Tracking Clean Energy Progress 2016

Energy Technology Perspectives 2016 Excerpt
IEA Input to the Clean Energy Ministerial

International Energy Agency
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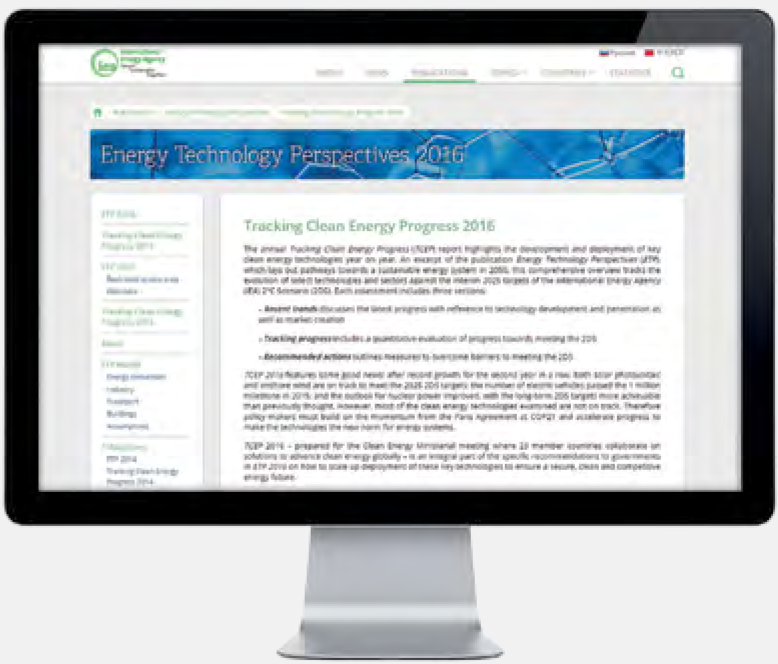

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The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
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The European Commission also participates in the work of the IEA.

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Foreword

The milestone COP21 Paris Agreement recognised the importance of energy technology and innovation in meeting our climate objectives while dictating new climate goals that are more ambitious than ever. The International Energy Agency (IEA) stands ready to provide technology and policy advice to rise to the new challenges our leaders have put before us. This year's edition of *Energy Technology Perspectives* (*ETP 2016*) – marking the 10th anniversary of our flagship publication on energy technologies – showcases the importance the IEA places on supporting clean energy and energy efficiency. Similarly, our Energy Technology Network, which has been running now for more than 40 years and comprises 39 Technology Collaboration Programmes with the participation of more than 6 000 experts worldwide, highlights our commitment to fostering multilateral technology co-operation.

While the accomplishment of COP21 was an important step forward, the focus must now turn to implementation. We need to put actions behind our words to lend credibility to our commitments. We will succeed in this only through greater reliance on partnerships and collaboration. Just as I have emphasised that the IEA has to "open its doors" to the emerging economies if global energy challenges are to be tackled effectively, so must we look at energy technology partnerships at multiple levels, such as between the public and the private sectors as well as among various sectors of the economy and between the different levels of government.

The Paris Climate Agreement was made possible in great part by the realisation that a deal could only work based on a bottom-up approach with proper consideration given to the views of all stakeholders. Thus, the active engagement of cities, civil society and private entities brought confidence that all parties could work together to build a world where human development and environmental responsibility are compatible with economic growth. The importance of cities is clear: they represent almost two-thirds of global primary energy demand and account for 70% of carbon emissions in the energy sector. Recognising the success of COP21, and building on the role of cities as drivers of economic growth and global energy use, *ETP 2016* highlights how national energy policy makers can work with local governments to make cities more efficient, secure and healthy places to live, while also contributing to national and global sustainability objectives.

Our analysis shows that clean energy technologies and policies can indeed meet multiple objectives in the most effective way. For example, sustainable mobility solutions can increase access to services while reducing congestion and increasing productivity. Efficient building technologies can reduce energy investment needs while increasing comfort for residents. Local sources of energy and integrated distribution systems can decrease the costs associated with delivering various services, while improving resiliency and flexibility. Cities can also be drivers of innovation, acting as real-life test-beds where linkages between various technologies, and between technologies and market structures, can be evaluated to create innovative solutions and business models that can be exported to other settings. Through case studies, we demonstrate the various opportunities local and national collaboration can offer, for example, showing how Mexican cities can be key partners to enable the very ambitious energy transition enacted by the Mexican federal government.

Recent years have shown how progress can be achieved, but major challenges lie ahead. With CO_2 emissions stagnating for the second consecutive year in 2015 despite a growing global economy, we now have proof that sustainability and growth can go hand in hand, but the uncertainty associated with lower fossil fuel prices may tempt policy makers to act based on short-term opportunities. I hope that this edition of *Energy Technology Perspectives* will promote a longer-term strategic perspective and that local as well as national governments will take on board the policy advice provided here to make cities strategic drivers of a low-carbon future.

Dr. Fatih Birol
Executive Director
International Energy Agency

Key Messages

Clean energy technologies continued their advancement as mainstream energy solutions in 2015. However, policy makers need to remain committed, to avoid a lowering of priorities due to low oil and coal prices at this critical time, to the transition to a decarbonised energy system.

- **The threshold of one million electric cars was crossed in 2015, with an overall annual sales growth rate of 70%.** While still small in absolute terms relative to the entire vehicle stock, this growth provides confidence in a viable alternative technology. Continual annual average growth of at least 39% is required to remain on track with the *Energy Technology Perspectives* 2°C Scenario (2DS) 2025 sales objective. This ambitious near-term objective seems achievable with sustained policy and funding support.
- **Renewable power generation grew by an estimated 5% in 2015 and now accounts for around 23% of total electricity generation globally.** New renewable electricity capacity grew at its fastest pace in 2015, supported by policies driven by energy security, local pollution concerns and climate benefits. With the momentum of the United Nations Framework Convention on Climate Change (UNFCCC) 21st Conference of the Parties (COP21) and recent policy changes, the outlook for renewable power is more optimistic. However, policy uncertainties, non-economic barriers and grid integration challenges persist, preventing renewables from being fully on track with the 2025 2DS target.

Key Numbers

7.3 billion global population in 2015

Ongoing over **80%** dependence on fossil fuels

Global annual average increase since 2010

1.9% energy demand < **2.5%** GDP USD (2005)

Globally **coal** continues to account for almost

29% of energy demand

38% of energy related CO_2 emissions

493 USD billion fossil fuel consumption subsidies in 2014

6 countries with electric car sales above 1% of the new car market

- **Nuclear power plant grid connections doubled in 2015.** Furthermore, progress and construction times in 2015 show the long-term 2DS targets to be more achievable than previously thought. However, several policy matters have the potential to impede the deployment of new nuclear power plants. In particular, more support is needed for the existing fleet to prevent early closures.
- **Further proof of the technical viability of carbon capture and storage (CCS) was demonstrated in 2015.** The current wave of CCS projects continued to move forward, with two new projects beginning operation in 2015. CCS has applications across both the power and non-power sectors, including in processes that may have no alternative for deep emissions reductions (e.g. cement, steel); however, progress is falling short, with no new investment decisions or advanced planning for projects in 2015. Industry and governments need to make significant investment in projects and technology development to get CCS on track to meet the 2DS target.
- **Energy efficiency improvements continued at a steady pace, with buildings and appliances improving at a faster rate than other end uses.** However, more aggressive measures are vital in the short term to stay on the least-cost pathway to meet 2DS targets and fulfil the role of energy efficiency as the largest contributor to greenhouse gas emissions reductions under International Energy Agency (IEA) scenarios, and contribute to achieving energy-related emissions peaking in the short term.
- **Despite a notable scale-up of production capacity over 2014-15, advanced biofuels are not on track to meet 2DS targets.** Biofuels mandates, strengthened recently in several key markets, including Brazil and Indonesia, have effectively shielded biofuels demand from a low-oil-price environment that reduced prices for gasoline and diesel. However, while conventional biofuels are on course to meet 2DS targets for 2025, significantly accelerated commercialisation of advanced biofuels is necessary to fully achieve 2DS requirements for decarbonisation of the transport sector, including aviation.
- **The recent successes in energy storage solutions are a result of long-term technical innovation.** To have continued advances in maturity and scale, sustained support is required. Incentives are needed that increase the uptake of system integration technologies, which closely match supply with demand and improve overall system performance, especially in countries and regions where the electricity grid is expanding.

SHARE OF TOTAL ELECTRICITY GENERATION IN 2013

41%
COAL

21%
RENEWABLES

10%
NUCLEAR

21%
NATURAL GAS

36%
of total primary energy used for electricity generation

37%
overall efficiency of thermal electricity generation

The adoption of existing readily available technologies needs to be accelerated to keep open the window of opportunity to meet long-term climate targets and ensure sustainable development.

- **Widespread deployment of existing best available technologies and energy efficiency measures could yield significant annual savings.** Effective measures that can be implemented quickly in the short term include international and regional alignment on the stringency and coverage of minimum energy performance standards for appliances and equipment, such as building heating and cooling equipment, industrial motors, and vehicles.
- **Decarbonising electricity generation is imperative in order to meet 2DS targets.** Final electricity prices need to reflect the environmental and other costs of fossil-based generation. Recognition needs to be given to the emissions reductions that clean energy generation technologies can provide and the energy security and flexibility made possible by these resources, whether variable and distributed renewables or large centralised clean energy solutions such as nuclear and CCS. Decarbonising electricity generation is an imperative in order to meet 2DS targets.
- **Global solar heat deployment has slowed in recent years due to challenging economics, insufficient support and non-economic barriers.** The potential for solar heating to help decarbonise the sector remains largely untapped (1% of global heat demand) but requires a significant ramp-up across all market segments for residential, commercial and industrial applications. To accelerate deployment, efforts should focus on reducing costs for all system sizes, ensuring that existing support mechanisms are adequate and creating a comprehensive policy framework for renewable heat.

Change in 2013:

1.60% PRIMARY ENERGY	**2.18%** FINAL ENERGY	**2.22%** ENERGY RELATED EMISSIONS
0.48% primary energy consumption per capita	**1.18%** GDP USD (2005) per capita	**-0.69%** primary energy per unit GDP USD (2005)

Broader integration of sustainable energy into policy and market frameworks is needed, as well as strategic planning in all energy end-use sectors, to avoid lock-in of an inefficient energy future.

- **In the transport sector, improved land-use, infrastructure and integrated territorial planning are key to curtailing energy demand.** Especially in urban areas, avoiding unnecessary transport activity through improved land-use planning is the first step of the "Avoid/Shift/Improve" strategy needed for more efficient mobility. Similarly, public transport infrastructure planning is vital to achieve shifts to more energy-efficient modes of transport.
- **Significant untapped energy efficiency potential is available in buildings, and a variety of different actors need to be engaged**. The rate and ambition of energy retrofits of existing buildings need to be improved. Because buildings are long-lived assets, swift and effective short-term targets must be implemented to avoid lock-in of an inefficient building stock. For new building stock additions, spatial and urban planning should identify cost-effective clean energy opportunities for building heating and cooling.
- **The growth rate in electricity consumption by buildings needs to be halved to meet 2DS targets.** Legislation and standards need to evolve with technology developments, especially for networked devices. The policy response to controlling the energy consumption and efficiency of "smart devices" has been slow; however, recent initiatives such as the connected devices alliance instigated by the Group of Twenty (G20) industrialised and emerging economies are signs that action is starting.
- **A co-ordinated public-private effort is needed to advance industry energy efficiency.** Energy-intensive industrial sectors account for approximately two-thirds of total industrial energy use, highlighting the need to reduce the overall impact of industrial products through cross-sectoral integrated approaches that examine recycling potential, material and resource efficiency, and life-cycle assessment.

Current annual energy consumption levels

22 MWh primary energy per person

3 MWh electricity per person

14% renewables share in total primary energy

3.4% electricity generated from variable renewables

Associated annual energy-related emissions:

4.5 tonnes CO_2 per person

0.2 tonnes CO_2 per MWh

Peak coal consumption highlights the successful impact of historical environmental policy measures and decouples energy demand from economic growth.

- **The big news in energy trends in 2015 is that coal consumption is believed to have peaked.** Notwithstanding weakened demand, the possibility that coal has peaked instils confidence that policy measures such as pollution control and the phase-out of inefficient power plants are effective. China had the first decrease in coal-fired power generation in 40 years and set a new standard by requiring 28% of coal-fired generation to be combined heat and power by 2020.
- **Policy makers should not be complacent as the availability of cheap coal is still a significant threat to decarbonising electricity generation.** As a result of continuing low coal prices relative to natural gas, a reversal occurred in the trend of moving away from coal-fired power plants in the United States in 2015. Another concern is that in emerging economies where coal-fired capacity is expanding, less-efficient plants still dominate new additions.

In 2015, persistent low oil prices presented challenges for clean energy technologies but also opportunities to eliminate persistent barriers, such as fossil fuel subsidies.

- **Fossil fuel subsidies create an uneven playing field for clean energy technologies.** The main barriers to the development of clean energy technologies include high capital costs, insufficient support schemes and fossil fuel subsidies, which distort the energy markets.
- **Eliminating fossil fuel subsidies would unlock a significant financial resource, which could be redirected to implementing existing cost-effective energy efficiency measures.** True environmental costs and energy market frameworks need to be put in place to maintain the progression of clean energy technologies, ensuring uninterrupted investment and competitiveness improvements.

7.7 EUR/tCO_2
average 2015 carbon price in Europe

72%
increase in the average short-term price between 2013 and 2015

112 USD
billion global renewables subsidies in 2014

23 USD
billion global subsidies for biofuels in 2014

17.6
USD billion
IEA governments energy RD&D budgets in 2014

of which

23% for renewable energy sources

21% for energy efficiency

- **Over the past three decades, the transport sector has not diversified away from its heavy dependence on oil, which accounts for 93% of transport demand, raising energy, environmental and security concerns.** A low oil price does not encourage decisive near-term actions that are required to bring transport emissions onto a trajectory consistent with the 2DS. Demand for mobility is expected to increase, so growth needs to be as efficient as possible.

Enhancing international co-operation is a favourable way to achieve and accelerate innovation, and building on the historic climate agreement in Paris in December 2015, this co-operation can help to decouple economic growth and climate impacts.

- **International co-operation can accelerate the spread of clean energy technologies, through knowledge-sharing and the swift implementation of policy and best practices.** The IEA's Energy Technology Network – 6 000 scientists and experts working together in 39 Technology Collaboration Programmes across more than 50 countries – offers a unique global network of activities related to energy technology and innovation. Public-private partnerships can unlock the investments needed to advance and accelerate innovation and technology development where the policy support exists.
- **Policy attention and investment in research and development of clean energy solutions are essential to facilitate achieving long-term goals.** Sustained support of investments is required so that the technologies will be available when needed. To fully appreciate the contribution of clean energy technologies, analysis needs to be expanded – not only to cover individual technologies but also to track the overall progress and implementation to ensure the overall impact is of the appropriate magnitude and pace to meet 2DS targets and other policy objectives.
- **Globally there needs to be more emphasis on improving data availability and coverage as well as usage of clean energy technology indicators in order to understand the aggregate impact of progress made in the development and deployment of clean energy technologies.** There are multiple ways to do so, and particularly encouraging is the move to track progress of Nationally Determined Contributions by the UNFCCC, which will create demand for more detailed data and quantitative analysis.

GIGATONNES CO_2 CUMULATIVE EMISSIONS REDUCTIONS TO 2025

14	9.1	7.5	25
industry	transport	buildings	power sector

DIRECT EMISSIONS REDUCTIONS IN 2025 RELATIVE TO CURRENT TRAJECTORIES

20%	22%	26%	39%
industry	transport	buildings	power sector

Table 1 Summary of progress

	Status against 2DS targets in 2025	Policy recommendations
Renewable power ↗	With the improving competitiveness of a portfolio of renewable technologies and after the recent policy changes around COP21, the outlook for renewable power is more optimistic. Onshore wind and solar PV are on track to meet their 2DS targets but more effort is needed for other technologies to ensure renewable power is fully on track with 2DS.	▪ Maintain or introduce further policy support and appropriate market design that enhance competition while sending clear and consistent signals to investors, notably long-term arrangements needed to de-risk investment in capital-intensive technologies. ▪ Avoid any policy uncertainties – especially retroactive change – that can create higher risk premiums, undermining the competitiveness of renewables. ▪ Take a holistic approach that maximises the value of a renewables portfolio to the overall system. Countries beginning to deploy variable power plants should implement well-established best practices to avoid integration challenges.
Nuclear power ~	Long-term policy and financial uncertainty remain for nuclear power, but significant increases in both construction starts and grid connections in 2015 helped make progress towards meeting 2DS targets.	▪ Policy support is needed to encourage long-term operation of the existing fleet and construction of new plants, given their vital contribution to GHG emissions reductions, as well as their contribution to energy security. ▪ Incentives such as carbon taxes or electricity market designs providing stable revenues may be required in liberalised markets, which otherwise favour lower-fixed-cost technologies.
Natural gas-fired power ~	The recent fall in coal prices relative to natural gas and falling electricity demand have curtailed growth in capacity and generation, making it difficult to gauge if natural gas-fired power would reach its 2DS potential.	▪ To encourage coal-to-gas switching, electricity market incentives, such as carbon prices and more stringent regulation of plant emissions, are needed. ▪ Electricity market mechanisms are needed that recognise natural gas-fired power's operational flexibility to support the integration of variable renewables.
Coal-fired power ~	Despite a slowdown in coal consumption globally, the projected trajectory of emissions reduction from coal is not on track to meet 2DS projections.	▪ Where coal-fired capacity is expanding, policy measures are required to ensure assessment of the full range of lower-carbon generation options to satisfy new capacity. ▪ Generation from the less-efficient subcritical coal units should be phased out and new coal-fired units should have efficiencies consistent with global best practice – currently supercritical or ultra-supercritical technology.
CCS ↗	Moderate progress in CCS was made in 2015. Significant investment in projects and technology development by industry and governments are needed to get CCS on track to meet the 2025 target of 541 million tonnes of carbon dioxide (CO_2) stored per year.	▪ New projects need to be proposed and supported from development to operation to ensure a growing stream of projects through the development pipeline. ▪ Investment in storage resource development will de-risk projects and shorten the development time. Storage characterisation and assessment are often the longest aspect of project development and outside the skill base of CO_2 capture project developers. ▪ Continued research and development of CO_2 capture technologies are needed, including innovative technologies to reduce the costs and operational penalty of CO_2 capture.

On track?: ● Not on track ● Improvement, but more effort needed ● On track, but sustained deployment and policies required

Recent trends: ↘ Negative developments ~ Limited developments ↗ Positive developments

Table 1 Summary of progress (continued)

	Status against 2DS targets in 2025	Policy recommendations
Industry (~)	Progress in industry continues, but the pace of improvements needs to increase to meet 2DS by 2025, bringing energy use to 12% and CO_2 emissions to 16% below the current trajectory by 2025.	■ Incentivise fuel switching, energy efficiency and deployment of best available technologies (BATs) in all industrial sectors by valuing these developments via international co-ordination and long-term stability on carbon-pricing mechanisms and energy taxation. ■ Encourage efficient use of all resources, and enable integrated, cross-sectoral benefits through sustainable diversification of production. ■ Create frameworks for co-operative, co-ordinated international and public-private efforts to accelerate development of innovative technologies globally.
Aluminium (~)	Though progress has been made in improving energy intensity, continued demand growth will make 2DS increasingly difficult to attain without major technological innovations and renovations.	■ Prioritise recycling and material efficiency through all steps in the product chains. ■ Encourage producers to upgrade to BATs, make continual improvements to optimise equipment operation and phase out outdated equipment, such as Søderberg smelters. ■ Engage all stakeholders to support development of alternative process technologies, such as inert anodes, to reach deeper emissions reductions for the long term.
Transport (~)	Transport emissions have increased at a rate of 1.9% per year over the last decade. To meet 2DS targets, emissions must peak and begin to decline within the coming decade.	■ Policies must raise the costs of owning and operating transport modes with high GHG emissions intensity. ■ Fuel subsidies must be phased out and emissions-based fuel taxes established. ■ Vehicle taxes must also be levied according to vehicles' emissions intensity performance, with monitoring and enforcement to ensure that the purported performance levels are being achieved. ■ Fiscal policies must be supplemented by other national (e.g. emissions and fuel economy standards) and local (e.g. parking and congestion pricing, public transport investment) measures.
Electric vehicles (↗)	Electric cars have the potential to displace internal combustion engine (ICE) cars in the context of sustained RD&D, together with differentiated vehicle taxes and fuel taxes that incorporate social costs of GHG emissions.	■ Continued RD&D support is needed to hasten the milestone year when purchase costs of electric cars with all-electric ranges capable of accommodating most driving needs reach parity with ICE cars. ■ Governments must also prioritise comparative policy analysis and market research focusing on consumer preferences. ■ Differentiated vehicle taxes (such as "feebates") and high fuel taxes align the private and social costs of vehicle ownership, thereby closing the gap between purchase cost parity of electric and ICE cars.
Aviation (~)	While recent annual average fuel efficiency improvements of 3.9% have exceeded aviation industry targets, meeting targeted fuel efficiency improvements beyond 2020 of 2% per year to 2050 will become increasingly challenging.	■ The introduction of CO_2 taxes on aviation fuels and mobilisation of investments for the development of high-speed rail networks would contain activity growth. Carbon taxes will be needed to promote fuel efficiency improvements exceeding International Civil Aviation Organization's targeted 2% annual improvement rate. Achieving the CO_2 emissions reductions targeted by the Air Transport Action Group would most likely require the introduction of biofuel mandates or other market-based incentives.

On track?: ● Not on track ● Improvement, but more effort needed ● On track, but sustained deployment and policies required

Recent trends: ↘ Negative developments ~ Limited developments ↗ Positive developments

Table 1 Summary of progress (continued)

	Status against 2DS targets in 2025	Policy recommendations
Biofuels ↗	Modest growth rates (2% per year) in global conventional biofuels production and the early stage of development in the advanced biofuels sector have resulted in a downward revision of the contribution of biofuels within the 2DS.	■ Ambitious and long-term targets are needed for the transport sector relating to emissions reductions, shares of renewable energy and phasing out fossil fuels. ■ Widespread and strengthened advanced biofuel mandates or alternative policies that stipulate reductions in the carbon intensity of transportation fuels should be considered. ■ Financial de-risking measures may be needed to facilitate advanced biofuel production capacity investment. ■ Biofuels policies are needed that work within suitable governance frameworks to ensure that environmental, social and economic sustainability impacts are avoided.
Buildings ↗	Current investment in buildings energy efficiency is not on track to achieve the 2DS targets. Globally, buildings energy performance (per square metre) needs to improve from a rate of 1.5% per year in the past decade to at least 2.5% per year over the next decade to 2025.	■ All governments need to develop rigorous and enforceable building energy codes and performance criteria for both new and existing buildings. ■ Effective policies and financial incentives are needed to leverage aggressive energy efficiency action in buildings to establish market demand. ■ Near-zero and zero-energy buildings should be promoted across all regions with supporting incentives and energy performance standards for very-high performance building products and equipment.
Building envelopes and equipment ↗	Progress on adoption and enforcement of building energy codes and equipment energy performance standards is promising, but action has to date not kept pace with buildings sector growth. Deep energy renovations of existing buildings are not on track to achieve the recommended 2% to 3% annual building renovation level.	■ Policy makers should continue to develop, adopt, enforce and review building energy codes and standards to improve the energy efficiency of new building construction. ■ Governments need to promote deep energy renovation of existing building stock during normal refurbishment, including deep energy retrofits in public buildings to demonstrate the potential and economic value of these renovations. ■ Labelling and minimum performance standards for building components need to be enforced to accelerate the deployment of energy-efficient technologies, including financial incentives for very-high-performing products to increase adoption of BAT.
Appliances and lighting ↗	The global coverage of energy efficiency standards and labelling programmes has increased (more than 80 countries, covering more than 60 different types of appliances and equipment), but further efforts are needed.	■ Increase coverage and stringency of energy efficiency standards, and increase effectiveness of labelling. ■ Phase out inefficient technologies such as halogen lamps. ■ Increase international and regional alignment where possible. ■ Develop policies and approaches aimed to reduce miscellaneous electric loads.
Solar heating ~	Solar thermal heating has the potential to contribute to decarbonising the heat sector, but if recent trends in challenging economics, inadequate support and non-economic barriers continue, deployment will not progress fast enough to meet the global 2DS target.	■ Government efforts should focus on increasing the economic attractiveness across all solar thermal market segments such as providing adequate and consistent incentives over a predictable period of time and promoting innovative business models aimed at reducing high up-front costs. ■ Successful policies that set targets, mandate obligations and raise public awareness of solar thermal technologies should be replicated to create an enabling environment for solar heat.

