas emission performance of conventional biofuels varies substantially, raising questions about their sustainability. End-of-life treatment of solar PV modules and the related impacts is another focus of discussions about sustainability. Sustainability is a multi-dimensional concept, and assessments of technologies therefore should incorporate indicators that deal with both socio-economic as well as environmental and resource impacts of technologies.

6.3.5 Unleashing innovation

Proposal #20: Develop targeted policies that support the technology life cycle.

Innovation requires more than basic research and contribution to the further development of breakthrough technologies. A more intense focus on the adaptation of mature technologies to specific environment conditions, guarantees for further innovation in the long term and improved energy efficiency are also highly recommended. Examples include high-altitude wind turbines, smart grids and heat pumps using natural refrigerants (hydrocarbons, carbon dioxide, etc.).

Co-ordination between the domains of energy policy, industrial policy and research and development is fundamental to enable an effective renewable energy technology innovation policy. In addition to this requirement, specific policies have to be tailored to country requirements and customised for the technologies of interest.

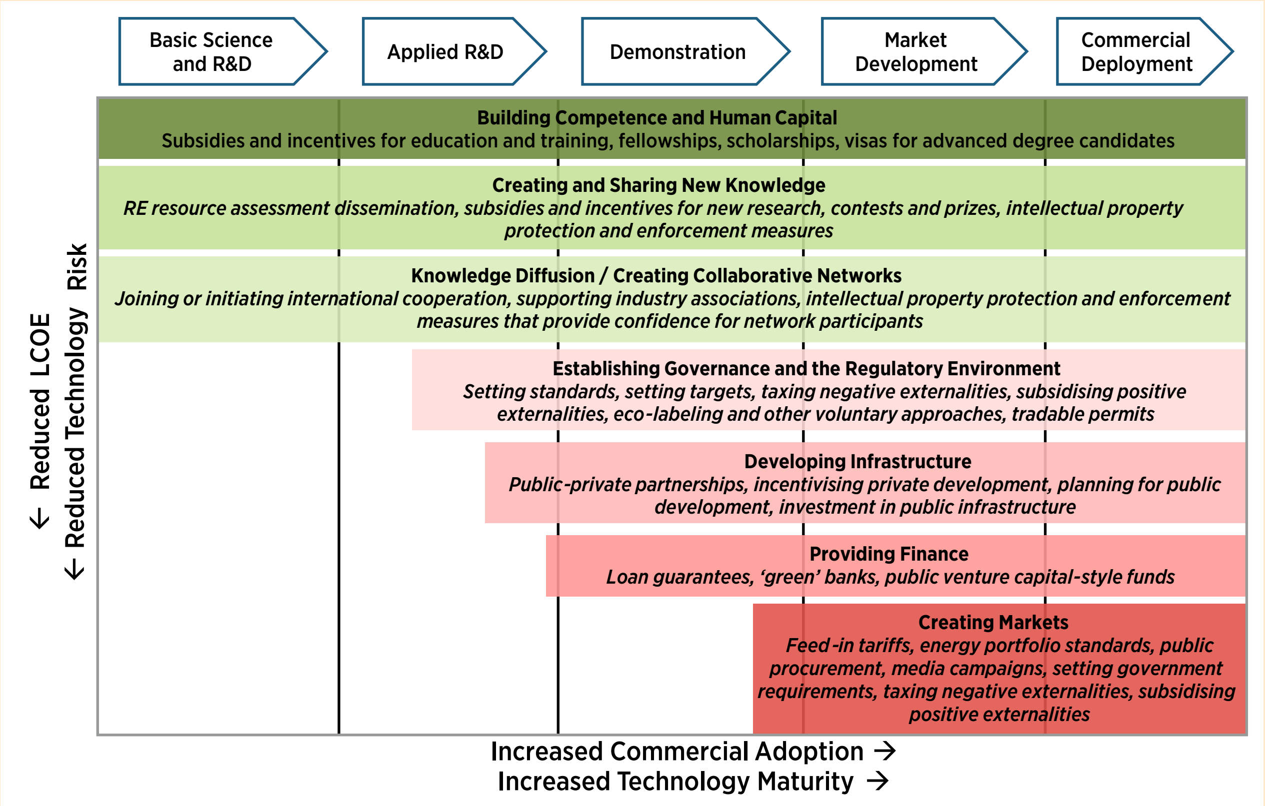
The capacity of innovation in renewable energy technology varies widely according to a number of regional, national and sub-national factors (IRENA, 2014k). Innovation can be the result of an efficient combination of these factors; hence, every country has innovation potential, but opportunities will differ. Three main innovation modes can be defined based on the different country contexts: 1) adaption, 2) commercial scale-up and 3) technology venture. Countries need to identify their innovation mode in order to adopt the best-suited instruments.