On track?: ● Not on track ● Improvement, but more effort needed ● On track, but sustained deployment and policies required

Recent trends: ↘ Negative developments ~ Limited developments ↗ Positive developments

Table 1 Summary of progress (continued)

	Status against 2DS targets in 2025	Policy recommendations
Co-generation and district heating and cooling ~	Shifts away from conventional, inefficient power generation are critical to achieving 2DS targets, and combined heat and power with modern, efficient district heating and cooling (DHC) systems can help reduce primary energy demand and improve overall system efficiency.	▪ Mapping of heating and cooling opportunities across the energy economy can identify potential synergies and technology choices in electricity and heat generation and identify cost-effective opportunities to develop DHC networks in a more efficient, integrated energy system. ▪ Policy measures are needed that facilitate investment in modernising and improving existing DHC networks to make them more energy efficient and maximise opportunities to use low-carbon energy sources as well as industry excess heat recovery. ▪ Policy makers should remove market and policy barriers that prevent co-generation and DHC from competing as efficient and low-carbon solutions, such as high up-front investment costs, inflexible business structures, and lack of long-term visibility on policy and regulatory frameworks.
Smart grids ~	Growth in smart-grid technologies decelerated in 2014, driven by market saturation and uncertainty in some key markets. Smart-grid technologies leveraging information technology solutions compensated for the stagnant growth in physical network assets.	▪ Adapt regulations to capture the value of smart-grid investments in cost and performance targets of network owners and operators. ▪ Encourage widespread adoption of standards and interoperability throughout the smart-grid value chain. ▪ Increase awareness of cybersecurity and data ownership issues to prepare for widespread deployments.
Energy storage ↗	Rapid cost reductions, accelerated deployment pace and specific policy action would justify a green rating. Sustained deployment and policies are required to maintain these trends.	▪ Adapt market and regulatory frameworks to maximise value from storage deployments. ▪ Diversify RD&D of storage technologies beyond lithium ion chemistries. ▪ Promote training and capacity-building programmes for grid integration of storage.

On track?: ● Not on track ● Improvement, but more effort needed ● On track, but sustained deployment and policies required

Recent trends: ↘ Negative developments ~ Limited developments ↗ Positive developments

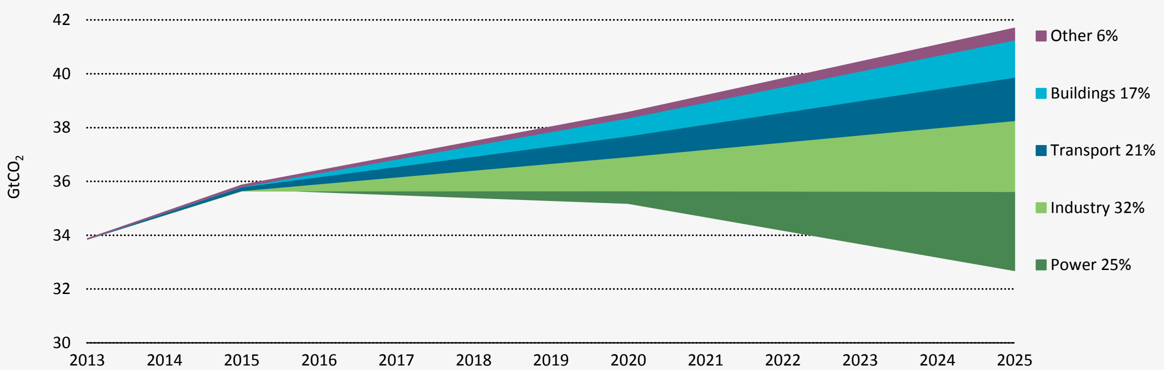
Tracking Progress: How and Against What?

Tracking Clean Energy Progress (TCEP) examines the progress of a variety of clean energy technologies towards interim 2025 2DS targets. Published annually, *TCEP* highlights how the overall deployment picture is evolving. For each technology and sector, *TCEP* identifies key policy and technology measures that energy ministers and their governments can take to scale up deployment, and drive efforts to achieve a more sustainable and secure global energy system.

TCEP uses interim 2025 benchmarks set out in the 2DS, as modelled in *ETP 2016*, to assess whether technologies, energy savings and emissions reduction measures are on track to achieve 2DS objectives by 2050. As in previous *TCEPs*, there is an evaluation of whether a technology or sector is on track, needs improvement or is not on track to meet 2DS targets. Where possible this "traffic light" evaluation is quantitative. There is also a short-term evaluation of progress in the most recent year for which data are available.

The report is divided into 18 technology or sector sections, and uses graphical overviews to summarise the data behind the key findings. The 2DS relies on development and deployment of lower-carbon and energy-efficient technologies across the power generation, industry, transport and buildings sectors (Figure I.1).

Figure I.1 Sector contribution to emissions reduction



Note: $GtCO_2$ = gigatonnes of carbon dioxide.

Key point *Reduction efforts are needed on both the supply and end-use sides; focusing on only one does not deliver the 2DS.*

For each technology or sector, *TCEP* examines under the headings of "recent trends", "tracking progress" and "recommended actions".

Recent trends are assessed with reference to the three *TCEP* measures that are essential to the success of individual technologies: technology penetration, market creation and technology development.

- Technology penetration evaluations include: What is the current rate of technology deployment? What share of the overall energy mix does the technology represent?
- Market creation examines what mechanisms are in place to enable and encourage technology deployment, including government policies and regulations. What is the level of private-sector investment? What efforts are being made to increase public understanding and acceptance of the technology? Are long-term deployment strategies in place?
- Technology developments discuss whether reliability, efficiency and cost are evolving and at what rate? What is the level of public investment in technology research, development and demonstration (RD&D)?

Tracking progress: For each technology or sector, progress towards 2DS objectives is evaluated.

Recommended actions: Policy measures, practical steps and other actions required to overcome barriers to 2DS objectives are identified.

Box I.1 Scenarios in *ETP 2016*

The *ETP* model comprises four interlinked technology-rich models, one for each of four sectors: energy supply, buildings, industry and transport. Depending on the sector, this modelling framework covers 28 to 39 world regions or countries, over the period 2013 to 2050.

Based on the *ETP* modelling framework, the scenarios are constructed using a combination of forecasting to reflect known trends in the near term and "backcasting" to develop plausible pathways to a desired long-term outcome. The *ETP* scenarios should not be considered as predictions, but as analyses of the impacts and trade-offs of different technology and policy choices, thereby providing a quantitative approach to support decision making in the energy sector. The *ETP* scenarios are complementary to those explored in the *World Energy Outlook* (IEA, 2015c).

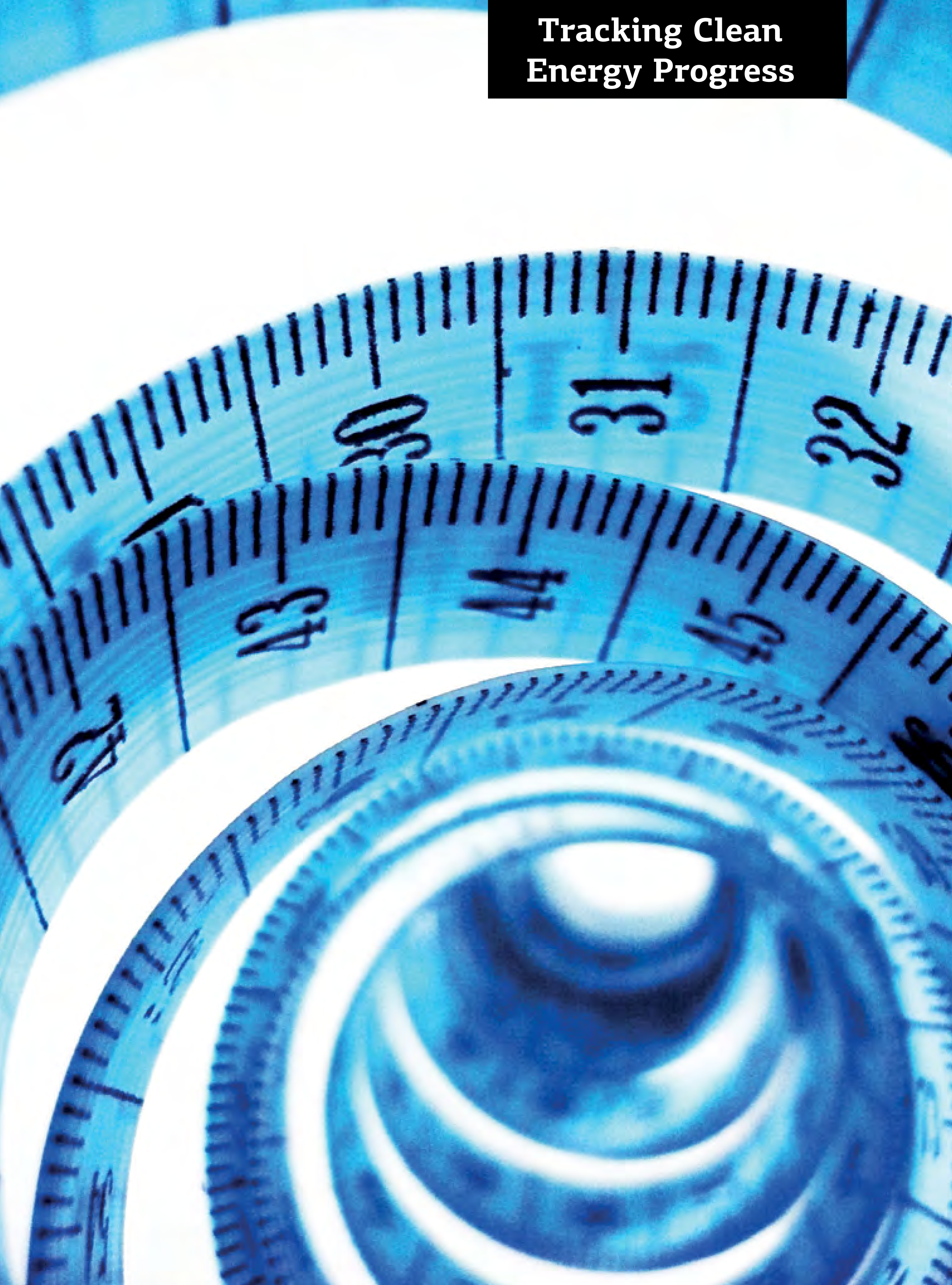
The **6DS** is largely an extension of current trends. Primary energy demand and CO_2 emissions (including process and feedstock emissions in industry) would grow by about 60% from 2013 to 2050, with about 1 700 $GtCO_2$ of cumulative emissions. In the absence of efforts to stabilise the atmospheric concentration of GHGs, the average global temperature rise above pre-industrial levels is projected to reach almost 5.5°C in the long term and almost 4°C by the end of this century.

The **4DS** takes into account recent pledges by countries to limit emissions and improve energy efficiency, which help limit the long-term temperature rise to 4°C. In many respects the 4DS is already an ambitious scenario, requiring significant changes in policy and technologies compared with the 6DS. This long-term target also requires substantial additional cuts in emissions after 2050, yet with average temperature likely to rise by almost 3°C by 2100, it is likely to cause serious climate impacts.

The **2DS** is the main focus of *ETP 2016*. It lays out an energy system deployment pathway and an emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C. The 2DS sets the target of cutting CO_2 emissions by almost 60% by 2050 (compared with 2013), reaching a cumulative emissions level of about 1 000 $GtCO_2$ from 2013 to 2050. Carbon emissions from fuel combustion and industrial processes are projected to continue their decline after 2050 until carbon neutrality is reached. The 2DS identifies changes that help ensure a secure and affordable energy system in the long run, while emphasising that transforming the energy sector is vital but not enough on its own. Substantial effort must also be made to reduce GHG emissions in non-energy sectors.

Notes: Full descriptions of the scenarios and extensive additional global and regional scenario results can be found online at: www.iea.org/etp.

Tracking Clean Energy Progress



Renewable power

Improvement needed
↗ Positive developments

Renewable power capacity grew at its fastest pace in 2015, supported by policies driven by energy security, local pollution concerns and climate benefits. With ambitious pledges put forward for the 21st Conference of the Parties (COP21) and recent policy changes in various countries, the outlook for renewable power is more optimistic than the forecast presented in the International Energy Agency (IEA) *Medium-Term Renewable Energy Market Report* (*MTRMR*) in October 2015 (IEA, 2015a). However, further policy action is needed to tackle both economic and non-economic challenges to deployment and put renewable power on track with the *Energy Technology Perspectives* (*ETP*) 2°C Scenario (2DS) target.

Recent trends

In 2015, global renewable electricity generation rose by an estimated 5% and accounted for around 23% of the overall generation. The People's Republic of China (hereafter "China") remained the largest market, accounting for an estimated 23% of global renewable electricity generation in 2015, followed by the European Union (17%) and the United States (US) (11%).

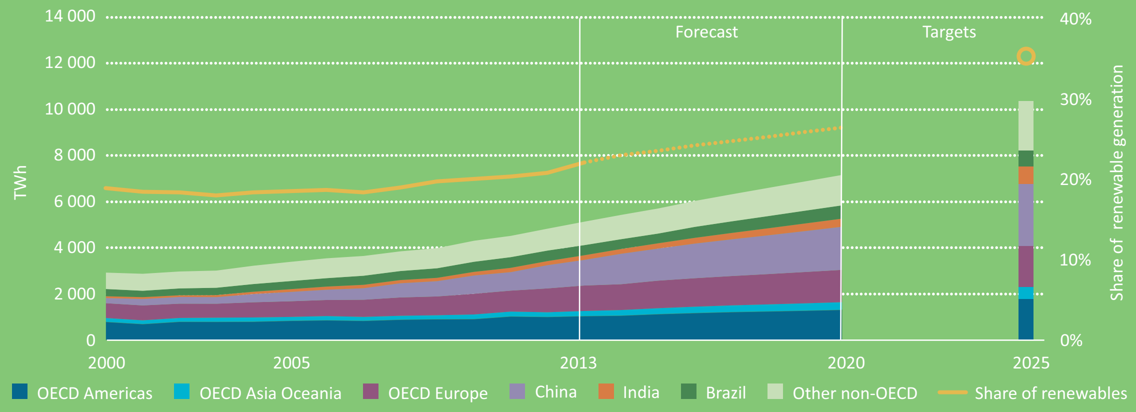
In 2014, net additions to grid-connected renewable capacity grew at their fastest pace, with 130 gigawatts (GW) installed globally. Early estimates show that this growth could be even higher in 2015, marking another record. In 2015, around 40% of new renewable additions came from onshore wind, with the commissioning of an estimated 60 GW of new grid-integrated capacity. China installed more than half of global onshore wind additions (33 GW), as developers rushed to commission their projects by January 2016 so as not to be affected by the feed-in tariff (FIT) reduction. The European Union added around 10 GW, which was slightly lower than 2014 additions, as lower capacity came on line in Germany. The United States added close to 8.5 GW, followed by Brazil (2.7 GW) and India (2.3 GW).

Solar photovoltaic (PV) capacity grew by 45-50 GW in 2015. China (15 GW) and Japan (11 GW) together represented more than half of this growth. New additions in the United States were 15% higher than the previous year, with around 7.3 GW installed. In the European Union, solar PV annual installations increased by around 10% to 7.5 GW. This new capacity was led by the United Kingdom (3.6 GW) Germany (1.3 GW) and France (1 GW). The expansion of solar PV in India picked up and reached 2 GW last year.

Hydropower additions are estimated to decrease for the second consecutive year since 2013, with fewer new capacities installed in China (19 GW including pumped-storage capacity) and Brazil (2 GW). Offshore wind annual deployment marked a new record, with over 3 GW connected to the grid, as a number of delayed projects in Germany became fully operational. Two large solar thermal electricity projects came on line, one in the United States (Crescent Dunes – 110 megawatts [MW]) and one in South Africa (KaXu Solar One – 100 MW). In 2015, the annual new installed capacity for bioenergy for power almost doubled, with major capacity coming on line in China, India and Thailand, while geothermal additions were around 300 MW.

Renewable costs, especially solar PV and onshore wind, have fallen dramatically in recent years. From 2010 to 2015, indicative global average onshore wind generation costs for new plants fell by an estimated 30% on average, while costs for new utility-scale solar PV declined by two-thirds. Over 2015-20, new onshore wind costs are expected to decline by a further 12%, while new utility-scale solar PV will decline by an additional quarter. These cost reductions are in line with the *ETP* 2025 targets. For offshore wind, costs have been increasing over the past few years as the majority of projects are being installed farther from the coasts and in deeper water. However, the results of the recent tender in Denmark and the contract for difference in the United Kingdom for projects that will come on line over 2018-20 have already shown a cost reduction potential

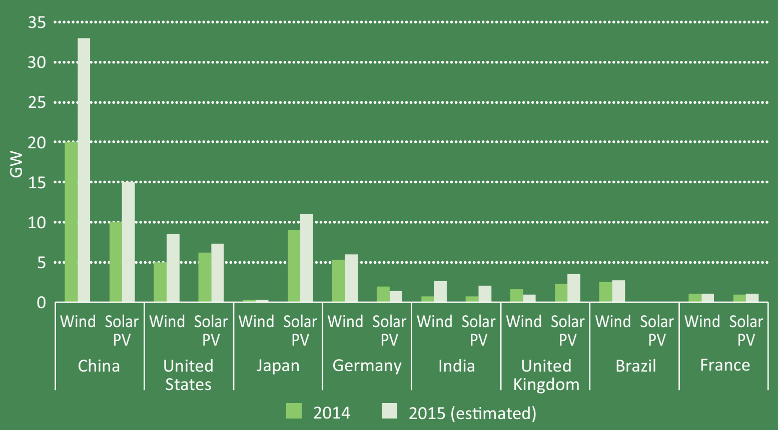
1. Renewable power generation by region



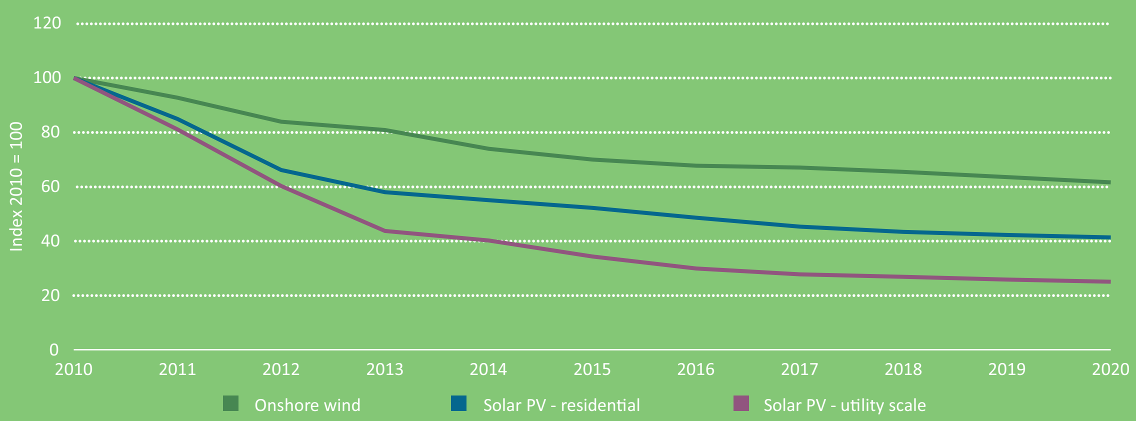
65%

AVERAGE COST DECLINE FOR UTILITY-SCALE SOLAR PV FROM 2010 TO 2015

2. Wind and solar PV additions



3. Indexed levelised cost of electricity



For sources and notes see page 66

up to 20%, compared with similar projects awarded three to five years ago.

The cost-effectiveness of some renewable options has improved because of a combination of sustained technology progress, expansion into newer markets with better resources, and better financing conditions, often supported by market frameworks based on price competition for long-term power purchase agreements (PPAs). Recently announced long-term remuneration contract prices offer evidence of such indicative forecast costs and suggest even lower generation costs are possible in the next few years. New onshore wind can be contracted today in a number of countries at USD 60/MWh-USD 80/MWh, with the best cases closer to USD 50/MWh (e.g. Brazil, Peru, Egypt and some US states). Meanwhile, new utility-scale solar PV projects can be contracted at USD 80/MWh-USD 100/MWh (e.g. France, Germany and Uruguay), with the best cases at around USD 60/MWh (e.g. Chile, Peru, United Arab Emirates, Jordan, South Africa and some US states).

While onshore wind and solar PV have not yet achieved widespread competitiveness versus fossil fuels, these benchmark cost ranges are comparable in some countries and regions with generation costs from gas, even in the current fuel price regime. In countries such as Australia, Brazil, Chile and South Africa, onshore wind can represent a more cost-effective source of new generation than fossil fuels. However, these cost trends do not automatically imply that solar PV and onshore wind are fully competitive. Competitiveness also depends on the value of the generation, where and when it is produced, and the system costs associated with integrating higher shares of variable renewables.