IRENA promotes strategies for effective and efficient innovation in renewable energy technology deployment as an incremental approach to reach and exceed the target of doubling the share of renewables in the global energy mix by 2030. The policy instruments to be applied depend on technology maturity, cost and risk. Figure 6.2 is a toolbox of instruments that map policy functions within the technology maturity space. It illustrates the relationship between different stages of technological development and the policy objectives needed to support renewable energy uptake, with a focus on three main areas: competency building, knowledge creation and diffusion, and deployment. Within the three areas outlined, a range of enabling policy actions and instruments should be implemented. Doubling the share of renewable energy by 2030 will require a context-specific mix of policy interventions, including innovation, deployment and other complementary policies, to ensure fulfilment of the REmap Options that have been identified.

A strong and stable political commitment towards the promotion of innovation in the energy sector is indispensable in transitioning to a suitable energy regime and transforming an energy matrix at a national level. Policies that support the complete technology life cycle, from basic research to commercialisation, should be co-ordinated. Local manufacturing of equipment and technology should be promoted. The REmap Options are built upon existing renewable energy technology achievements, and IRENA encourages governments to implement these options in their energy plans and programmes.

In spite of the tremendous existing potential to carry out REmap Options and globally double the share of renewable energy by 2030, these options are technologically constrained to the emerging and mature technological applications now known. Going beyond this scientific and technological knowledge to surpass the doubling of the renewable energy share is possible only with novel renewable energy technology solutions and applications. IRENA calls for the support of governments to boost these new solutions, stimulate innovation and research and make a higher share of renewable energy technology possible worldwide. Governments should also facilitate implementation of pilot and demonstration plants to bridge the gap between R&D and commercialisation.

Figure 6.2 Guide for policies in the technology life cycle



Source: Obtained from IRENA (2013h)

Proposal #21: Review energy applications of high relevance and low renewable energy potential and develop programmes to fill the gap with new technology.

The REmap Options, in combination with efficiency and access, can result in a doubling of the global renewable energy share by 2030 if there is rapid growth in a number of technology areas. This growth is uncertain. There are still some areas where no significant renewables potential has been identified so far (such as steel making, shipping and aviation). Moreover, higher shares of renewables will be needed after 2030. Therefore, it is important that policies should not only focus on the market development and commercial diffusion side of the technology life cycle, but also consider basic research, applied R&D and demonstration.

6.4 International co-operation

REmap analysis clearly underlines the necessity for national actions and international co-operation to support the transition to a doubling of the share of renewables in the global energy mix by 2030. International co-operation is essential to foster innovation in renewable energy technology and markets. It is of paramount importance in developing successful and goal-oriented science, technology and innovation programmes. International co-operation also creates a platform where experiences and best practices in renewable energy technology innovation are shared and transferred across countries.

Based on the national policy action areas, this chapter discusses the opportunities and potential areas of greater international co-operation across governments, and highlights the role that IRENA can play, as the recognised hub for renewable energy, to further facilitate the transition.

6.4.1 International co-operation for deployment at scale

As national policy makers work to ensure that the right policies and financing are in place, that markets are stimulated and accessible, and that technological innovation is nurtured, countries are increasingly exploring new modalities of international co-operation to find sustainable energy solutions to meet their growing energy needs without negatively affecting the climate system. This co-operation is critical to attain the goals of REmap 2030.