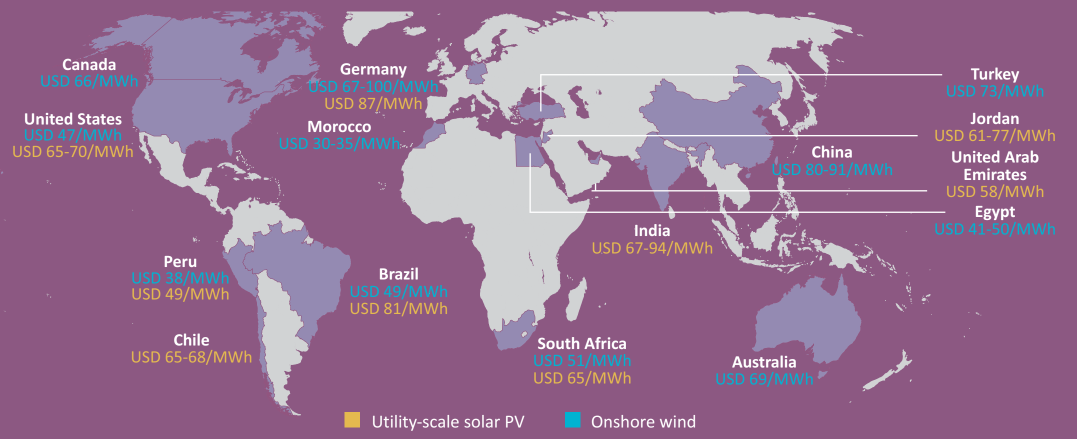
Over the last year, 160 Intended Nationally Determined Contributions (INDCs), representing 188 countries accounting for about 97% of global emissions, were submitted both before and after the COP21 meeting. More than 90 parties outlined renewable energy as a priority area with high mitigation potential, while more than 40 countries highlighted renewable electricity as part of their greenhouse gas (GHG) reduction strategy. Of the Organisation for Economic Co-operation and Development (OECD) countries, Japan, Australia, Chile, Israel, New Zealand and Turkey introduced renewable electricity targets in their INDCs. In non-OECD countries, Brazil announced its intention to increase the share of non-hydro renewables in power generation to 23% by 2030, from around 9% today. India's INDC pledges to increase its solar capacity twenty-five-fold to 100 GW and to more than double wind capacity to 60 GW by 2022. In addition to those highlighted in INDCs, many more countries announced new renewable power targets, both ahead of and after COP21. France's "energy transition law" set a new goal of 40% renewable power by 2030. The United States pledged to increase the share of renewables in electricity generation (excluding hydropower) from 7% to 20% by 2030.

Overall, policy remains vital to achieve these ambitious targets because it has a direct impact on the attractiveness and deployment of renewables. Over the last year, some positive developments have taken place to address renewable policy uncertainties in various countries. In the United States, the production tax credit (PTC) for onshore wind was extended through the end of 2019, but will be progressively reduced from 2017. For other renewable energy technologies (geothermal, municipal waste, landfill gas, and open- and closed-loop biomass), the PTC was only extended through the end of 2017. The investment tax credit (ITC) was extended through to 2022 for utility-scale solar PV, but it will gradually decrease in 2020 from 30% to 26%; to 22% for facilities starting operation in 2021; then dropping to 10% for utility and commercial applications. For residential systems, the ITC will be phased out through 2021 following the same schedule. These extensions are expected to give a longer-term visibility to renewable energy developers, lifting a major policy uncertainty and accelerating deployment.

In September, Mexico released rules for electricity and clean energy certificate markets, which included the schedule of renewable auctions with long-term PPAs that will be awarded in 2016. In France, the enactment of the "energy transition law" is expected to facilitate the deployment of renewable energy projects with strong binding targets, as well as the introduction of new zoning and permitting regulations. In Latin America, recent changes in the auction design in Chile have enabled wind and solar PV to be part of annual energy tenders offering lower prices than fossil fuel alternatives.

Not all policies introduced over the last year were supportive to renewable deployment. For instance, in the United Kingdom, the government decided to cut the FIT for both small-scale solar PV and large onshore wind projects. The Department of Energy and Climate Change (DECC) also confirmed that it will end support for all new solar farms supported through the Renewables Obligation. Having approved a renewable energy law in April 2015, replacing the green certificate scheme with

4. Long-term contract prices for 2016-19 project commissioning



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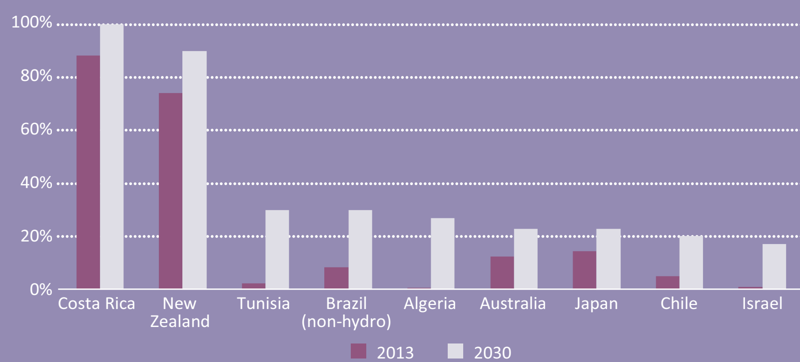
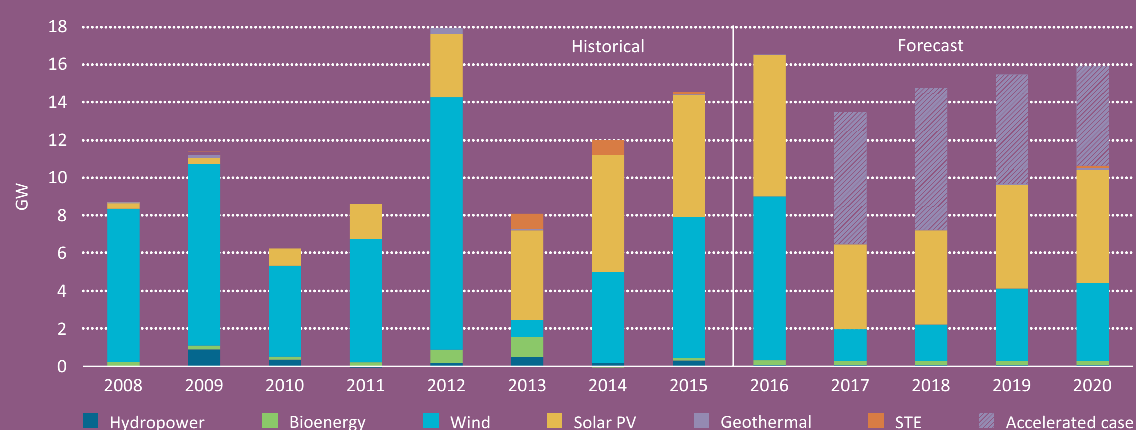
COUNTRIES HIGHLIGHTED RENEWABLE ELECTRICITY AS PART OF THEIR GHG REDUCTION STRATEGY IN THEIR INDCS

5. Renewable power generation goals in selected INDCs



6. Projected impact of US federal tax policy change on capacity additions



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auctions, the Polish government decided in December 2015 to postpone the implementation of the law for six months. In Nevada, the Public Utilities Commission approved a new net metering policy that changed remuneration of excess electricity from the retail to the wholesale rate, for both existing and new projects.

Tracking progress

Renewable electricity generation is expected to grow by over 30% between 2014 and 2020, reaching 7 300 terawatt hours (TWh), and is currently at risk of falling short of the 2DS target of 10 340 TWh by 2025. This result is subject to strong regional differences across technologies and regions.

Solar PV is fully on track to meet its 2DS power generation target by 2025. Its forecast is more optimistic over the medium term, reflecting more optimistic growth prospects and expectations of improving economics. The growth should be robust in OECD countries, with decreasing annual additions in Europe compensated by strong expansion in the United States, Chile, Japan and Mexico. In non-OECD countries, growth of solar PV should continue spreading geographically. Deployment trends in China are strong, owing to improving economics and growing distributed generation opportunities. If these medium-term trends continue, solar PV could even surpass its 2025 target.

Onshore wind, the second-largest renewable technology, is also on track. In OECD countries, the outlook in the United States is more optimistic after the long-term extension of the PTC. However, grid integration and policy uncertainty challenges persist, especially in the European Union and Japan. Doubts over governance of the European Union's 2030 climate change goals and recent policy changes in the United Kingdom and Poland are expected to affect the deployment. In non-OECD countries, onshore wind is expected to grow fast, especially in China, Brazil and India. However, integrating large amounts of new onshore wind power remains a challenge, especially in China and India.

For offshore wind, OECD countries, particularly in Europe, are expected to lead deployment driven by cost reductions and grid connection improvements. With this prospect, OECD countries are on track to meet their 2DS targets. Deployment is still falling behind in non-OECD countries, especially in China, as investment costs remain high and technological challenges persist.

Hydropower needs improvement to reach its 2DS generation target. Over the medium term, new additions of hydropower capacity are expected to fall in OECD countries, mainly due to decreasing resource availability. In non-OECD countries, new additions are expected to be strong, with great potential still available in Asia and Africa. However, environmental concerns and lack of financing pose challenges to large-scale projects. In China, annual growth of hydropower is expected to slow down due to similar challenges.

High investment costs for solar thermal energy (STE) are slowing the pace of deployment. The potential for electricity generation from geothermal energy remains largely untapped. However, pre-development risks remain overall high. For biomass, sustainability challenges and long-term policy uncertainty have been affecting the economics of large projects, particularly in OECD countries. Ocean power is still at the demonstration stage, with only small new projects deployed mostly in Europe and North America.

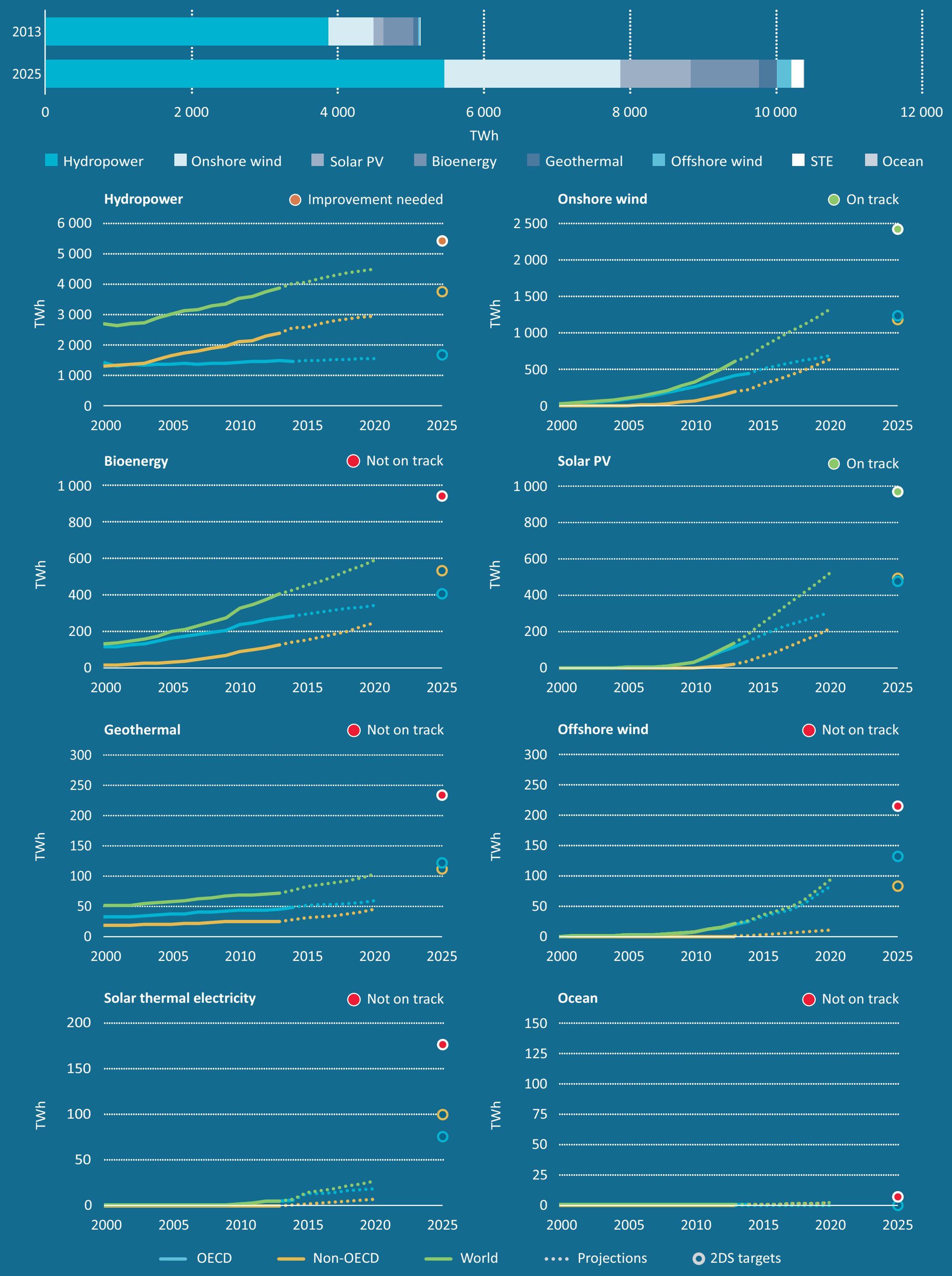
Policy recommendations

The drivers for renewables – energy security, local pollution reduction and decarbonisation – remain robust, supporting record-level deployment in both 2014 and 2015 in the power sector. This growth is underpinned by dramatically falling costs for renewable power in many parts of the world, driven also by policies that have enhanced competition and have provided long-term revenue streams. Countries should learn from factors that have led to lower remuneration levels.

Targets and policies announced before and after the COP21 meeting in Paris are expected to enhance deployment. Achieving the objectives of COP21 will, however, require policy makers to send clear and consistent signals, and maintain policy support and appropriate market design. Any policy uncertainty can create higher risk premiums, which directly undermine the competitiveness of capital-intensive renewables.

Countries beginning to deploy variable renewable power plants should implement well-established best practices to avoid integration challenges. Markets where variable renewable penetration is already high should take advantage of their existing flexibility assets, and consider other flexibility mechanisms to optimise the balancing of their overall energy system.

7. Renewable power generation by technology



For sources and notes see page 66

Nuclear power

Improvement needed

~ Limited developments

Global nuclear generation continued to increase gradually. At the end of 2015, 67 reactors were under construction. Construction starts rose again in 2015 to seven units, up four from 2014, and the number of grid connections doubled from five in 2014 up to ten in 2015.

Recent trends

Perhaps the biggest nuclear news of 2015 was the restart of the first two reactors in Japan under the new regulatory regime set up following the accident at Fukushima Daiichi in 2011. Sendai 1 and 2 restarted, becoming the first two reactors in Japan to receive full safety and local government approval, successfully navigating the new regulatory and approval process. Additional units are preparing to restart in early 2016. China is by far the leader in new plant construction, connecting 14 reactors to the grid in the last three years with an average construction time of 5.5 years. Another 24 units are currently under construction, including three Hualong One reactors – a domestic advanced reactor design that China is looking to market worldwide.

Several policy matters have the potential to impede the deployment of nuclear power. India's 2010 Civil Liability for Nuclear Damage Act, which allows the operator recourse against suppliers under certain circumstances, is still a matter of concern, in spite of the establishment in 2015 of a nuclear insurance pool. Commercial negotiations are ongoing with a number of reactor vendors, but no firm contract has been signed. In July 2015, the French Parliament passed a new "energy transition" bill aimed at reducing carbon emissions across the energy sector. Although the French electricity mix is virtually decarbonised (74% nuclear, 13% hydro, 3.8% wind and solar [IEA, 2015b]), the bill also sets a target of reducing the share of nuclear electricity to 50% by 2025. This generation is to be replaced by renewables (with backup technologies, presumably gas), leading to an increase in carbon dioxide (CO_2) emissions from the power sector.

In the United States and Europe, reactor operators continue to re-evaluate the continued operation of nuclear power plants in deregulated markets, claiming that the importance of large, base-load power from non-emitting sources is not being recognised in the market pricing mechanisms. In the United States, Entergy announced it would shut down the Pilgrim plant in 2019, though it has a licence to operate until 2032, and later announced it would also shut down its FitzPatrick plant in New York. In Sweden, Vattenfall announced the earlier-than-anticipated shutdown of Ringhals 1 in 2020 and Ringhals 2 in 2019, instead of 2025, and E.ON announced the immediate shutdown of Oskarshamn 1 and 2 initially due to shut down between 2018 and 2020. These utilities blame low wholesale electricity prices, the burden of Sweden's tax on nuclear power and the cost of upgrading the plants.

At the same time, Électricité de France's Hinkley Point C plant in the United Kingdom seems to have found a financing option that other countries with liberalised electricity markets may decide to follow; its guaranteed pricing contract for difference (CfD) agreement having withstood legal challenges to date. In 2015, Finland became the first country to licence construction of a permanent repository for high-level waste.

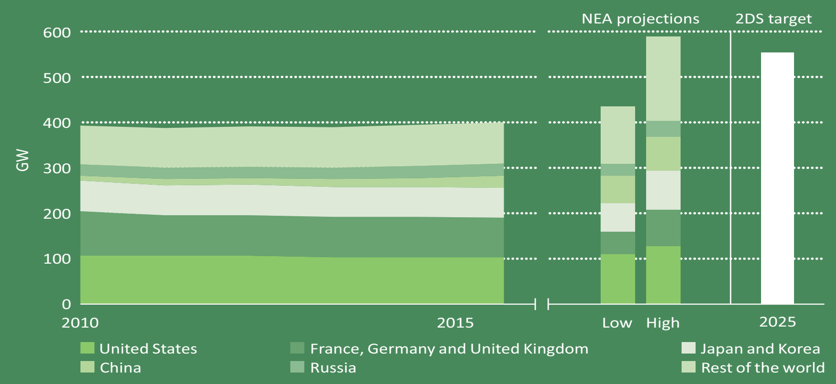
Tracking progress

According to the most recent *Red Book* (NEA and IAEA, 2014), gross installed capacity is projected to reach 438-593 GW by 2025, up from the current 403 GW; in the 2DS, global nuclear capacity would need to reach 553 GW by that time. Several nations, including China, have announced ambitious nuclear power expansion plans as part of their clean energy goals, which will be necessary to meet the 2DS targets.

Recommended actions

The realisation that swift action is needed to reduce GHG emissions and air pollution from fossil-based generation has highlighted again the potential of nuclear power to help meet these challenges. This awareness has yet to be translated into policy support for long-term operation of the existing fleet to prevent early closures of safe, reliable low-carbon base-load power plants, and facilitate construction of new units. Market incentives – in the form of carbon taxes or electricity market arrangements, or both – are needed to favour all low-carbon technologies.

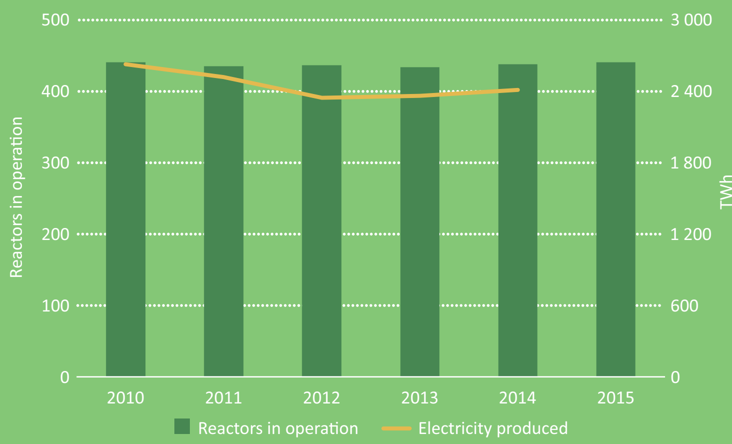
8. Installed gross nuclear capacity



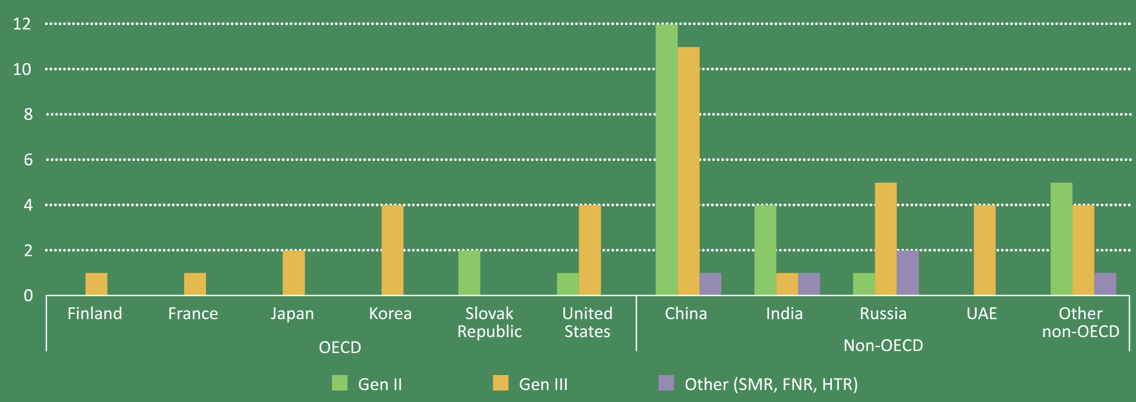
9 GW NEW CAPACITY CONNECTED IN 2015

2 400 TWh ELECTRICITY GENERATION FROM NUCLEAR IN 2014; THE SECOND LARGEST LOW-CARBON SOURCE AFTER HYDROPOWER

9. Operable reactors and electricity production



10. Reactors under construction



For sources and notes see page 66

Natural gas-fired power

Improvement needed

~ Limited developments

Natural gas-fired power generation accounted for 21.7% of total global power generation in 2013 (5 066 TWh), a year-on-year decrease of 0.4%. The recent fall in coal prices relative to natural gas, the rising generation from renewables, as well as falling electricity demand have curtailed the growth in capacity and generation of natural gas-fired power.

Recent trends

Following an increase of 2.2%, global natural gas demand reached around 3 500 billion cubic metres (bcm) in 2013, while demand in 2014 showed a small year-on-year decrease of 0.7%. In 2014, natural gas demand in OECD countries decreased by 2.3% over the previous year, while gas demand for power generation decreased by 1.5%, mainly owing to slow electricity demand growth and a continued and robust deployment of renewables. In contrast, natural gas demand in non-OECD economies increased by 0.8%, albeit less than the 2% or higher increases of recent years. Apart from the fall in coal prices relative to natural gas, policies that favour coal use in many Asian countries have been considered the main cause of falling gas demand. Nonetheless, the main contributor to the rise in gas demand in non-OECD economies was power generation, for which gas consumption increased by 33 bcm (4.1%). For example, Mexico's power sector gas demand rose to 41 bcm in 2013, up 34% on the previous year, and in 2014, natural gas plants made up 47% of Mexico's total power generation capacity.

In 2014, gas production in the OECD rose by 2.2% year-on-year, which was mostly driven by the United States (+5.9%) and Canada (+3.8%). In 2013, Canada added 1.6 GW of gas-fired power generation capacity, the highest among OECD countries, while in the United States, the particularly cold winter of 2014 was believed to have resulted in a gas demand rise of 18.4 bcm. The contribution from the two countries offset a substantial decrease in Europe (-7.5%). In Japan, gas-fired generation replaced roughly two-thirds of lost nuclear output from the Fukushima Daiichi accident, pushing its liquefied natural gas (LNG) imports up by about 29.9% between 2010 (the year before the accident) and 2014.

In China, natural gas prices have twice risen sharply since its gas pricing reform in 2013. As a result of the higher price, gas usage increased by less than 4% in 2014, despite 10 GW of new gas-fired generation capacity being added. However, the drop in oil prices from the last quarter of 2014 brought an opportunity to narrow the price gap between coal and gas, which made gas an increasingly attractive option from an environmental viewpoint. China is, however, scaling back its recent ambitious targets for domestic shale gas production. In 2013, it produced around 3 bcm of coalbed methane, 0.2 bcm of shale gas and around 45 bcm of tight gas.

In non-OECD economies outside China, 2013 saw increased gas demand in the power sector registered in Saudi Arabia (5.6 bcm) and Brazil (5.4 bcm). In India, however, high costs of imported LNG and relatively low electricity prices in 2014 saw the utilisation rate of India's 22 GW of gas generation capacity barely rise above 20%.

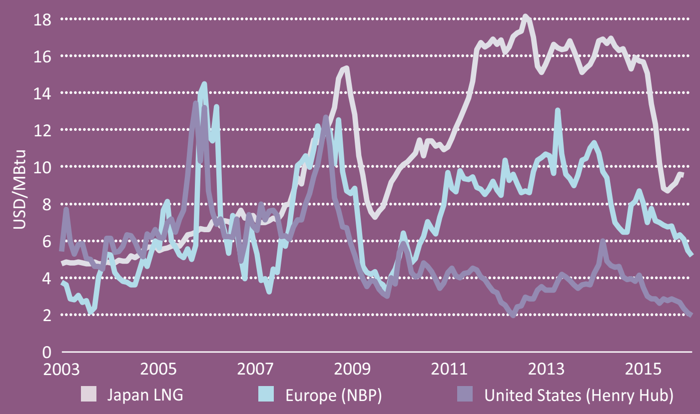
Tracking progress

An important medium-term role for natural gas in the 2DS is to facilitate the transition to low-carbon electricity generation. Given that the current growth rate of natural gas-fired power generation is down 0.4%, with its share in global power generation of 21.7%, natural gas-fired power has not been matching the strong growth in coal-fired generation.

Recommended actions

The competitiveness of natural gas relative to coal in daily electricity system operation is highly dependent on regional market conditions, in particular fuel prices. The introduction of carbon taxes and regulation of plant emissions could encourage coal-to-gas switching, while other electricity market mechanisms are required that recognise the potential benefits offered by natural gas-fired power, e.g. as a lower-carbon alternative to coal-fired generation and its operational flexibility to support the integration of variable renewables.

11. Natural gas spot prices



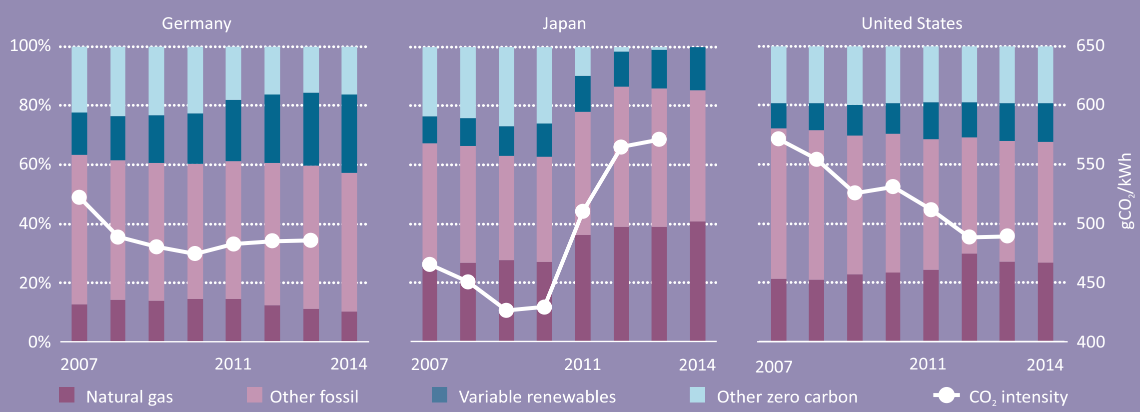
Recent developments

Persistent low gas prices in 2015 led gas generation to almost equal coal in the United States

Divergent trends in coal-to-gas switching are continuing in different regional markets

Sluggish electricity demand and increasing competitiveness of renewables eclipse gas-coal competition

12. Power generation mix and related CO_2 intensity



EU CO_2 PRICE

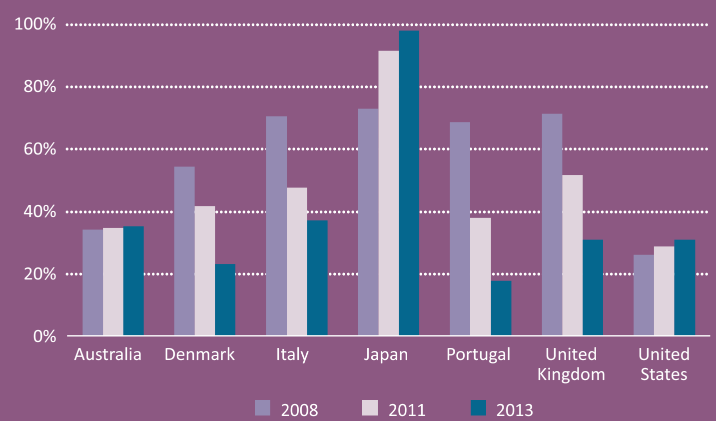
49 EUR/tCO_2

FOR SHORT-TERM COAL-TO-GAS GENERATION SWITCH

20 EUR/tCO_2

LONG-TERM CAPACITY INVESTMENT SWITCH

13. Natural gas-fired power capacity factors



For sources and notes see page 66

Coal-fired power

Not on track

~ Limited developments

In 2013, global gross electricity production increased to 23 322 TWh, 41% of which was generated from coal-fired power plants. While total generation increased by 2.9%, the contribution from coal rose by 5%. In 2014, global coal consumption decreased from 7 991 million tonnes (Mt) to 7 920 Mt, declining for the first time this century.

Recent trends

In OECD countries, coal was responsible for 33% of the electricity generated in 2013, compared with 49% in non-OECD economies. Total coal-fired power generation in OECD countries continued to decline, with an estimated 3 435 TWh in 2014, down 2.1% from 3 508 TWh in 2013. This total was the lowest value for coal-based electricity generation in the OECD in the last decade. The decrease was driven mainly by developments in OECD Europe, where coal-based electricity generation fell by 68 TWh (-7.5%) in 2014 compared with 2013. The largest contributor to this decline was the United Kingdom, with a decrease of 34 TWh, corresponding to a year-on-year drop of 25%.

The United States has encountered a 20% decline in coal's share of power generation since 2000, due largely to weak electricity demand growth, low gas prices and competition from other fuels. Generation from coal rose by 69 TWh in 2013 and 3 TWh in 2014. On the other hand, Japan's coal-fired power generation has followed a stable growing trajectory, with its share increasing from 29.6% in 2012 to 32.4% in 2013, and to 33% in 2014.

In 2014, while China's electricity generation continued to increase, coal's share fell from 74% to 70% – down 203 TWh to 3 908 TWh. This decline marked the first decrease in coal-fired power generation in 40 years, largely as a result of an increase in electricity demand of just 3.8% in 2014, much lower than in the past. Circumstances contributing to this historic event were the combined effects of strong hydropower generation, new hydropower capacity additions, and increased generation from renewables and nuclear energy. China has set new standards for its coal power generation fleet, with programmes to continually improve performance and, importantly, an initiative that requires 28% of coal-fired generation to be combined heat and power (CHP) by 2020.

At the end of 2013, the capacity of coal-fired plants in OECD countries was 537 GW, down more than 82 GW compared with 2012. The United States made the greatest contribution, having retired around 6.8 GW in 2013, with a further 4 GW in 2014. In contrast, Japan increased its coal-fired capacity, adding more than 1.6 GW in 2013. Overall, Chinese coal-fired power capacity in 2013 increased by 35 GW to 792 GW, manifestly lower than the capacity increases in 2011 (+59 GW) and 2012 (+48 GW). In India as well, to meet the rapidly growing electricity demand, the installed capacity of coal-fired power plants rose from 158 GW in 2014 to 173 GW in 2015 (CEA, 2015), almost tripling since 2000.

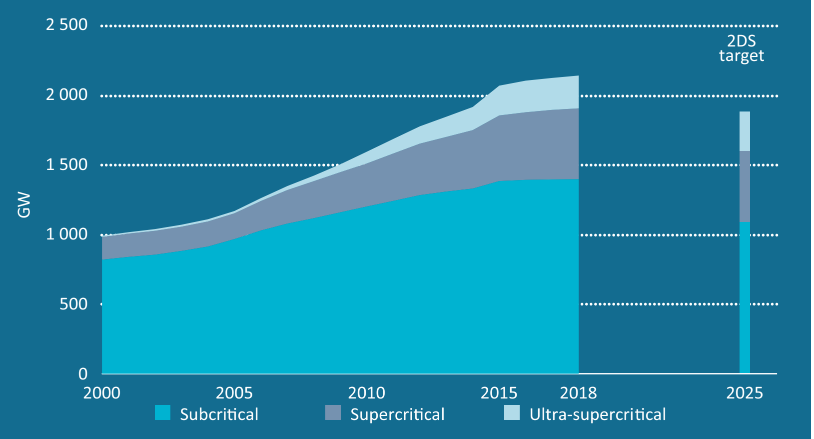
Tracking progress

The growth in global coal-fired generation between 2012 and 2013 was 455 TWh, with a capacity growth of 46 GW over the same period. These numbers suggest a slowdown from the growth rates of recent years. To meet the 2050 2DS targets, however, global emissions of CO_2 must plateau and then fall within the next five to ten years. While China is on target to meet this trajectory, coal-fired generation in India and the emerging economies of South-East Asia is projected to grow rapidly over the next decade or longer implying increases in CO_2 emissions.

Recommended actions

In general, though particularly in the emerging economies where coal-fired capacity is expanding, policy measures are required to ensure that processes are in place to assess the potential to deploy lower-carbon generation options, that generation from the less-efficient subcritical coal units is phased out and that new coal-fired units have efficiencies consistent with global best practice – currently supercritical or ultra-supercritical technologies. Where feasible, new coal-fired units should also be constructed carbon capture and storage (CCS) ready. Then, when policy or economics dictate, CCS should be deployed.

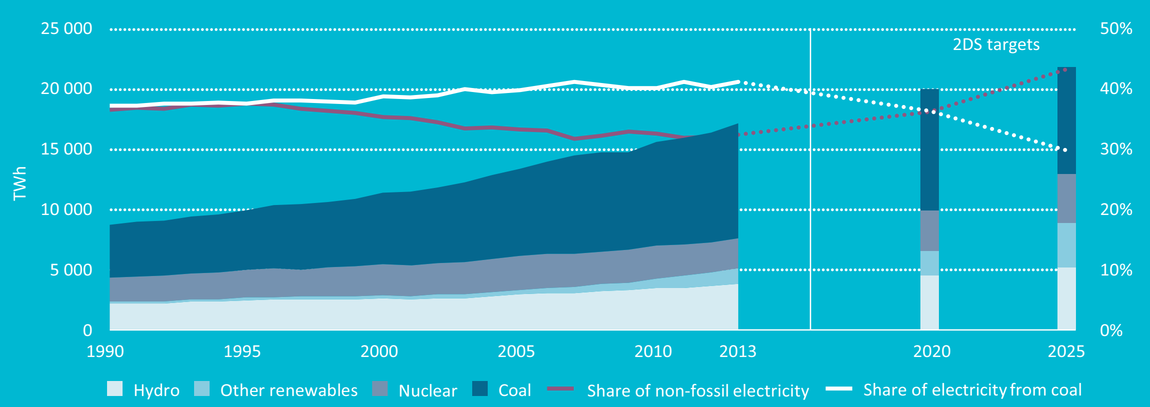
14. Coal capacity deployment



49%

OF ELECTRICITY GENERATED IN NON-OECD ECONOMIES IS FROM COAL-FIRED POWER PLANTS

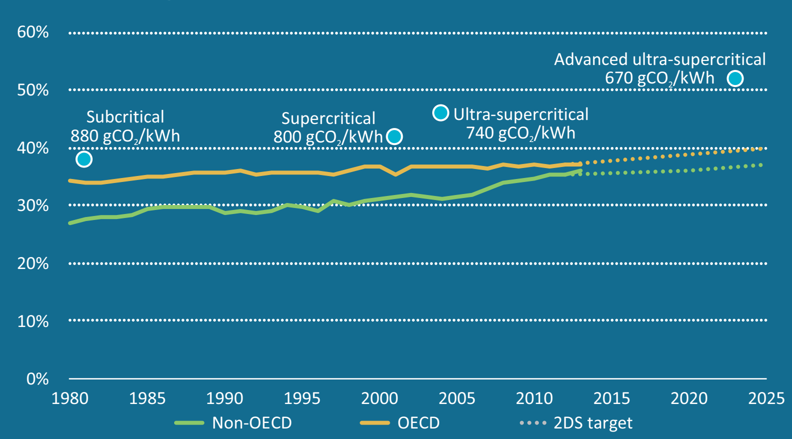
15. Coal and non-fossil power generation



70%

OF CHINA'S ELECTRICITY IS GENERATED FROM COAL

16. Average coal fleet efficiencies



For sources and notes see page 66

Carbon capture and storage

Not on track

Positive developments

In 2015, two new CCS projects began operating, including the Quest project with saline aquifer CO_2 storage; however, no investment decisions were taken on new projects. More investment from industry and support from government are needed to bring projects into the development pipeline to meet 2DS targets in 2025.

Recent trends

In 2015, two new large-scale CO_2 capture projects began operating. The Quest project in Canada's oil sands captures up to 1 million tonnes of CO_2 ($MtCO_2$) per year from hydrogen production at the Scotford Oil Sands Upgrader for storage at a depth of around 2 kilometres in an onshore saline aquifer. The Uthmaniyah project in the Eastern Province of Saudi Arabia will capture around 800 000 tonnes of CO_2 per year from the Hawiyah natural gas liquids recovery plant to be injected for enhanced oil recovery (EOR) at the Ghawar oil field. These two projects bring the total number of operating CO_2 capture projects globally to 15.

No positive investment decisions were taken on CCS projects, nor did any advanced planning begin in 2015, resulting in a fall in the total number of projects in the development pipeline. A constant flow of projects through development to operation is crucial to meeting the targets under the 2DS and for maintaining and growing the global technical capacity in CCS. Currently 17 projects are in development, with 7 under construction and 10 in advanced planning, down from a total of 24 in 2014.

A majority of CCS projects today supply or intend to supply CO_2 for EOR. Of the 32 CO_2 capture projects currently in advanced planning, construction or operation, 21 projects are providing CO_2 for EOR,[1] while 11 are storing or will store CO_2 in saline aquifers or depleted oil and gas fields.

A strong market for CCS does not yet exist in most regions globally. The implicit or explicit value of avoiding emissions in most areas is not yet sufficient to make CCS an attractive mitigation option in the absence of other support mechanisms. As economies look for deeper emissions cuts, CCS will become a more desirable mitigation option. As with other low-carbon technologies, the market for CCS projects in most regions will be created by policy and regulation; however, recently, a number of projects have been cancelled due to changes in policy and reductions in government financial support for CCS. One such notable change was the cancellation of the 1 billion British pound CCS competition in the United Kingdom in November 2015.

In a handful of regions, most notably in North America, the demand for CO_2 for use in EOR is creating a market for CO_2 capture. Over half of the CO_2 capture projects in development or operation globally are in North America, and all but one of these projects provides or intends to provide CO_2 for EOR.

Tracking progress

CCS is not on a trajectory to meet the 2DS target of 540 $MtCO_2$ being stored per year in 2025. At the end of 2015, the 15 large-scale operational projects have a total potential capture rate of 28 $MtCO_2$ per year, but only 7.5 million tonnes of the captured CO_2 is being stored with appropriate monitoring and verification. CCS needs to increase by an order of magnitude in the next decade to be on track to meet the 2DS in 2025.

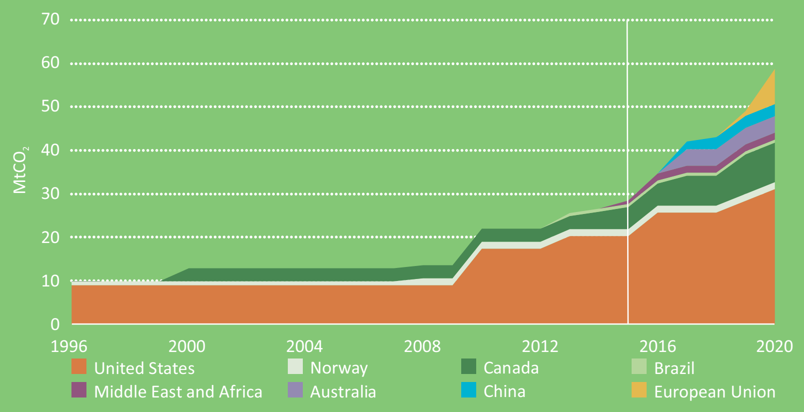
Recommended actions

Financial and policy support for CCS from governments is necessary to encourage projects into the development pipeline. At present, neither the cost of emitting CO_2 nor the level of government support is yet sufficient to make CCS an attractive emissions mitigation option in most contexts. Investment is needed now for CCS to be deployed in the next decade because projects typically take five to ten years from conception to operation.

Investment in storage resource development will de-risk projects and shorten the development time of projects. Storage characterisation and assessment are often the most time-consuming aspects of project development and outside the skill base of CO_2 capture project developers. Accessible developed storage resources will lower the costs and technical barriers for many potential CCS projects, particularly in industrial sectors.

1 CO_2 is retained and eventually stored through injection for EOR; however, additional monitoring and planning are needed to ensure the CO_2 is effectively stored. Refer to Technology overview notes page 66 for more information.

17. Large-scale CO_2 capture potential



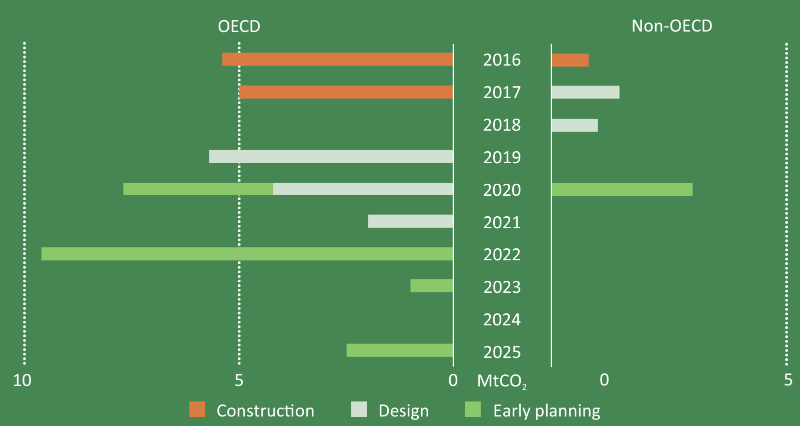
440

THOUSAND TONNES OF CO_2 CAPTURED IN THE FIRST YEAR OF OPERATION AT BOUNDARY DAM

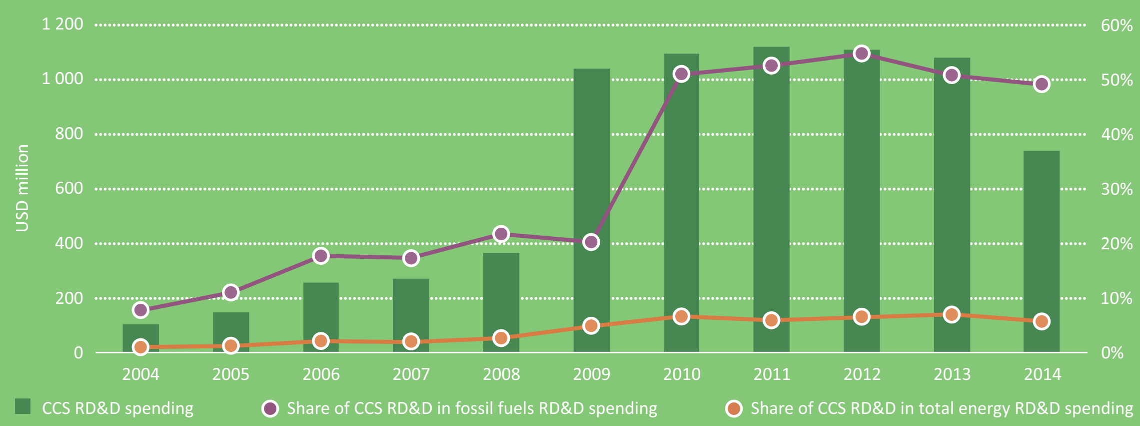
27%

OF CAPTURED CO_2 IS BEING STORED WITH MONITORING AND VERIFICATION TO ENSURE EFFECTIVENESS

18. Pipeline of capture capacity additions



19. IEA public RD&D spending



For sources and notes see page 67

Industry

Improvement needed

~ Limited developments

Industrial energy consumption grew to 152 exajoules (EJ) in 2013, 35% of the global total. Demand growth will put pressure on efforts to meet 2DS targets. Growth in CO_2 emissions must be reduced to 0.7% per year through 2025, while growth in energy demand must be limited to 2.0% annually, and innovative technologies quickly scaled up and deployed.

Recent trends

In 2013, energy consumption in industry[2] grew by 2.3%, with 62% of that growth occurring in China and India, where industrial final energy use jumped by 3.6%. Industrial energy use in OECD countries grew 3.3%, while Africa's growth was moderate at 1.2%, the Middle East declined by 1.9% and Latin America declined by 0.1%. No major changes in sectoral distribution of energy use occurred in 2013, with energy-intensive sectors[3] accounting for 68% of the industry total.

Despite an expected slowdown in demand for industrial products in China in coming years, non-OECD economies, led by India, have potential for strong demand growth. Some regions, such as China and Europe, are addressing overcapacity in key industrial sectors, particularly iron and steel and cement, to improve economic competitiveness, presenting both opportunities to improve efficiency and challenges for implementation of new technologies.

Policy makers throughout the world are increasingly considering cross-sectoral opportunities for energy efficiency and emissions reduction. A pilot programme in China encourages recycling, resource efficiency and life-cycle approaches to reduce the overall impacts of industrial products (SCC, 2013). The Perform Achieve and Trade (PAT) programme in India will be broadened in the second three-year cycle of the programme (Powermin, 2015). Public-private partnerships, such as SPIRE, FPInnovations and European Technology Platforms, incentivise the development of low-carbon industrial technologies and address barriers to adoption (IEA, 2015d).

Tracking progress

Globally, CO_2 emissions must be limited to 9.7 gigatonnes (Gt) of CO_2 in 2025, peaking by 2020, while industrial energy consumption growth must be limited to 2.0% annually, on average, through 2025 in the 2DS. The reduction in CO_2 emissions can be achieved, despite growth in energy consumption, through energy efficiency, best available technologies, switching to lower-carbon fuels, recycling and implementation of innovative process technologies in the long term. CCS will need to be introduced in industry as soon as 2020 and rapidly scaled up to capture 209 $MtCO_2$ by 2025.

Despite modest recent progress on technology demonstration and supportive policy frameworks, CCS in industry remains underdeveloped. In the context of volatile energy prices, energy savings-related investments will face challenges and require policy stability to minimise short-term uncertainty.