REmap 2030 analysis shows that development and deployment of renewable energy technologies cannot be contained within national borders. The deployment of renewable energy technologies in one country will have an impact – through energy prices, technology learning, externalities and finance flows, for example – on the deployment of renewables elsewhere. At the same time, renewable energy technologies are products in themselves; they use resources, components and manufacturing capabilities contributed by multiple countries.

International co-operation is therefore vital to advance the deployment of renewables and ensure that countries meet their energy needs while reaping the benefits of sustainable solutions that renewable energy provides. While this co-operation may take many forms, priority must be placed on those areas where the impact of such co-operation would be the greatest.

The first national policy action area focuses on **planning transition pathways**. Planning is the first step towards increasing the deployment of renewable energy use. The comparison of the 26 REmap countries showed that the existing policy frameworks vary widely and there are large gaps in the policy frameworks between some of them. International co-operation can play a role in strengthening national renewable energy plans, both in the REmap countries and beyond. Specific areas of co-operation include best-practice analysis and documentation of conducive and credible policy frameworks, including streamlined planning frameworks, targets and deployment policies. Sharing input from research institutions and other international knowledge hubs in the creation of national renewable energy plans can help. Co-operation is particularly interesting for countries which are in the same region, as there could be similarities across resource availability and economic development. A better understanding of the base case will need to be supported by internationally harmonised renewable energy data collected from countries.

To support international co-operation on planning transition pathways:

- IRENA is working with countries and regions to help reflect the renewable energy potential in long-term regional and national energy master plans.
- Given already the high attention from policy makers to the power sector and its increasing importance for renewable energy deployment, IRENA is also working with energy planning models which focus on national, regional and international level developments to gain more insight into policy-relevant information for countries and international co-operation.
- IRENA is also conducting an analysis of policy status and trends of countries based on standardised information which could be the basis for best-practice exchange as well as international discussions and co-operation.

The second area of national policy action is **creating an enabling business environment**. Only a few countries have developed long-term credible and predictable policy frameworks which create an enabling environment for renewable energy investments. Countries at an early stage of development and/or deployment can learn from other countries' planning frameworks and deployment policies. Regional co-ordination of policy initiatives, along with ensuring that trade in both resources and experience grows along with renewable energy markets, can help to attain the necessary economies of scale.

Energy pricing strategies often show similarity across countries within the same region, explained in part by resource availability. A better understanding of the energy pricing structure and market conditions is necessary to eliminate the risks related to the costs of financing as well as to develop international strategies for fading out fossil fuel subsidies. Deployment at a scale that would affect both the cost of technologies and stimulate private investment requires cross-border and regional co-operation. Despite the existence of funds invested in renewables, there is a significant lack of investment in cross-border and regional initiatives. For example, development banks invested a total of USD 60 billion in renewable energy in 2012 – more than half of their total investments in clean energy – but the bulk of this came from regional or national banks investing in national projects. Less than USD 10 billion represented North-South or South-South investments in renewables (BNEF, 2013).

Combustion of fossil fuels happens at a local scale, but greenhouse gas emissions and human health problems related to the use of fossil fuels result in international problems. Therefore, they require internationally agreed approaches, in part to endogenise these externalities in the price of conventional fuels.

Quality assurance and standardisation are critical for sustainable, long-lasting and safe equipment. Most policies aim to increase the use of local equipment and resources, but trade of renewable energy commodities will still increase. Furthermore, new renewable energy markets will accelerate global investments for renewable energy equipment manufacture.

To support international co-operation on creating an enabling business environment:

- IRENA is working with Middle East and North Africa (MENA) countries to understand different energy pricing structure and policies. IRENA is also supporting regional initiatives in Africa, Central America, Central and South Asia, Southeast Europe and the MENA region to create regional Clean Energy Corridors, intended to utilise the potential of abundant renewable energy sources to meet growing energy needs and increase access to modern energy services.
- IRENA is also deploying its tool of Project Navigator to help developers access financing for bankable projects with countries, finance organisations and the private sector.
- Another field of international co-operation is IRENA's support to regional initiatives to operationalise standards and quality-assurance mechanisms together with regional technical institutes.