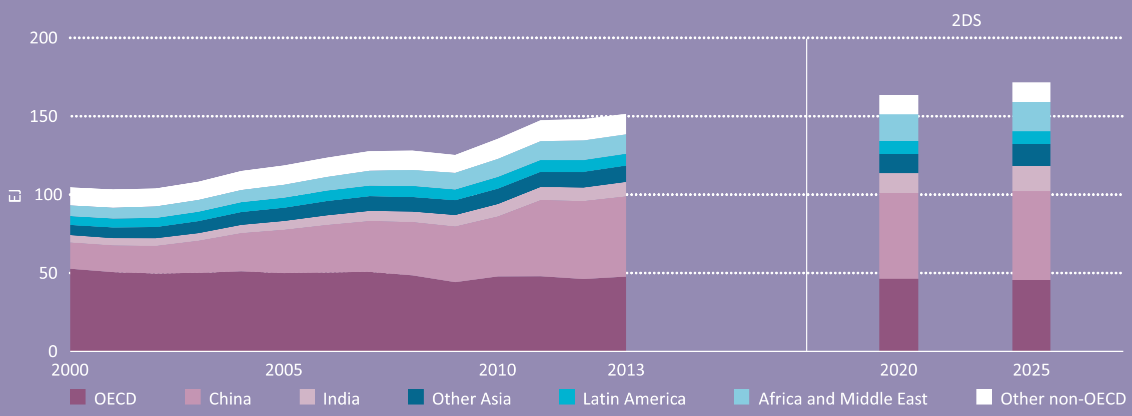
Recommended actions

Policy makers should continue to use traditional policy tools, such as fiscal benefits, energy performance standards for equipment, and promotion of energy management systems to support efficient technologies and practices. The impacts could be boosted by auditing installations and rewarding efficient performance. Improving the technological detail of industrial energy statistics would facilitate their implementation.

Industries should optimise use of locally available energy and material resources, by maximising process integration and efficiency, and by identifying nearby compatible uses for industrial by-products, such as excess heat. Governments should support these efforts through stable, long-term, low-carbon strategies, including tools such as legally binding emissions targets, carbon pricing or the removal of energy subsidies. Improving co-ordination between national and regional policies is also important, for example, by considering findings of heating and cooling mapping exercises in energy infrastructure planning. Public-private partnerships along product value chains should be encouraged as tools to identify and prioritise opportunities for energy and material efficiency. This type of collaboration can also unlock investment in research, development, demonstration and deployment for low-carbon processes that will become increasingly important in the long term.

2-3 Refer to Technology overview notes page 67 for notes associated with this section.

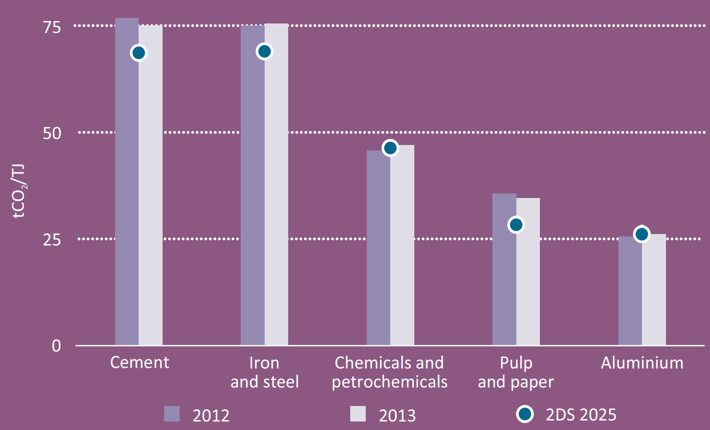
20. Global industrial energy use



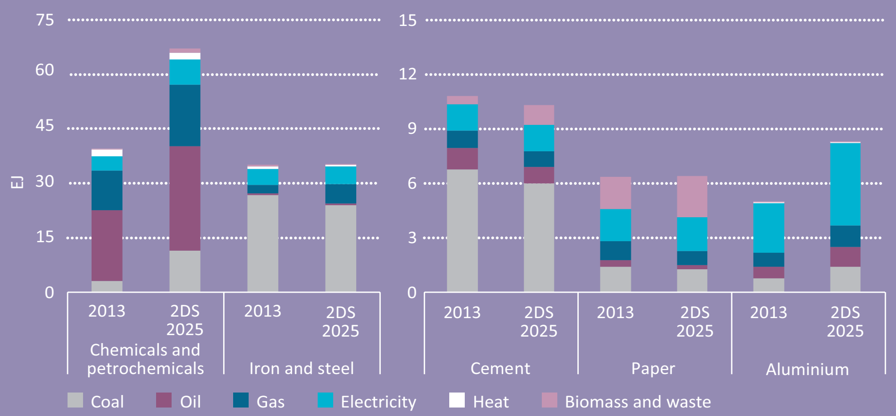
68%

OF INDUSTRIAL FINAL ENERGY IS USED IN FIVE ENERGY-INTENSIVE SUB-SECTORS

21. Direct energy-related CO_2 intensity



22. Industrial energy mix



Key point

CCS in industry will need to be introduced by 2020 and rapidly scaled up

For sources and notes see page 67

Aluminium

Improvement needed

~ Limited developments

Incremental improvements in key processes have cut the energy intensity of primary aluminium production by 5.3% since 2000 (IAI, 2015a), but significant low-carbon technology developments will be needed to counteract continued increases in production. Recycled aluminium offers energy and emissions benefits, but is limited by scrap availability.

Recent trends

Primary aluminium production has grown significantly in the past few decades, by 110% from 24 Mt in 2000 to 51 Mt in 2013 (USGS, 2015, 2004). Secondary aluminium production, which requires up to 95% less final energy than primary production (IAI, 2009) before additional energy for scrap cleaning and alloy dilution is considered, is estimated to have grown by 88% to nearly 23 Mt.[4] Primary aluminium smelting is an electrolytic process, so electricity plays an important role. Fuels and feedstock in anode production and refining of bauxite into alumina are also required, and quality of bauxite influences the energy intensity of alumina refining. In recent years, energy intensities of aluminium smelting and alumina refining have decreased, while maintaining a share of secondary aluminium of over 30%,[5] even as total production increased dramatically. From 2000 to 2013, average primary smelting electricity intensity decreased by 5.3% and energy intensity of alumina refining by 8.7%.[6] At the same time, aluminium production growth contributed to an increase of 31% of energy consumption in the non-ferrous metals sector.[7] The trend towards diversified applications of aluminium in buildings, transport and consumer goods is expected to drive demand growth.

Global smelting energy intensity decreased by 0.5% in 2013. Chinese producers have overtaken most primary smelters to become the world's most efficient, at 13 740 kilowatt hours per tonne of aluminium (kWh/t Al).[8] China has also improved dramatically in alumina refining, with Bayer process intensity levels converging with other Asian and African refiners. However, non-Bayer process refining of low-quality feedstock is common in China, and raises the overall intensity level.[9] Latin America remains the least energy-intensive in alumina refining, at 8.8 GJ/t alumina in 2013. Regional energy intensity of secondary production is more difficult to track, because data are not publicly available. However, the increase in secondary production bodes well for aluminium production energy intensity.

Tracking progress

Growth in final energy use of no more than 3.6% a year on average to 2025 is required to meet the 2DS trajectory, while total aluminium production is expected to grow by 3.9% per year. Even greater reductions in CO_2 emissions are needed in the long term. Inert anode technology, if commercially demonstrated, could address the issue of process CO_2 emissions, which make up 37% of direct emissions in the aluminium sector, but will require significant deployment efforts in the long term.[10]

Co-ordinated efforts to deal with anode effects, non-CO_2 GHGs and outdated technology have reduced the sector's environmental impact. Nonetheless, several barriers remain to further improvement and to reaching the 2DS pathway. This sector's impact is highly correlated with CO_2 intensity of electricity generation. Low-quality bauxite, particularly in China, has given rise to alternatives to the Bayer process, which can be up to three times as energy-intensive (Rock, M. and M. Toman, 2015). The scope for shifting production to secondary routes is limited by scrap collection and availability. Most direct emissions reductions are incremental, as producers move towards point-feed prebake cells, decreased anode-cathode distance and optimised cathode design. Following a 2DS pathway requires more reliance on low-carbon innovative processes in the long term.

Recommended actions

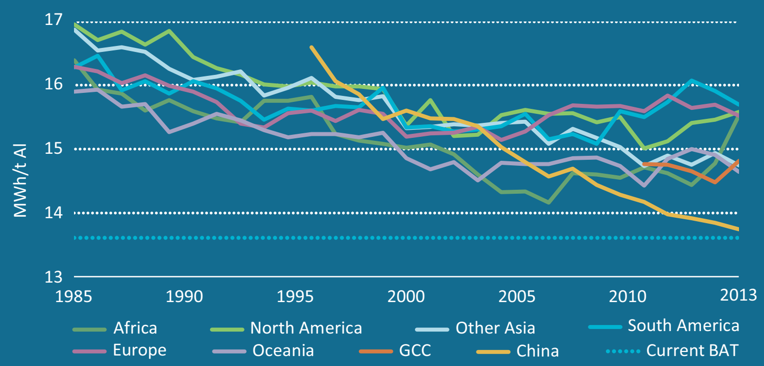
Aluminium sector stakeholders should collaborate with the public sector to develop and demonstrate innovative low-carbon technology options, such as inert anodes. Industry should collaborate with policy makers along the product value chain to push sectoral material and energy efficiency,[11] and consider life-cycle impacts and possible energy demand and carbon emissions reductions in other sectors (e.g. vehicle light-weighting). Major aluminium-producing countries should ensure their capacity is highly efficient, phasing out Søderberg smelters and using a modified Bayer process for refining low-quality bauxite.

4-11 Refer to Technology overview notes page 67 for notes associated with this section.

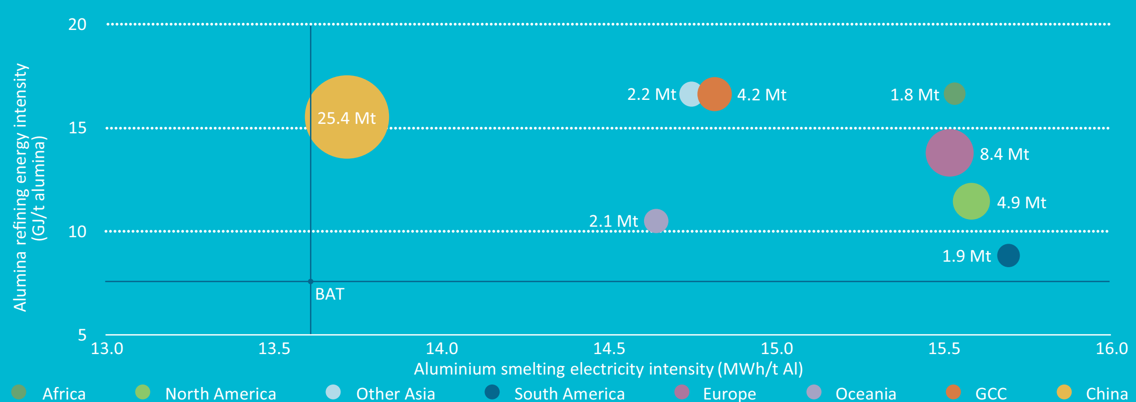
32%

SHARE OF SECONDARY PRODUCTION IN 2025 BUT DEEPER CO_2 CUTS ARE NEEDED[12]

23. Electricity intensity of smelting

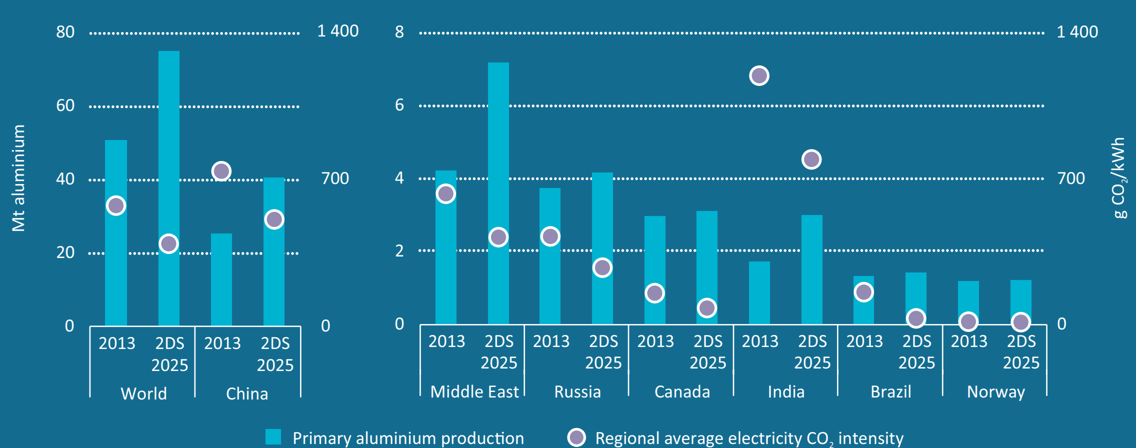


24. Alumina refining and aluminium smelting energy intensities



Bubble size refers to primary aluminium production in millions of tonnes.

25. Primary aluminium production and average electricity CO_2 intensity



For sources and notes see page 68

Transport

Improvement needed
~ Limited developments

Transport sector GHG emissions account for 23% of global energy-related GHG emissions, and have grown at a rate of 1.9% per year over the last decade. Continued dependence on oil means that nearly all growth in transport energy use translates directly into higher GHG emissions. Decisive near-term actions are required to bring transport emissions onto a trajectory consistent with 2DS.

Recent trends

Transport is the least diversified energy demand sector. The portfolio of energy supply sources has not noticeably changed in more than three decades. Prior to the 1973 oil crisis, 94% of transport total final energy consumption (TFC) came from petroleum products. In 2015, more than 93% of TFC was still sourced from petroleum-based fuels. Biofuels and natural gas have made some inroads; biofuels now provide 2.5% of TFC in transport, and natural gas provides 2.8%. In certain markets that provide a strong and consistent portfolio of fiscal and regulatory policies, electric vehicles are beginning to offer a viable alternative to conventional internal combustion engine (ICE) road vehicles.

Most of the growth in transport energy over the past 15 years is attributable to non-OECD economies, accounting for 86% of the global increase in passenger activity, 73% of the growth in freight activity, 91% of the increase in energy use, and 94% of the increase in GHG emissions. Rising standards of living over the coming 15 years across the developing world are likely to spur growing demand for mobility services and freight movement.

Between 2000 and 2015, despite sizeable increases in global activity – passenger activity (in passenger-kilometres) grew by 87%, and freight activity (in tonne-kilometres) grew by 68% – energy use and emissions increased by only about 38% (2.15% per year). The difference between activity growth on the one hand and energy use and emissions on the other is explained by technological and operational improvements in vehicle efficiency and by modal shifts.

Disparate levels of access to modern mobility are reflected by the wide regional discrepancies in transport energy use per capita (which vary across regions by more than an order of magnitude) and in aggregate. Greater energy use is not necessarily coupled with superior mobility, because it can also indicate inefficiencies in providing adequate access to mobility and goods.

Tracking progress

Transport energy demand has increased at an annual rate of just under 2.0% over the last decade. The fact that emissions increased more slowly than they did in the first decade of this century, when they grew at an annual rate of 2.15%, can be attributed primarily to efficiency improvements, above all in the passenger light-duty vehicle (PLDV) fleet, which further shows that transport emissions can be brought under control.

To meet 2DS targets, energy demand must stabilise, and GHG emissions need to peak and begin to decline within the coming decade. Negligible progress has been made in weaning transport off its dependence on oil. Moreover, gains in PLDV efficiency have been undermined to some extent by a growing gap between tested and real-world fuel economy.

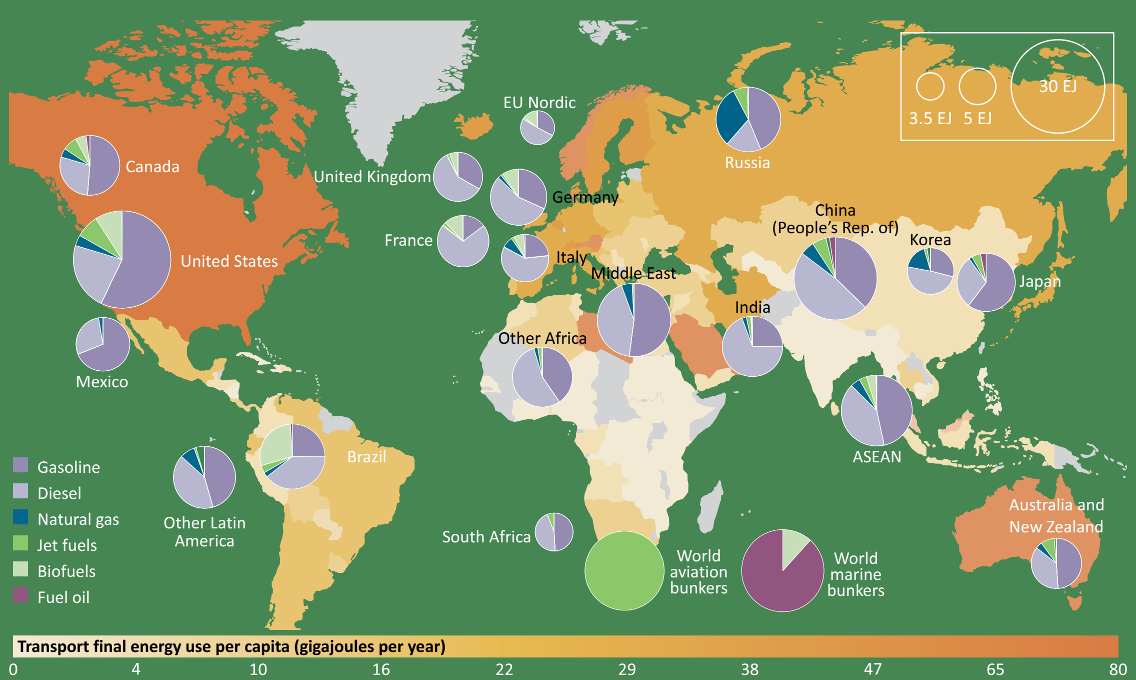
Recommended actions

Transport policies must raise the costs of owning and operating the highest GHG emissions-intensity modes, especially in the current context of low oil prices. Fuel subsidies must be phased out and alternative fuel taxes based on well-to-wheel[13] GHG emissions established in their stead. Vehicle taxes must also be levied. Ideally, these taxes should be tiered according to vehicle energy- or emissions-intensity performance (i.e. as "feebates"). Feebates can be revenue-neutral, but are more effective in curbing transport energy demand if they are applied so as to increase net governmental revenues, which can then go to other transport efficiency investments (e.g. low-carbon fuel research, development and demonstration [RD&D], public transport). Fiscal policies must be supplemented by other national and local measures. Regions that do not currently enforce fuel economy and tailpipe emissions regulations of light-duty vehicles and freight trucks should set up such frameworks.

13 Refer to Technology overview notes page 69 for notes associated with this section.

26. Developments in passenger and freight transport

27. Transport energy use, total and per capita, 2013



For sources and notes see page 69

Electric vehicles

On track

Positive developments

The threshold of 1 million electric cars[14] on the road was crossed in 2015. Annual electric car sales grew by 70% over 2014, catching up to rates needed to meet the 2DS target. Nevertheless, even in a context of rapidly decreasing battery costs, ramping up from 1.15 million electric cars today to 20 million by 2020 remains a very ambitious challenge that will not be met without sustained government support.

Recent trends

With a growing selection of models on the market, 477 000 electric passenger cars were sold in 2015, of which 51% were BEVs. The main markets were China – which became the world's largest electric car market in 2015 – the United States, the Netherlands and Norway. Together, these countries accounted for 70% of electric cars sold worldwide. Electric cars are gaining a foothold in a growing number of national markets; the number of countries with a market share of electric cars greater than 1% has grown from three in 2014 to six in 2015.

The provision of public charging infrastructure continued to accelerate, with the number of alternating current (AC) "slow" chargers growing from 94 000 in 2014 to 148 000 by the end of 2015. Installation of direct current (DC) "fast" chargers grew fastest – 4.5 times in China alone – and with a global network estimated at 57 000 chargers by the end of 2015. The build-out of fast chargers, many of which are publicly accessible, in parallel with steady progress towards extending the driving range of electric vehicles (EVs) may narrow the gap between EVs and conventional ICE performance, fostering broader EV adoption.

Electric 2-wheelers far outnumber electric cars, with more than 200 million units operating in China alone. Electric buses, which can make major contributions to reducing pollution in urban areas, have been widely deployed in China, growing from 29 500 vehicles in 2014 to more than 170 000 in 2015. For other vehicle types (e.g. light commercial vehicles, freight trucks and other specialised operations) data are scarce; sales have yet to take off as they have in electric passenger vehicles. A few initiatives may, however, indicate an emerging niche for electrification. Manufacturer BYD is expanding its focus beyond electric cars and buses to construction vehicles, seaport and airport operations vehicles, and other specialised niche markets (Hanley, S., 2015). La Poste, the national mail carrier in France, has electrified its delivery fleet with 5 000 fully electric Renault Kangoos and plans to double its electric fleet by 2020 (Renault, 2015). In a city such as Paris, where buses and trucks are responsible for more than half of the mono-nitrogen oxide emissions from transport (Airparif, 2012), electrifying urban bus and truck fleets can deliver cost-effective GHG and local pollutant reductions.

Tracking progress

Electric car sales grew by 70% in 2015, a positive development after a slowdown in annual sales growth (53%) in 2014. Remaining on track with the 2DS will require sustained annual average sales growth (from 66% through 2020 to 39% through 2025). This ambitious near-term objective seems achievable with sustained policy and funding support for technology improvements, consumer purchase and use incentives, and infrastructure deployment.

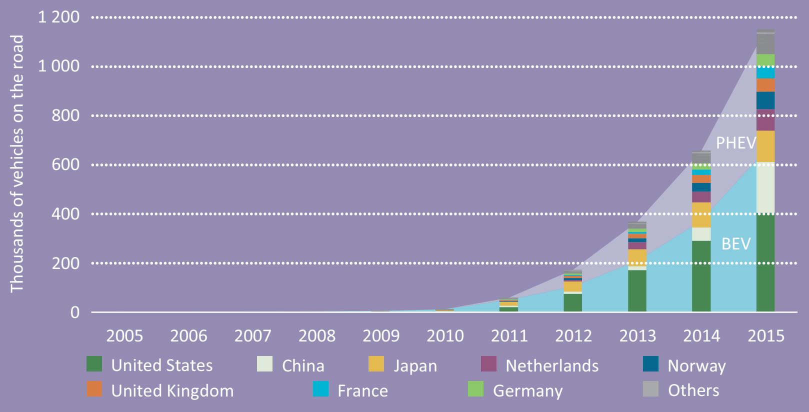
Recommended actions

Continued support for RD&D is needed to hasten the milestone year when purchase costs of cars with all-electric ranges capable of meeting most driving needs reach parity with ICE cars. In addition to funding basic and applied technical research, governments must also prioritise comparative policy analysis and market research focusing on consumer preferences to enable electric cars to bridge the proverbial chasm to the mainstream market.

Public policy can also play a powerful role in aligning private and social costs of vehicles. Differentiated vehicle taxation, based on environmental performance, can be used to bring purchase prices faced by car consumers closer to parity with ICE vehicles, and can be designed to be revenue-neutral (or even as net revenue sources), hence increasing their fiscal durability. The vehicle taxation structure played a key role in the successful EV deployment that is taking place in Norway and the Netherlands.