The third area of national policy action is **managing knowledge of technology options and their deployment**. Reliable data and information are key to improve the knowledge base for national, regional and international actors in the field, which include governments, investors, industry and the public. To support international co-operation on managing knowledge of technology options and their deployment:

- IRENA has initiated the work aiming to build and consolidate public support for renewables, and the Renewable Costing Alliance, which compiles information on real-life project costs, is intended to strengthen this effort.
- Through the Global Renewable Energy Atlas, which provides resource-assessment data, IRENA is working closely with countries to collect the most complete and up-to-date renewable energy data to develop a global renewable energy statistics database. Such data is the foundation of all analytical work required to support governments on discussions and co-operation at the national, regional and international levels,
- IRENA is also working on understanding the changes in environmental impacts from reduced fossil fuel use, but also related to the impacts of different renewable energy technologies.

The fourth group of national action items is **ensuring smooth integration of renewables into the existing infrastructure**. Electricity grid interconnectors exemplify the benefits of international co-operation, with both exporting and importing countries benefitting from increased renewable energy use. IRENA analysis (IRENA, 2013k,m) highlights the importance of interconnectors in the African context to spread the benefits of large renewable-resource potential in different regions of the continent. Trade in renewable power could account for 15-20% of the power supply in West Africa and Southern Africa, the analysis shows. Electricity exports from the Grand Inga project in the Democratic Republic of the Congo alone could reduce average regional power generation costs in the Southern African power pool by nearly 10% in 2030.

Bioenergy trade is also important. Based on the REmap analysis, international bioenergy trade could account for 20-35% of total bioenergy demand in 2030. The economic value of global biomass trade flows would be in the range of USD 100-400 billion. This trade poses a significant business opportunity, but it requires a widely applied, uniform framework to ensure sustainability and the development of the necessary logistical infrastructure.

Sustainable management of the water, energy and land nexus is a major aspect of international discussions because these resources are traded and shared, often as embedded inputs, internationally and the drivers behind their growth, such as population growth, urbanisation or climate change, are all interconnected and related to economic developments worldwide. To support international co-operation on ensuring smooth integration of renewables into the existing infrastructure:

- IRENA is developing a grid-stability assessment methodology for different regions and countries to determine how their power grids can be transformed to accommodate an increasing share of variable renewables.

- IRENA is undertaking efforts to bridge the knowledge gap on the role of renewable energy in the water, energy and land nexus by developing quantitative analysis focusing on the impacts of renewable energy on the different elements of the nexus.

The fifth area of national policy action is **unleashing innovation**. Research and development in technology is international. Furthermore, technology development benefits largely from regional and international strategies and co-operation. Networking of research centres, knowledge transfer and sharing of best practices will help to improve the efficiency of existing technologies and also to develop breakthroughs, as identified in this study, to go beyond doubling.

To support international co-operation on unleashing innovation, IRENA is mapping the gaps and benefits for collaborative RD&D on technologies and in regions for enhanced innovation through international co-operation and streamlined national and regional RD&D plans.

6.4.2 IRENA as the SE4ALL renewable energy hub

As the only global intergovernmental *organisation* dedicated solely to renewable energy, IRENA is uniquely positioned to advance the aspirational goal of doubling the share of renewables in the global energy mix (Roehrkasten and Westphal, 2013). The SE4ALL initiative, launched in early 2012, aims to influence the global debate and promote renewable energy through public-private partnerships through the SE4ALL network. IRENA has been entrusted with the role of SE4ALL's Hub for Renewable Energy.

IRENA will engage with those who have made specific commitments to renewable energy, both within the initiative and in the context of different SE4ALL High Impact Opportunities, on issues related to its own programmes, such as studies on islands, cities, off-grid lighting and the water-energy-land nexus. Close co-operation with other SE4ALL hubs, as well as with the Global Facilitation Team, will be central to this role. IRENA will work closely with regional banks to ensure synergies and complementarity of effort with IRENA's activities in each region.