14 Including plug-in hybrid (PHEVs) and battery electric (BEVs) cars.

28. Global electric car stock



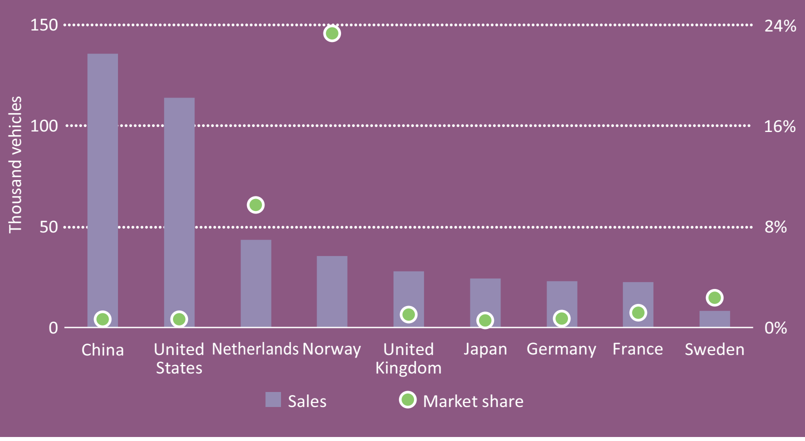
3%

APPROXIMATE SHARE OF EVS IN NORWAY'S PASSENGER CAR STOCK

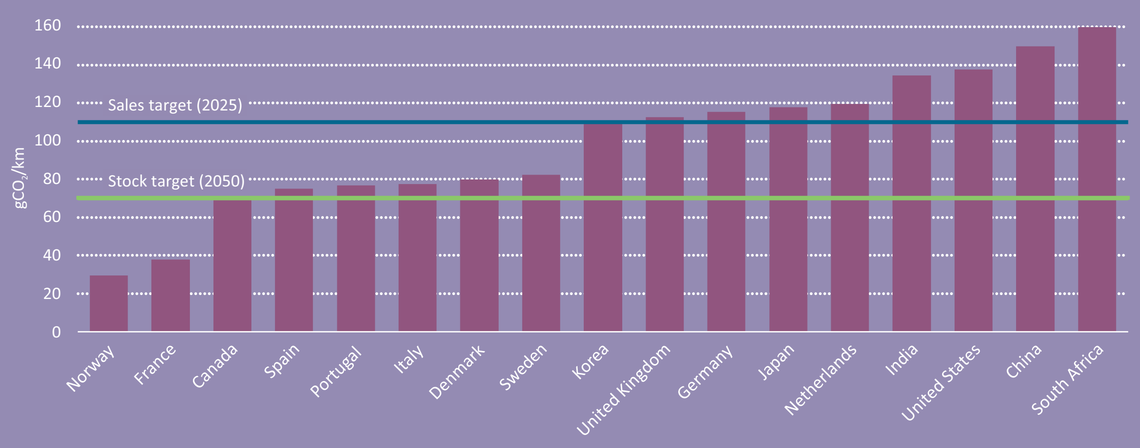
Key point

Decarbonisation of electricity must accompany the push to electrify transport in the 2DS

29. Plug-in electric car sales, 2015



30. Well-to-wheel GHG emissions intensity of new electric cars, 2015



For sources and notes see page 69

Aviation

Improvement needed
~ Limited developments

With a historical annual increase in passenger-kilometres of 5.3% since 2000, aviation is the transport mode projected to grow the most in the coming years, especially in non-OECD economies. In 2013, global aviation energy demand reached 11.1 EJ.[15] Associated CO_2 emissions due to fuel combustion accounted for 2.6% of the global total in the same year.

Recent trends

Aviation is the transport mode that experienced the greatest activity increase in the past decade, having reached total transport activity of 5.8 trillion passenger-kilometers in 2013.[16] OECD countries accounted for 59% of the total revenue passenger-kilometres in 2013 (down from 70% in 2005). Shares of energy demand and CO_2 emissions in both OECD countries and non-OECD economies closely track passenger-kilometre shares.

China, the Association of Southeast Asian Nations (ASEAN), and the Middle East experienced the largest increases in passenger-kilometres since 2000. Growth in the Middle East was augmented by increasing reliance on its large-capacity airports as connection points between the eastern and western hemispheres. China is expected to improve its aviation infrastructure by constructing 100 new airports by 2020 (JADC, 2014) to support growing domestic and international demand.

IEA data on energy consumption and International Civil Aviation Organization (ICAO) passenger-kilometre data show that the historical energy intensity, expressed in energy units per passenger-kilometre, declined by an average 3.9% per year, globally, from 2000 to 2013 (ICAO, 2013; IEA, 2015g). This exceeds the goal set in 2008 by the Air Transport Action Group (ATAG),[17] which committed to improve the fleet fuel efficiency by 1.5% per year through 2020 (UN, 2014). This also exceeds the goal set by ICAO in 2010 (reaffirmed in 2013) to improve fuel efficiency by 2% per year through 2020 (UN, 2014).

The average energy efficiency per passenger-kilometre of new aircraft improved more rapidly in the 1980s and thereafter continued to improve, though at a slower rate, after 1990. This seems to indicate that meeting fuel efficiency goals for 2020 will likely become more difficult over time (Kharina and Rutherford, 2015). Slackening efficiency improvements for new aircraft deliveries call for an increased focus on deploying technology that leads to fuel savings (e.g. lower empty weights per unit of pressurised floor area). Encouraging signs come from the recent work of airplane manufactures on efficient aircraft, such as the upcoming Airbus 320neo and the Boeing 737MAX (Kharina and Rutherford, 2015). Other positive developments include increasing load factors, partially achieved through technical advances accommodating higher seat density (Airbus, 2014) and through air traffic improvements (Boeing, 2014).

Aircraft manufacturers have begun demonstrating the feasibility of using biofuels for aviation and supporting biofuel development activities; one example of this trend is Boeing (2015). Industry initiatives, such as the European Biofuel FlightPath Initiative, aims to produce 2 Mt of aviation fuel from renewable sources per year by 2020.

Tracking progress

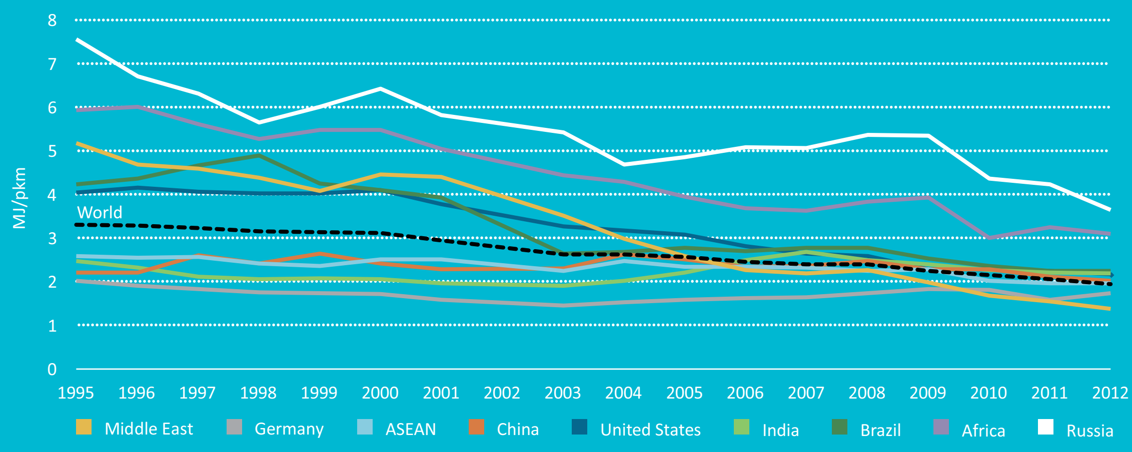
While recent annual average fuel efficiency improvements of 3.9% have exceeded aviation industry targets, meeting the aspirational global fuel efficiency improvement beyond 2020 of 2% per year to 2050 (ICAO, 2013) will become increasingly challenging, suggesting a serious risk of not meeting 2DS targets.

Recommended actions

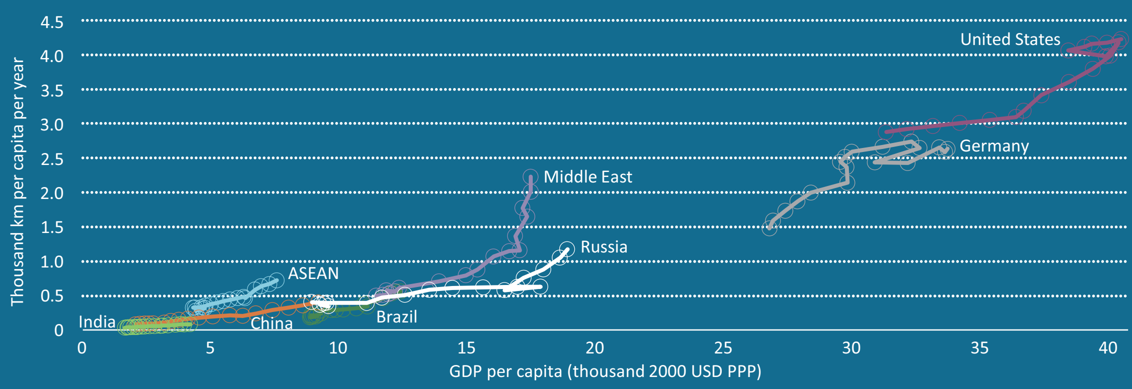
IEA analysis suggests that CO_2 taxes or other market-based policies will be needed to promote fuel efficiency improvements exceeding the 2% annual improvement set by the ICAO goal until 2050. The introduction of CO_2 taxes on aviation fuels and mobilisation of investments for the development of high-speed rail networks would contain activity growth. By incentivising aviation companies to reduce expenditures on fuel, carbon taxes also monetise energy efficiency improvements. Even accounting for significant shifts to high-speed rail and accelerated efficiency improvements, a 55% biofuel share in 2050 is necessary to achieve the carbon-neutral growth and the ATAG CO_2 emissions reduction targets.

15-17 Refer to Technology overview notes page 69 for notes associated with this section.

31. Energy intensity in aviation



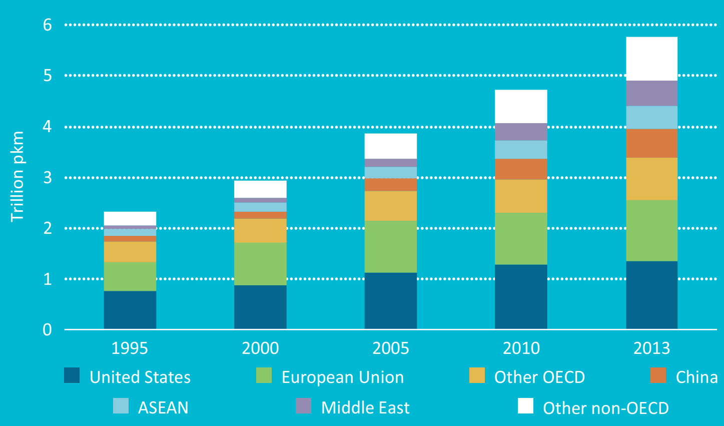
32. Aviation demand and GDP per capita, 1995-2013



50%

IATA target for CO_2 emissions reduction from 2005 levels by 2050. Airlines have responded by investing in biofuels production and signing long-term fuel off-take agreements. IATA also recommends the introduction of a global carbon offset programme.

33. Aviation demand by region



For sources and notes see page 69

Biofuels

Not on track
Positive developments

Despite a low oil price environment, global biofuels production increased to around 134 billion litres (L) (3.2 EJ) in 2015. However, while conventional biofuels are on course to meet 2DS targets for 2025, significantly accelerated commercialisation of advanced biofuels is necessary to fully achieve 2DS requirements for decarbonisation of the transport sector.

Recent trends

In 2015, conventional biofuels provided around 4% of world road transport fuel. Double-digit global production growth observed pre-2010 has slowed to a modest 2%[18] due to a combination of structural challenges and policy uncertainty in key markets. The increasing efficiency of the vehicle fleet in the United States, compounded by a low market penetration of flexible-fuel vehicles and absence of widespread fuel distribution infrastructure for high biofuel blends, has dampened growth. Brazilian ethanol consumption increased strongly in 2015, but the fragile economic state of the sugar cane industry means investment in ethanol production capacity is well below previous levels. Conversely, production is expanding to new areas, with promising new markets developing in the non-OECD Asia and non-OECD Americas regions.

Biofuels mandates, strengthened recently in several key markets, including Brazil and Indonesia, have effectively shielded biofuels demand from a low-oil-price environment that reduced prices for gasoline and diesel. These lower prices provided a window for countries such as India and Indonesia to remove fossil fuel subsidies.

After a prolonged assessment of land-use change sustainability considerations, the European Commission introduced a 7 percentage point (pp) cap on the contribution of conventional biofuels towards the European Union 2020 target of 10% renewable energy in transport. This revision, which also incorporates a 0.5 pp non-binding advanced biofuels sub-target, creates an opportunity for advanced biofuels to provide a larger contribution to meeting the remainder of the target.

A notable scale-up in the advanced biofuels sector has occurred, with seven new commercial-scale advanced biofuel plants using biomass wastes and agricultural residue feedstocks commissioned over 2014-15, bringing the total number of facilities to ten. The ability of these plants to demonstrate the economic and technical feasibility of commercial-scale production will shape future deployment prospects.

Tracking progress

Global production of conventional biofuels is on track to meet 2DS requirements. The visible advanced biofuels project pipeline could deliver production of around 2.8 billion L (0.06 EJ) in 2020 from a current low base. However, this production level would remain 14.7 billion L (0.4 EJ) short of 2020 2DS needs, and leaves a twentyfold scale-up in production volumes necessary between 2020 and 2025 to achieve the required 56.8 billion L (1.5 EJ) contribution of advanced biofuels to the 2DS in 2025.

Recommended actions

Stable and long-term policy frameworks can facilitate expansion of the advanced biofuels sector and enable investment and production cost reduction potential, providing a more favourable investment climate. National transport sector targets for emissions reduction, shares of renewable energy or, as in Sweden, phasing out fossil fuels provide a framework for biofuels markets to prosper. These targets can also include sub-targets for the harder-to-decarbonise road freight, marine and aviation sectors. Alternatively, legislation to stipulate defined reductions in the life-cycle carbon intensity of transportation fuels (e.g. as established in California) should ensure demand for biofuels with the highest emissions reduction potential.

Widespread advanced biofuels mandates will also be essential to accelerating uptake. These mandates can be complemented by the provision of financial de-risking measures to support expansion while initial investment costs remain high, tax incentives and financial mechanisms to support advanced biofuel technological innovation and commercialisation.

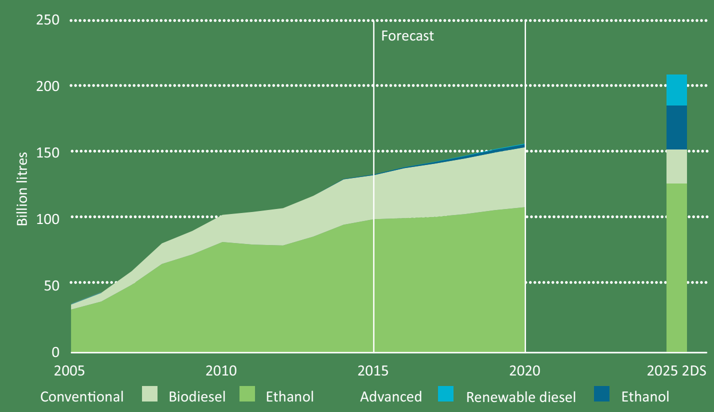
The expansion of the biofuels market must respect environmental, social and economic sustainability considerations via industry benchmarking against recognised sustainability indicators, such as those developed by the Global Bioenergy Partnership, and strong governance frameworks – for example those in place for the European Union sustainability criteria for biofuels.

18 Annual growth rate 2014-15 from IEA analysis. Refer to Technology overview notes page 70 for more information.

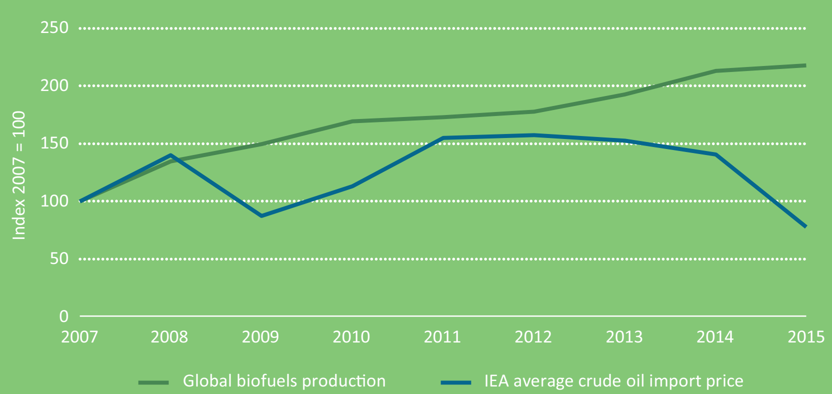
7

COMMERCIAL-SCALE ADVANCED BIOFUEL PLANTS COMMISSIONED IN 2014-15, ADDING OVER 650 MILLION LITRES OF NEW PRODUCTION CAPACITY

34. Global biofuels production



35. Biofuels production and crude oil price



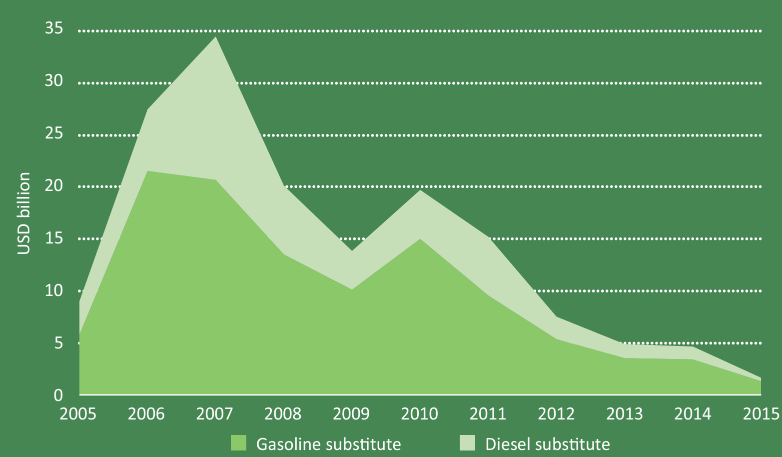
Key point

Mandates ensure biofuel demand during periods of low oil prices, allowing production to reach 4% of road transport fuel in 2015

95%

OF NEW REGISTRATIONS IN BRAZIL IN 2015 WERE FOR FLEXIBLE-FUEL VEHICLES

36. Global biofuels industry investment



For sources and notes see page 70

Buildings

Not on track

↗ Positive developments

Buildings sector energy intensity per square metre has improved in many regions, but not fast enough to offset the doubling of global floor area since 1990. Large energy efficiency potential remains untapped, and assertive action is needed now to speed up intensity improvements by at least 50% and avoid the lock-in of inefficient, long-lived investments to 2050.

Recent trends

The global buildings sector consumed more than 120 EJ in 2013, or over 30% of total final energy consumption. Direct coal consumption in buildings decreased significantly since 1990, while oil use remained flat. At the same time, natural gas use in buildings grew by 40%, meaning that total fossil fuel consumption grew by roughly 8%. Building electricity consumption has more than doubled since 1990, and buildings accounted for half of global electricity demand in 2013. When upstream power generation is taken into account, the buildings sector represents almost one-third of global CO_2 emissions.

A concerted global effort towards energy efficiency in buildings is crucial to offset building energy demand growth while still providing comfort and improved quality of life. The energy efficiency potential in the buildings sector is substantial: globally, the deployment of best available technology and energy efficiency policies could yield annual energy savings in buildings of more than 50 EJ by 2050 – equivalent to the combined energy use of buildings in China, France, Germany, the Russian Federation (hereafter "Russia"), the United Kingdom and the United States in 2012.

Global building energy performance (as measured by final energy consumption per floor area) improved by 1.5% per year over the last two and a half decades as the result of the development and enforcement of building energy codes and energy efficiency policies in many countries. Yet progress has not been fast enough to offset growth in building floor area and ownership of energy-consuming equipment. To date, very few countries have decoupled building energy consumption from population growth, and energy consumption per capita is still growing in most regions (IEA-IPEEC, 2015).

Noteworthy in 2015 was the announcement at COP21 in Paris of a new Global Building Alliance for Buildings and Construction on how to transform the buildings sector in support of a low-carbon economy. The Global Environment Facility, World Resources Institute and United Nations Environment Programme also announced the Buildings Efficiency Accelerator (BEA), with new funding to catalyse increased uptake of energy efficiency in buildings in developing countries.

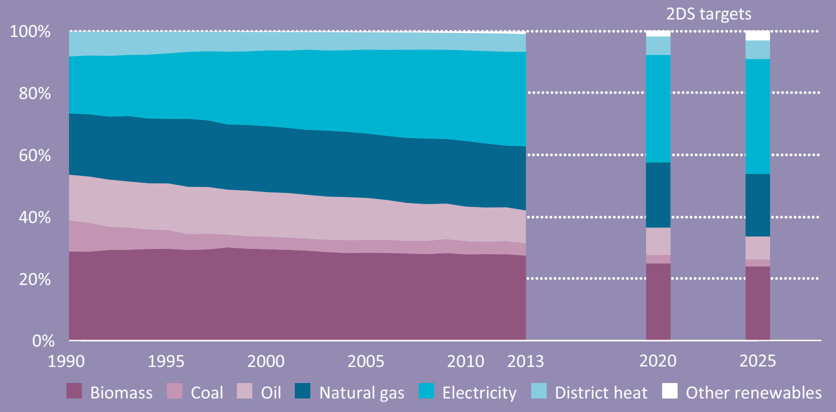
Tracking progress

Current investment in building energy efficiency is not on track to achieve the 2DS targets, or below 2°C as set out by COP21. While an increasing number of countries have implemented or improved energy efficiency policies related to building construction and equipment, progress has not offset increasing demand for thermal comfort and ownership of energy-consuming products. The adoption and implementation of energy efficiency need to be accelerated rapidly, especially in emerging economies, such as China and India, where a window of opportunity still exists to address future building energy demand and prevent the lock-in of inefficient, long-lived building investments. In developed countries, acceleration of deep energy renovations of existing buildings and installation of high-efficiency building products are critical to reaching 2DS targets (or below). Globally, building energy performance needs to improve from a rate of 1.5% per year from the past decade to at least 2.5% per year over the next decade to 2025.

Recommended actions

Governments need to develop and improve building energy codes and performance criteria for both new and existing buildings. Educational programmes, capacity building and improved building energy data resolution should be used to help inform and improve policy design, adoption and enforcement. Effective policies and financial incentives are needed to leverage aggressive energy efficiency action in buildings to establish market demand. These efforts are crucial in the short term because 2DS objectives will be more difficult to achieve if energy efficiency action is not taken in the coming decade given the long life of many building investments.

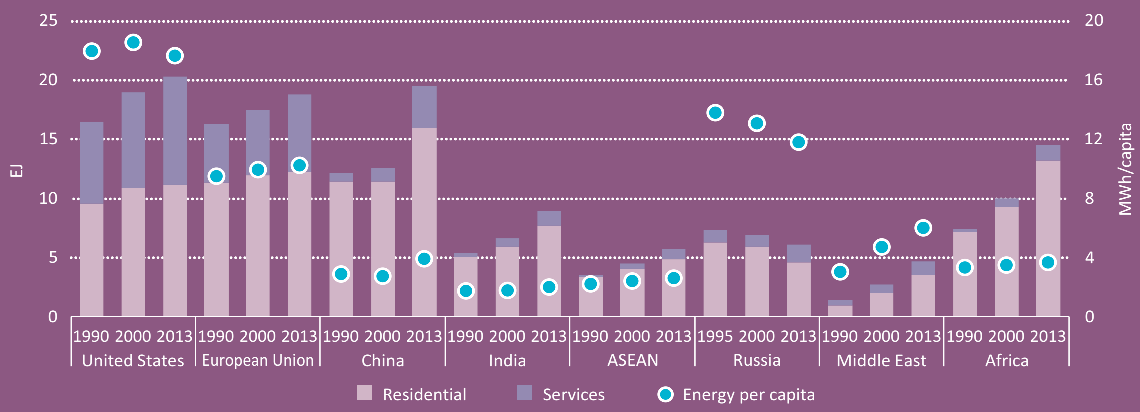
37. Buildings energy use by fuel



5%

DECREASE IN ENERGY PER PERSON IN THE UNITED STATES IN 2000-13 BUT INCREASES IN MOST COUNTRIES

38. Total and per-capita energy use in buildings



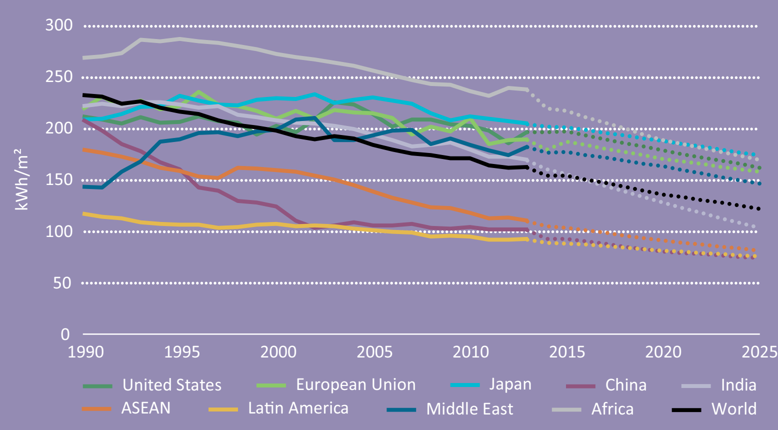
IMPROVEMENT RATE OF BUILDING ENERGY PERFORMANCE NEEDS TO GO FROM

1.5%

PER YEAR TO AT LEAST

2.5%

39. Energy use per square metre



For sources and notes see page 70

Building envelopes and equipment

Not on track

Positive developments

Continued adoption and enforcement of building energy codes and energy-efficient equipment have improved heating and cooling intensities since 1990. Yet investments have not kept pace with buildings sector growth and demand for greater comfort, especially in emerging economies. Deep energy renovations of existing buildings are not happening fast enough to meet 2DS targets.

Recent trends

Heating and cooling needs in buildings, including water heating, account for an estimated 55% of global building energy loads. Space heating continues to be the largest end use, accounting for roughly 35% of global building energy use in 2013, while space cooling is the fastest-growing end use, having increased by more than 4% per year since 1990. Progress has been made on improving the performance of equipment and building envelopes, which have the most influence over heating and cooling needs. However, energy intensity improvements (roughly 2% per year globally) have not been fast enough to offset growth in total building floor area (roughly 3% per year) and demand for greater comfort.

Advancement of deep energy renovations in the world's existing building stock is slow. Globally, improvements are far from the 2% to 3% annual deep energy renovation rates needed to meet 2DS targets. Some notable progress has been made in countries with strong building retrofit incentives, such as Germany and France, where 15 billion to 20 billion United States dollars have been spent in recent years on building energy efficiency, including renovating existing buildings (Robert, A., 2015; KfW, 2015). Typical building energy efficiency improvements in the 10% to 20% range are insufficient, locking in investments below the cost-effective potential.

Progress in new buildings through developing and improving enforceable mandatory building energy codes is slow, especially in rapidly emerging economies where efficiency improvements are not keeping pace with buildings sector growth. Notable progress includes recent state-level adoption of improved building codes in India, with 23 of the 36 Indian states and territories either having adopted or currently in the process of adopting the Energy Conservation Building Code. By contrast, a large number of countries still have voluntary or no building energy codes, while many markets still have weak enforcement infrastructure, limiting the effectiveness of mandatory codes.

Continued adoption of efficient space heating, cooling and water heating equipment is promising, with many countries having enacted mandatory or minimum energy performance standards (MEPS). However, equipment standards and average product efficiencies are still far below best available technology in many markets. A stronger push is needed to ensure the installation of high-efficiency equipment and to minimise the difference between MEPS and best-in-class equipment efficiency.

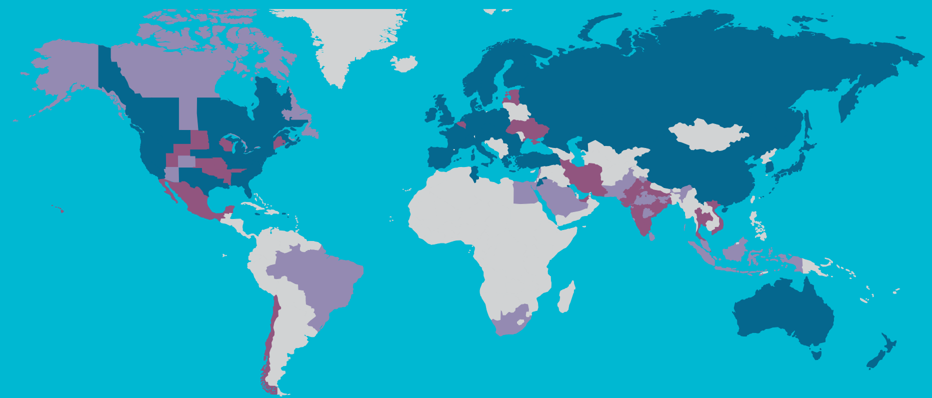
Tracking progress

Despite some progress on deep energy renovations in existing buildings, the current rate is not on track to achieve the recommended 2% to 3% annual building renovation level. Industry- and government-funded research and development (R&D) programmes have continued to enable demonstration and deployment of advanced building envelope and equipment technologies. These efforts have included advancements in super-insulating materials, improved air-sealing technologies and advancing cold-climate heat pump technology. However, the slow process for regional harmonisation and improvement of minimum energy efficiency standards continues to provide a very weak investment signal that could otherwise enable significant energy efficiency gains with minimal incremental costs beyond existing building construction investments.

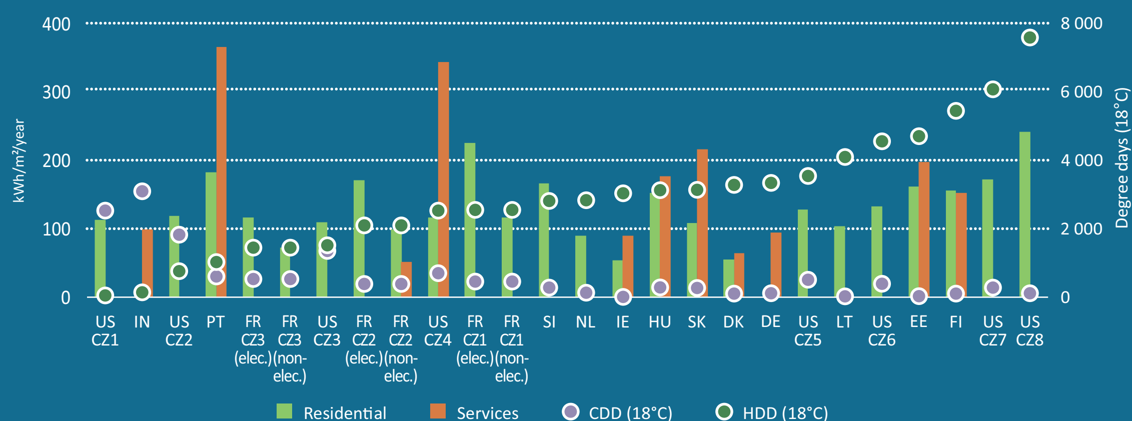
Recommended actions

Governments and industry should continue to fund R&D for energy-efficient technologies, including supporting international research through the IEA Technology Collaboration Programmes. Governments should also improve specifications for energy-efficient equipment and address existing building energy use by increasing funding for deep energy retrofit programmes, and accelerate deep retrofit activity in public buildings to demonstrate the potential and economic value of these retrofits.

40. Buildings energy code coverage



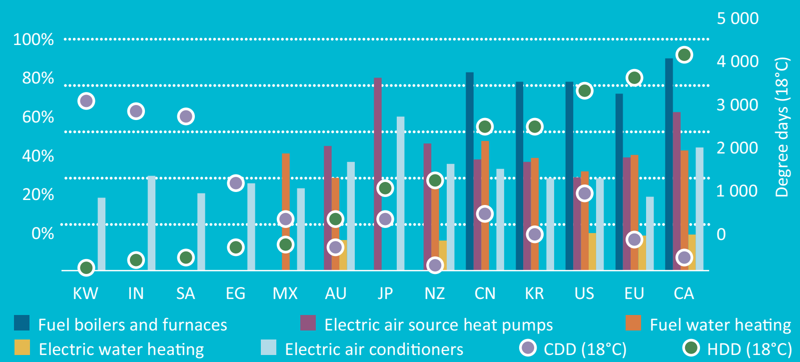
41. Minimum compliance with codes (primary energy)



4%

ANNUAL INCREASE IN SPACE COOLING SINCE 1990 – THE FASTEST GROWING END USE

42. Standards as a share of global best-in-class



For sources and notes see page 71

Appliances and lighting

Improvement needed
Positive developments

Proven achievements in energy efficiency standards and labelling (EESL) programmes should encourage their expansion across more countries and in a broadened range of product categories. Continued effort is needed to ensure that EESL programmes evolve with technology development to secure deployment of high-efficiency lighting, appliances and motors.

Recent trends

Global total final energy consumption for appliances, lighting and other equipment[19] continues to grow, although EESL programmes are helping to curtail energy demand growth. Evidence assembled in 2015 from a wide cross-section of countries with EESL programmes found that energy efficiency improvements in major appliances were around 3% to 4% per annum over a long period, compared with 0.5% to 1% per year for the underlying rate of technology improvement (4E TCP, 2015a). The most mature national EESL programmes are estimated to have saved as much as 25% energy consumption, depending on the country and the product.

Noteworthy in 2015 were requirements for transformers and water heaters that entered into force in the European Union and the United States (effective early 2016). Member states of ASEAN committed to regional harmonisation of lighting standards and policy – a decision expected to result in annual savings of 35 TWh of electricity (UNEP, 2015). The Clean Energy Ministerial Global Lighting Challenge also announced a race to reach global sales of 10 billion high-efficiency, high-quality and affordable lighting products as quickly as possible.

Growth in uptake and use of appliances, lighting and equipment continues to outpace the rate of energy efficiency improvements. This trend is especially true for televisions – whose ownership and average product size (e.g. average screen size) have reduced energy efficiency improvements – and other various plug loads (e.g. small appliances and electronics) that have continued rapid growth, often with no efficiency regulation. Despite policies designed to encourage more efficient appliances and equipment, technology choice has also meant missed opportunities for greater energy savings, as evidenced by the adoption of halogen lamps rather than compact fluorescent lamps (CFLs) or light-emitting diodes (LEDs) in the European Union. In other markets, such as the United States, adoption of LED lighting technology has increased rapidly in recent years.

"Smart" appliances and networked devices continue to grow in market share and have the potential to improve the way we manage energy, but they may also result in increased energy consumption if not managed properly, as shown in recent testing of smart lamps by the IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E TCP). Networked devices consume over 600 TWh globally (IEA, 2014), and this end use is growing rapidly. Policy responses to date have been varied for smart appliances and networked devices. One promising movement is the Connected Devices Alliance, comprising governments and industry formed under a G20 initiative in 2015, which aims to develop international approaches to maximise network-enabled energy savings and minimise the energy consumption from all networks and networked devices.

Tracking progress

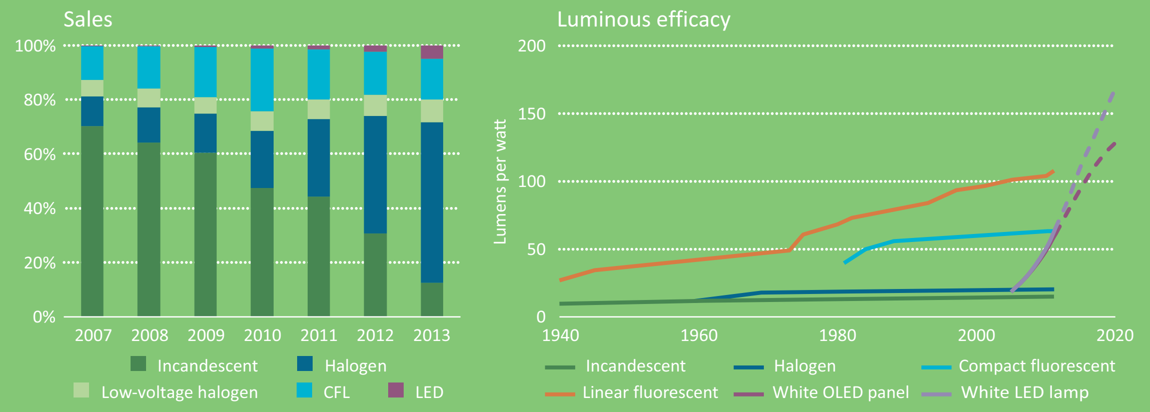
More than 80 countries have adopted some level of EESL for more than 50 types of appliances and equipment (4E TCP, 2015a), and more countries are either implementing or considering EESL programmes. Coverage of appliances and equipment continues to expand, although significant work is needed to address energy efficiency and product labelling for networked devices and other plug loads (e.g. portable electronics and small appliances). Electricity consumption growth needs to be halved, from the current 3% increase per year over the last decade to 1.5% in the 2DS.

Recommended actions

EESL programmes need regular review to ensure that efficiency requirements keep up with changes in technology and remain in line with policy objectives. Countries should focus on progressively increasing the stringency of EESL standards to promote continued uptake of high-efficiency technologies. This need for increased stringency includes monitoring of compliance and enforcement and expansion of existing EESL programmes to cover a broader range of products.

19 Other equipment includes pumps, motors, office equipment and other buildings-related electrical devices.

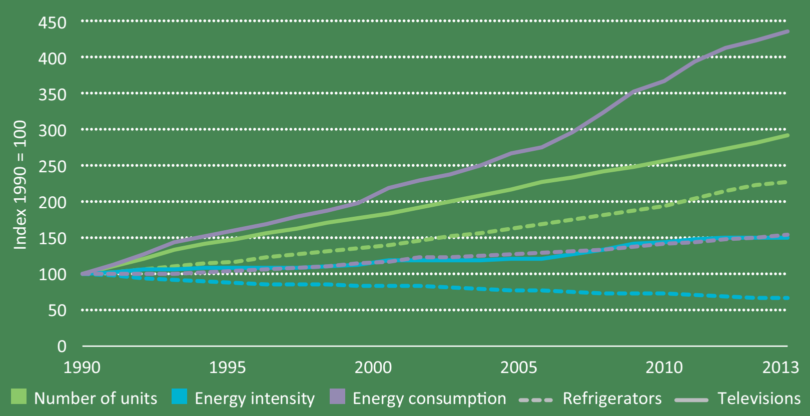
43. EU residential lighting sales and typical efficiencies



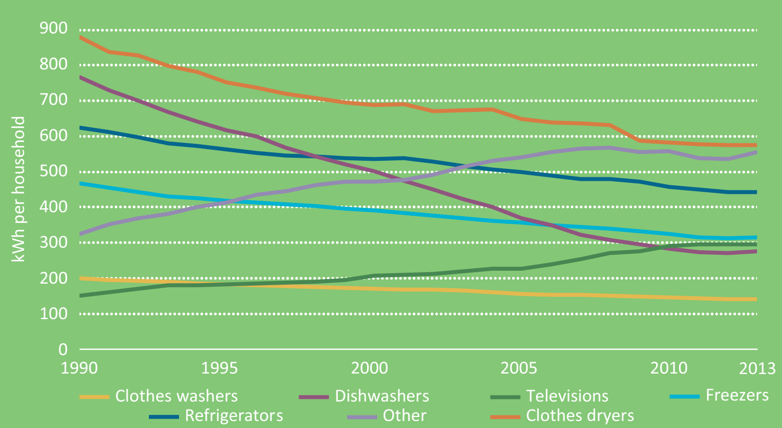
600

TWh ENERGY CONSUMPTION OF NETWORKED DEVICES WORLDWIDE IN 2013

44. World refrigerator and television energy use



45. World household appliance intensities



2DS REQUIRES ANNUAL GROWTH RATE OF ELECTRICITY FOR APPLIANCES AND EQUIPMENT TO

HALVE

FROM 3% TO 1.5%

For sources and notes see page 71

Solar heating

Not on track

~ Limited developments

Solar heat grew by an estimated 7% in 2014, but it still met less than 1% of global heat demand and needs to triple in absolute terms by 2025 to meet 2DS goals. Recent growth, however, has been significantly slower, and if challenging economics and inadequate support continue, solar heating will not be on track.

Recent trends

Despite an estimated 10% (35 gigawatt thermal [GW_{th}]) increase in cumulative capacity, annual deployment declined in 2014, almost by 20% compared to 2013, mostly due to slower economic growth and lower fossil fuel prices in major markets.[20] Global installed capacity reached an estimated 400 GW_{th} in 2014, although uncertainty exists over the exact figure due to data quality issues. Monitoring solar heat deployment is a challenge in many countries, because the small and fragmented nature of distributed technologies makes them difficult to track.

Annual deployment in China, the world's largest market, is estimated to have declined in 2014 for the first time in recent years due to a slowing economy and a weakening construction industry. With over 90% of the cumulative capacity in the residential sector, deployment has been slowing, and sustained solar heating growth in China will require faster uptake of larger systems for commercial and industrial applications.

Europe remained the second-largest solar thermal market in terms of cumulative capacity, but annual growth has also slowed recently as a result of the economic slowdown and inadequate policy support amid lower fossil fuel prices. To stimulate deployment, the French government reinvigorated its tax relief scheme in late 2014, and Germany reintroduced subsidies in April 2015. By contrast, growth continued in Turkey as it became the second-largest annual market in 2014, due to favourable resources and attractive economics for hot water systems. Elsewhere, other positive developments were seen in South America, the Middle East and southern Africa, where load shedding has driven the switch from electricity to solar thermal for water heating.

Over 95% of solar thermal heat is produced in the buildings sector, mostly from domestic hot water systems in single-family homes. By contrast, deployment for industrial process heat has been limited and concentrated mostly in lower-temperature applications. However, the increase in average system size by over 70% since 2007 reflects a growing market trend towards larger systems, where more favourable economics may be possible with higher and more constant heat demand. Chile commissioned the world's largest solar process heat plant (27 megawatts thermal [MW_{th}]) for copper mining in 2013, and Oman has announced plans to construct a 1 GW_{th} plant to produce steam for enhanced oil recovery operations. Solar thermal heat plays a marginal role in global district heat networks (less than 0.1%), except in Denmark where the largest solar thermal district heating plant (50 MW_{th}) was completed in 2015, and an even larger one (100 MW_{th}) is currently under construction.

Tracking progress

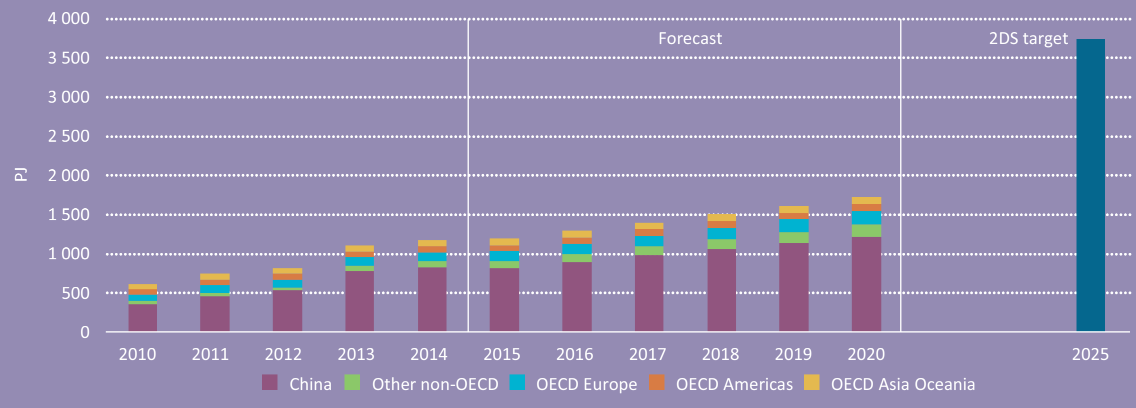
Despite robust growth over the last decade, solar thermal heat produced less than 1% of global heat demand in 2014 (around 1.2 EJ) and would have to more than triple in absolute terms by 2025 to meet the 2DS target. Achieving that goal, however, would require an annual deployment rate twice as fast as expected over the medium term, where annual additions are seen levelling off around 40 GW_{th} due to continued policy uncertainty and challenging economics. Without stronger and more widespread policy support, particularly for larger market segments, deployment trends will remain unchanged, and the 2DS 2025 target will not be reached.

Recommended actions

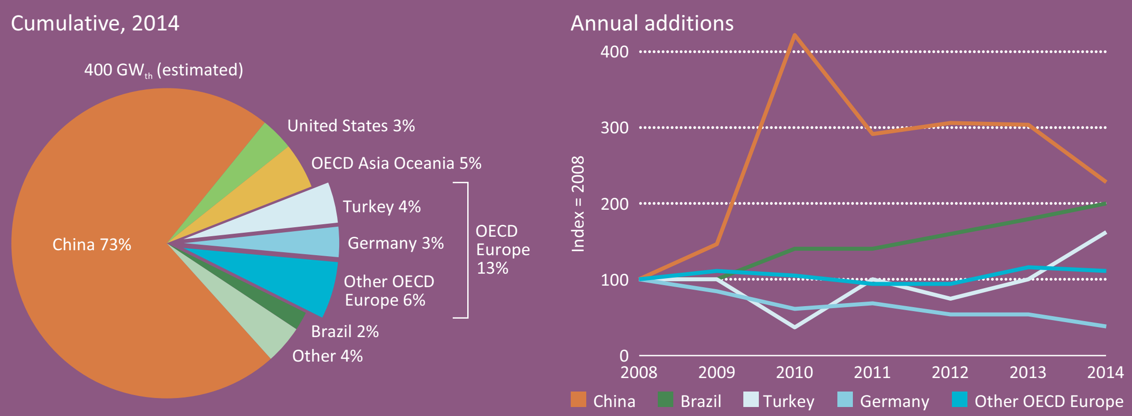
Governments should aim to create a stable, long-term policy framework for solar heating (including target setting and obligations), preferably in the context of an overarching strategy for renewable heat. Increased policy support is needed to scale-up investment across all solar heating market segments, particularly through mechanisms that increase their economic attractiveness against conventional heating technologies. Policy makers should ensure that financial incentives are adequate and consistent over a predictable period of time as well as promote innovative business models aimed at reducing high upfront costs.