A formal framework of co-operation will be established with the World Bank, an SE4ALL Knowledge Hub, to leverage respective strengths in the area of renewables. In partnership with the SE4ALL Energy Efficiency Hub in Denmark, IRENA will promote the necessary and inseparable link between renewables and energy efficiency. Another important area of future work, which this roadmap exercise has highlighted, is to pursue a more detailed assessment of the potential of sustainable biomass.

Over the course of 2014/15, IRENA will create REmap Action Teams, bringing together interested countries and other stakeholders to work together under the REmap 2030 umbrella on specific issues, such as transportation, joint strategies for renewables and energy efficiency, and other areas that could have a transformative impact on the deployment of renewables. IRENA will also expand the range and scope of its technological, geographic and topical work to provide a sound knowledge base for efforts to provide sustainable energy for all.

Another way that IRENA will expand its work is to engage in deeper analysis for the 26 countries encompassed by REmap studies to date, as well as to broaden the scope of countries included in this global roadmap exercise. In doing so, it is hoped, we can advance IRENA's mandate – adopted by founding members in 2009 and embraced by over 160 participating countries to date – to promote the widespread and increased adoption and sustainable use of all forms of renewable energy to ensure a sustainable energy future for future generations.

6.5 Next steps

This roadmap shows how a doubling of the global renewable energy share can be achieved by 2030. This is the first global study to provide renewable energy options based on the bottom-up analysis of 26 countries which account for three-quarters of the projected global energy demand. In addition to the power sector, the study encompasses developments and potential in end-use sectors, which often are not dealt with in detail.

The starting point of this study is, to the extent possible, the official national sources. This roadmap showed the realisable potential of renewable energy technologies beyond the Reference Case – the REmap Options – in 2030 at the country and sector levels as well as their costs. The study concludes that a doubling of the global renewable energy share is possible at negligible additional costs. When socio-economic benefits are included, the result is a net savings.

As represented by RE+ Options, doubling the renewable energy share by 2030 is not an end point. More needs to be done and is possible. This requires greater efforts, however, through modal shifts and early retirement and more innovation in breakthrough technologies. Going from R&D to significant deployment can take some decades, so action to develop and commercialise these options must be taken now.

The results of this roadmap show that there are opportunities for renewables everywhere and every region has a role to play.

This study is a living document. In order to assess this additional potential and to account for the developments in countries, this study will be updated continuously as part of IRENA's 2014/15 Work Programme. This will be done in dialogue 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 for doubling the global renewable energy share and going beyond.

Country analysis will also be expanded to include other energy users, in particular from regions where the coverage of this study was limited, such as the countries in Africa or Latin America. To complement country analysis, IRENA is already carrying out assessments at the regional level, such as for South Asia, and will continue with similar assessments for other regions.

Alongside the REmap 2030 analysis, IRENA will develop country action plans for the implementation and application of REmap Options. IRENA will organise REmap Action Teams to translate the national policy suggestions into an action agenda for transport sector and energy efficiency activities, and provide guidance to the High Impact Opportunities under the SE4ALL initiative.

By the end of 2015, the outcome will be a more comprehensive and acknowledged roadmap on options and action required for doubling the share of renewable energy in the fifteen years to 2030. It will also monitor the progress achieved globally and in the REmap countries between 2010 and 2015, and will provide comparisons with the technology development trends estimated in this roadmap.

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LIST OF ABBREVIATIONS

BEV	battery-electric vehicle
BNDES	Brazilian Development Bank
CAGR	compound annual growth rate
CCGT	combined-cycle gas turbine
CCS	carbon capture and storage
CH_4	methane
CHF	Swiss francs
CHP	combined heat and power
CIS	Commonwealth of Independent States
CO	carbon monoxide
CO_2	carbon dioxide
COP	coefficient of performance
CSP	concentrated solar power
DME	dimethyl ether
EJ	exajoule
EOR	enhanced oil recovery
ETH	Technical University of Zurich
EU	European Union
EV	electric vehicle
GCC	Gulf Cooperation Council
GDP	gross domestic product
GEA	Global Energy Assessment
GFC	gross final consumption
GJ	gigajoule
GSHP	ground-source heat pump
Gt	gigatonne
GW	gigawatt
GW_e	gigawatt-electric
GW_{th}	gigawatt-thermal
HEV	hybrid-electric vehicle
ICT	information and communications technology
IEA	International Energy Agency
IEA-ETSAP	Energy Technology Systems Analysis Programme of the IEA

IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPR	intellectual property rights
IRENA	International Renewable Energy Agency
kt	kilotonne
kW	kilowatt
kWh	kilowatt-hour
kW_e	kilowatt-electric
kW_{th}	kilowatt-thermal
LCOE	levelised cost of energy
LED	light emitting diode
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MENA	Middle East and North Africa
MSW	municipal solid waste
Mt	megatonne
MW	megawatt
MWh	megawatt-hour
MW_e	megawatt-electric
MW_{th}	megawatt-thermal
NO_x	mono-nitrogen oxide
NREAP	National Renewable Energy Action Plan
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OTEC	ocean thermal energy conversion
PHEV	plug-in hybrid electric vehicles
PJ	petajoule
PM	particulate matter
ppm	parts per million
PPP	purchasing power parity
PV	photovolatics
QI	quality infrastructure
R&D	research and development
RD&D	research, development and deployment
R&D	research and development
SE4ALL	Sustainable Energy for All

SHS	solar home systems
SME	small and medium-sized enterprise
SNG	synthetic natural gas
SO_2	sulphur dioxide
TFC	total final consumption
TFEC	total final energy consumption
TJ	terajoule
TPES	total primary energy supply
TWh	terawatt-hour
UAE	United Arab Emirates
UK	United Kingdom
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USD	U.S. dollars
VAT	value-added tax
VOC	volatile organic compound
WACC	weighted average cost of capital
WBA	World Bioenergy Association
WEO	International Energy Agency's *World Energy Outlook* report
WHO	World Health Organization
WWF	World Wide Fund for Nature

Exajoule: One quintillion (10^{18}) joules.

Final energy: Energy in the form that it reaches consumers (such as electricity from a wall socket).

Gigajoule: One billion (10^9) joules.

Gigatonne: One billion (10^9) tonnes.

Gigawatt: One billion (10^9) watts.

Joule: A unit of measurement for energy, equivalent to one watt of power for one second.

Megawatt: One million (10^6) watts.

Petajoule: One quadrillion (10^{15}) joules.

Primary energy: A source of energy before any conversion has taken place, such as crude oil and lumps of coal.

Reference Case: In this study, the business-as-usual case under current policies and governmental plans.

REmap 2030: The name of this study and the collective outcome of the Reference Case and REmap Options.

REmap Options: The additional growth of renewables on top of the Reference Case.

RE+ Options: The additional growth potential on top of REmap 2030.

SE4ALL: Sustainable Energy for All, the UN Secretary General's initiative for global access to sustainable energy.

Terawatt-hour: One trillion (10^{12}) watt-hours.

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REmap 2030

The world can double the share of renewables in its energy use by 2030. REmap 2030, a renewable energy roadmap, is the first study of global renewable energy potential to be based on data from official governmental sources. Prepared by the International Renewable Energy Agency (IRENA) in consultation with governments and other stakeholders worldwide, the roadmap encompasses 26 countries representing three-quarters of current energy demand. In determining the potential to scale up renewables, the study not only focuses on technologies, but also on the availability of financing, political will, skills, and the role of planning.

The study finds that doubling of the share of renewable energy in total final energy consumption by 2030 would be nearly cost-neutral. When external costs that can be avoided by replacing conventional energy are taken into account, this ambitious transition even results in cost savings.

Nor is the proposed doubling an absolute limit; the world can increase the share of renewables much further, but policymakers need to make preparations for this long-term transition today. This has to start by providing investors in the sector with clear guidelines for the transition to a future driven by renewable energy.

This REmap 2030 report presents a comprehensive summary of its findings, while directing readers to the REmap 2030 web portal *(www.irena.org/remap)*, which presents extensive background documents. The study will continue to be updated in the years to come, as new countries join the process and as the data for all REmap countries becomes available.

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