20 Refer to Technology overview notes page 71 for notes associated with this section.

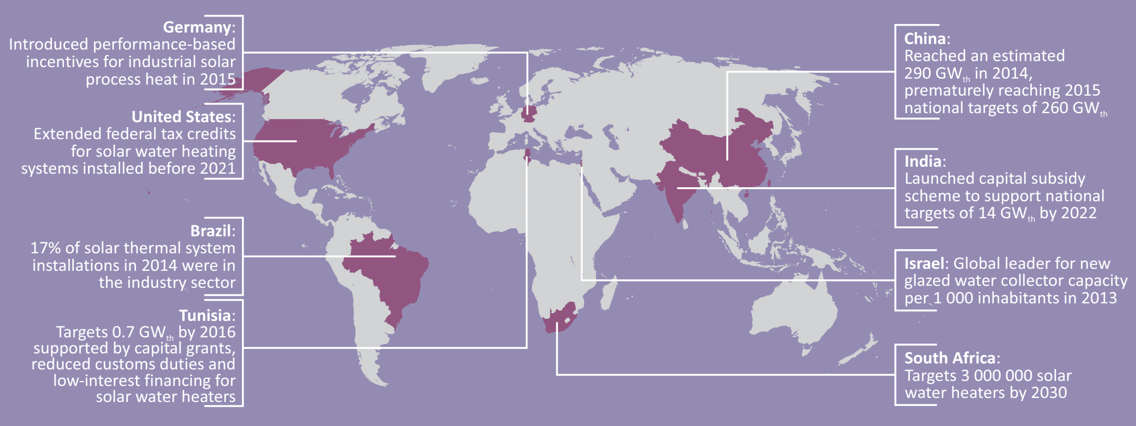
46. Solar thermal heat by region



47. Solar thermal capacity



48. Recent solar heating developments



For sources and notes see page 71

Co-generation and DHC

Improvement needed

~ Limited developments

Electricity generation using co-generation[21] technologies is stalled at less than 10%, despite increases in absolute terms. Efficient and integrated district heating and cooling (DHC) systems are promising, but significant progress is needed to capture this potential beyond select examples.

Recent trends

Global electricity and heat production[22] using co-generation technologies have increased on average by 1.2% per year since 2000, but not as fast as total electricity and commercial heat generation, which have grown at roughly 1.6% per year. Co-generation in global electricity production, therefore, decreased from 11% in 2000 to 9% in 2013, despite having a global average efficiency of 59% in 2013, compared with 37% for conventional thermal power generation.

District heat sales have grown steadily by roughly 1.2% per year since 2000, although district heat as a portion of buildings sector heat demand has remained relatively steady, increasing by only 0.3% per year since 2000. China is the world's largest network, and more than 90% of residents in north urban China are connected to district heat (IEA-TU, 2015). Performance of district heat varies by region, but globally the CO_2 intensity of district heat has improved only slightly since 2000. Coal and natural gas remain the dominant fuel choice for district heat production, although some countries have drastically reduced fossil fuel shares in district heat since 2000.

Globally district cooling networks continue to grow, with some countries, such as Sweden, increasing network length by as much as fourfold between 2000 and 2013 (Swedish District Heating Association, 2015). Data on progress are limited, as are overall data for improved understanding of CHP technologies and DHC network efficiency.

Notable progress in 2015 includes European Union efforts to assess multilevel actions for enhanced heating and cooling opportunities under the STRATEGO project.[23] China announced plans to assess industrial excess heat recovery potential for district heat in 150 cities (NDRC, 2015).

Tracking progress

Greater deployment of efficient and cost-effective co-generation and DHC could help to improve the emissions intensity of global electricity and heat production. Shifts away from conventional, inefficient power generation are critical to achieving 2DS targets, and CHP with modern, efficient DHC systems can help reduce primary energy demand and improve overall system efficiency. Advanced, integrated DHC systems can also facilitate a more flexible, integrated energy system, taking advantage of multiple potential low-carbon energy sources, such as variable renewables and industrial excess heat.

Recommended actions

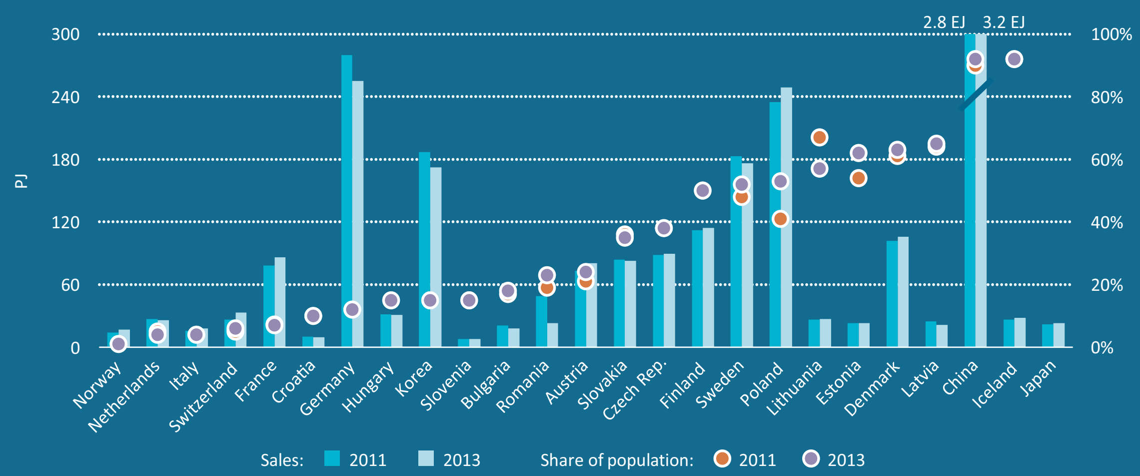
Data and improved resolution of co-generation and DHC technologies across the world's power generation, industrial and buildings sectors are critical to increase understanding of co-generation and DHC opportunities, which are typically a highly localised decision. Mapping of heating and cooling opportunities across the energy economy can also help to identify potential synergies and technology choices in electricity and heat generation.

Strategic planning of local, regional and national action should be pursued to identify cost-effective opportunities to develop co-generation and DHC networks in a more efficient, integrated energy system. Policy makers should remove market and policy barriers that prevent co-generation and DHC from competing as efficient and low-carbon solutions. Additional work is needed to address high upfront investment costs, inflexible business structures and lack of long-term visibility on policy and regulatory frameworks that limit co-generation and DHC.

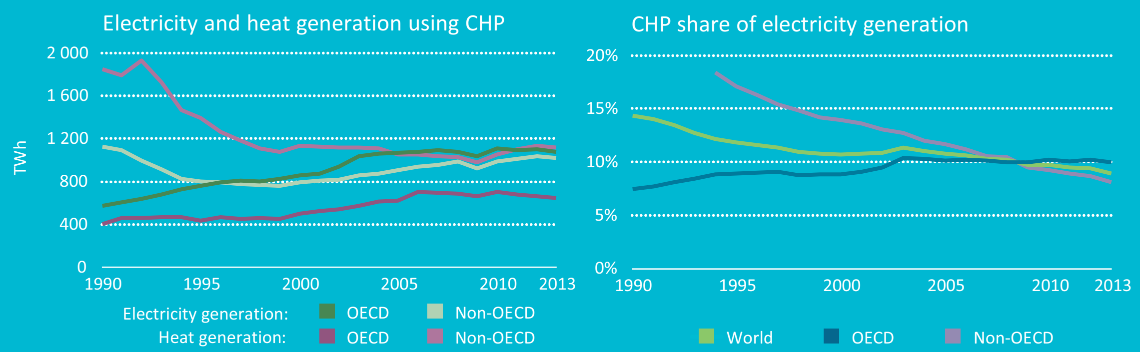
Further research is needed to improve understanding of the opportunities for co-generation and DHC under an increasingly dynamic, integrated energy system with various actors and energy sources. Improved understanding and enhanced strategies moving forward will help prevent lock-in of costly, long-lived decisions in electricity and heat generation in support of an efficient, low-carbon energy economy.

21-23 Co-generation refers to the combined production of heat and power. Refer to Technology overview notes page 72 for notes associated with this section.

49. District heat sales and share of population served



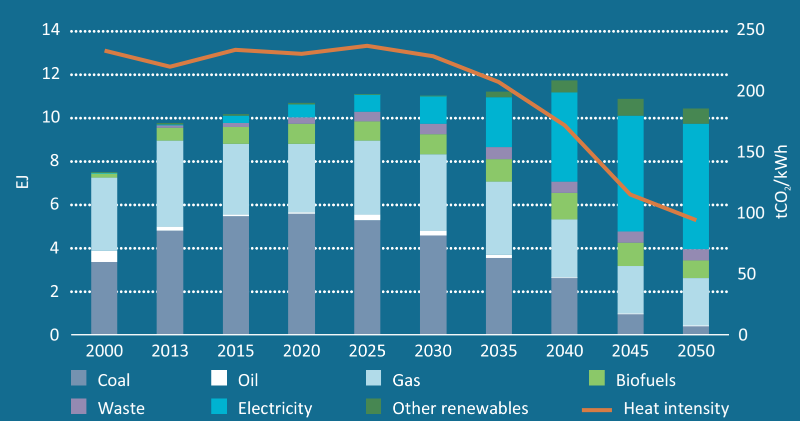
50. Co-generation trends



59%

GLOBAL AVERAGE EFFICIENCY OF CO-GENERATION IN ELECTRICITY PRODUCTION

51. District heating fuel mix and CO_2 intensity



For sources and notes see page 72

Smart grids

Improvement needed

~ Limited developments

Deployment of smart grid technologies has grown marginally compared to 2014 as smart meters reached saturation in many markets and investment in physical network assets waned. Information and operational technology (IT/OT) solutions are growth areas, increasing energy efficiency, power quality and network hosting capacity for clean energy.

Recent trends

The past year saw slowdowns in deployment of smart meters as some markets reached saturation, investment fell in distribution automation and other key new grid technologies, and uncertainties grew over the financial viability of incumbent utilities. As a result, annual growth in smart grid investment accelerated only marginally (BNEF, 2016). The widespread deployment of distributed generation is changing the load profiles typically seen by distribution network operators - putting pressure to invest in grid upgrades - and demand response enabled through advanced metering infrastructure (AMI) is gaining traction. However, regulatory frameworks do not always favour investment in innovative smart grid technologies.

Building on the first wave of AMI, utilities are looking for ways to implement business models based on 'big data' from highly distributed generation and load monitoring, increase the participation of energy consumers in electricity markets and enable demand side flexibility. Digital energy (IT/OT[24] solutions to improve operational capabilities of energy and network utilities) led growth in investment among all smart grid technology categories for network operators. The market for IT/OT solutions grew by 65% year-on-year (as anticipated in *TCEP 2015* [IEA, 2015k]) and is forecast to grow sixfold by 2023 (Navigant, 2014).

On the plant side, smart inverters for PV plants, wind farm automation, and control systems for wind- and PV-integrated energy storage, which reduce the impact of variable renewables (VRE) on distribution grids, are increasingly mandated through network codes. Distribution network operators in areas with high penetration of distributed and variable generation, including Germany, Italy and Hawaii (United States), are using smart grid technologies to monitor and control loads and generation. Among other benefits, these investments greatly reduce grid investment needs, or dramatically shorten permitting times for connecting distributed generation from weeks to near real time. Deployments in high-voltage transmission technology have kept a slower pace. Several projects for advanced high-voltage direct-current (HVDC) interconnection were inaugurated or close to completion, including the Belo Monte project in Brazil, a 2 GW Spain-France interconnection and an aggregate of 10 GW in China.

A recent emerging trend is the aggregation of loads and distributed generation to create "virtual power plants" (VPPs) and microgrids. VPPs can combine a rich diversity of independent resources into a network via sophisticated planning, scheduling, and bidding through IT-enabled smart technologies. Regional VPP demonstrations have been created in France (Nice Grid), Canada (PowerShift Atlantic) and the United States (Consolidated Edison of New York).

Tracking progress

Annual smart grid investments grew by 12% compared to 2014. IT-enabled solutions are increasing in importance as aggregators, VPPs and other business models based on physical smart grid infrastructure are expanding. Despite an increase in planned projects, large-scale interconnection has not kept up with the requirements in the 2DS, and some advanced HVDC technologies (e.g. voltage source converters and DC circuit breakers) required for interconnected DC grids are still to reach full market adoption.

Recommended actions

The increase in business models based on AMI and for distributed generation means strategies for smartening power grids need to be designed around customers and the opportunities opened up by big data. Key concerns remain for data privacy and security. Standard methods for accounting for the costs and benefits of smart grid technologies are still not widespread.

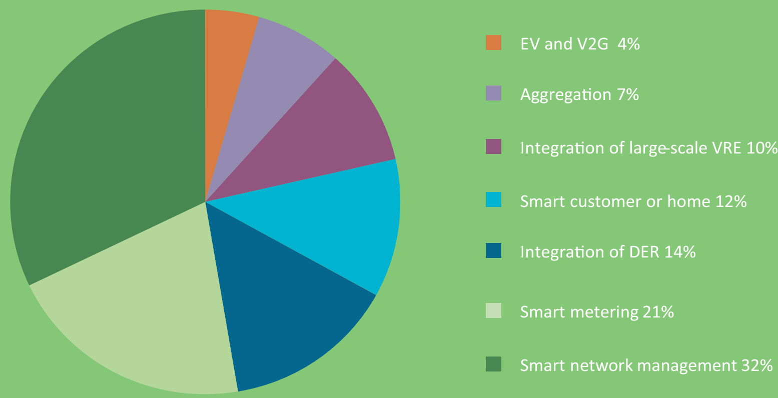
Inadequate interoperability and harmonisation of technology remain obstacles for smart grid technologies. Leveraging cross-sectoral interactions (e.g. power-to-heat, vehicle-to-grid [V2G]) requires a degree of interoperability not common in current practice.

24 IT refers to information technology (software component of a smart grid asset), whereas OT refers to operational technology (the physical component of a smart grid project).

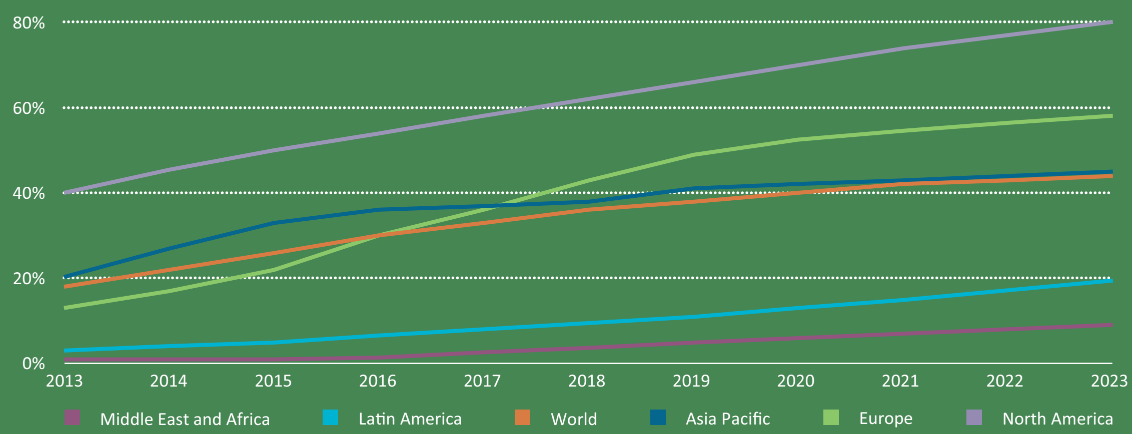
350

USD BILLION POWER GRID INVESTMENT BY 2020 ANNOUNCED IN CHINA (30% OF 2DS WORLD TOTAL)

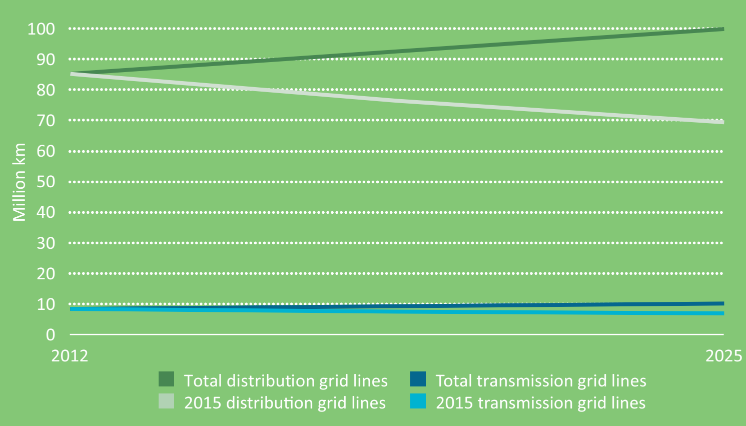
52. Projects by technology area



53. Smart meter penetration in key regions



54. Grid infrastructure in the 2DS



2.5

USD BILLION NEW INVESTMENT IN TRANSMISSION AND DISTRIBUTION REQUIRED BY 2025 (45% OF POWER SECTOR TOTAL)

For sources and notes see page 72

Energy storage

Improvement needed
Positive developments

Storage plays an important role in the 2DS vision, providing flexibility to energy systems, increasing the potential to accommodate variable renewables and distributed generation, and improving management of electricity networks. Storage technologies experienced a landmark year in 2014, largely driven by policy action and regulatory changes.

Recent trends

Large-scale energy storage continues to be dominated globally by pumped hydropower, both in terms of installed capacity (149 GW, or 96% of the total) and of new installations (over 5 GW completed in 2014, or 72% of the total). Battery storage, however, was deployed strongly through 2014, with a record 400 MW additions, more than doubling the installed base in 2013. Regulators worldwide (particularly in the United States, Europe and key markets in Asia) have introduced mandates and other policy instruments to spur storage deployment within their jurisdictions. In liberalised markets, rule changes increasingly allow storage to compete in markets for services beyond wholesale energy trade (e.g. markets for capacity or frequency regulation). Finally, in a growing number of countries, policy and regulation are aiming to explicitly capture more value from distributed resources through policy instruments that are opening opportunities for storing excess power production locally (e.g. tariff designs for self-generated and exported power).

This accelerated deployment has been accompanied by continued and rapid reductions in technology costs in battery technology, particularly in lithium-ion (Li-ion) chemistries. Since 2010, costs have followed a similar trend to those experienced by PV a decade earlier, with learning rates[25] averaging 22%. Increasing evidence exists, however, that drivers for recent cost reductions may echo those that have shaped the boom in PV installations since 2011. In the medium term, once markets rebalance cost reductions are likely to continue – in large part, due to knowledge acquired from lithium-ion batteries powering electric vehicles and consumer electronics. Particular attention is required in the area of balance-of-system costs.[26] These costs can greatly affect total installed costs and depend on local capacities, not technology trends.

Building-scale power storage emerged in 2014 as a defining energy technology trend. The market grew by 50% year-on-year. The commercialisation of the Tesla Powerwall (a 10-kWh lithium-ion storage solution) captured public attention and pressured other manufacturers to reduce costs. Such behind-the-meter battery storage allows private consumers to improve the economic value of self-generated electricity. This trend is expected to accelerate as more consumers look to reduce grid electricity expenditures, reduce capacity charges and maximise consumption of self-generated power.

Beyond lithium-ion battery storage, however, progress in other areas remains weak. The deep decarbonisation of power generation envisaged in the 2DS requires technologies better adapted to storing large volumes of energy that can be converted back to electricity, to compensate for extended periods of abundant or scarce generation arising from high shares of wind and solar power. With around 40 MW of planned deployments, flow batteries have shown significant progress and could fulfil this role. Progress in larger-scale solutions such as compressed air energy storage or pumped hydro has been thwarted by planning constraints and a lack of viable business models.

Tracking progress

Lower-than-anticipated costs and policy developments have accelerated deployment in some energy storage fields such as grid-tied battery technology. High upfront costs, however, remain an obstacle to wider deployment. Data gaps remain, particularly in the emerging market of behind-the-meter storage.

Recommended actions

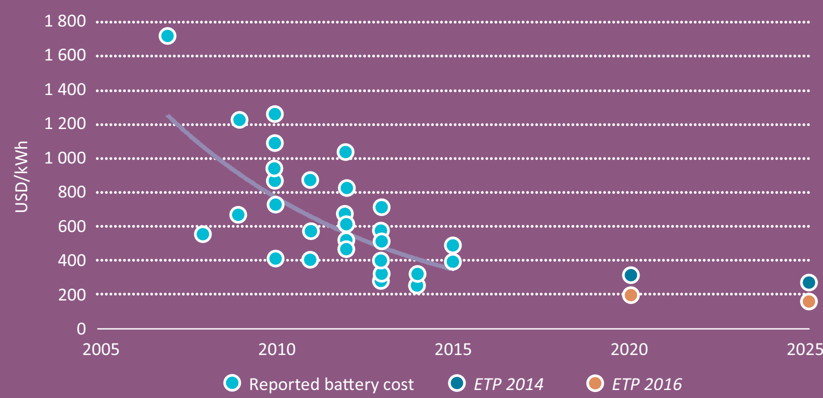
Market and regulatory frameworks that allow the energy system to capture the full benefits of storage must continue to be developed. These frameworks must reward how fast and how often a power system resource responds to changes in power supply or load. Particular attention is required in the area of integration of storage systems with existing grid infrastructure or with on-site power generation technologies. Training and capacity-building programmes, simplifying permitting schemes and better collection of market and technology data are also required.

25-26 Refer to Technology overview notes page 72 for notes associated with this section.

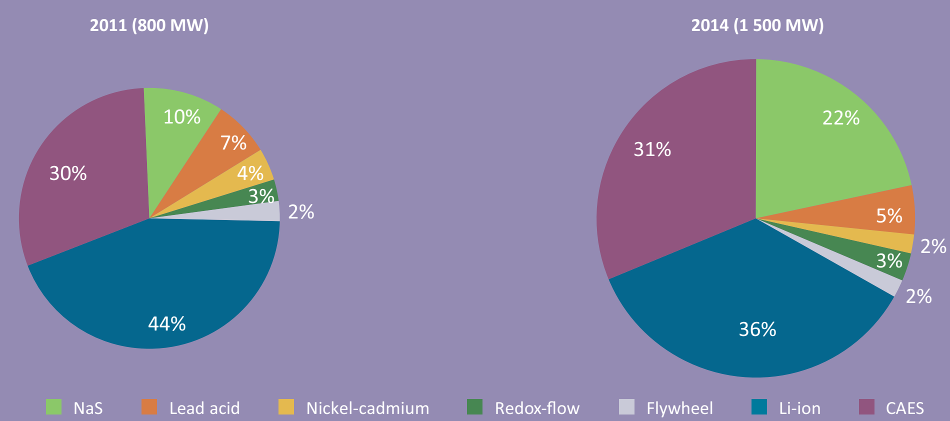
2.5

TIMES GROWTH IN UNITED STATES ENERGY STORAGE IN 2015

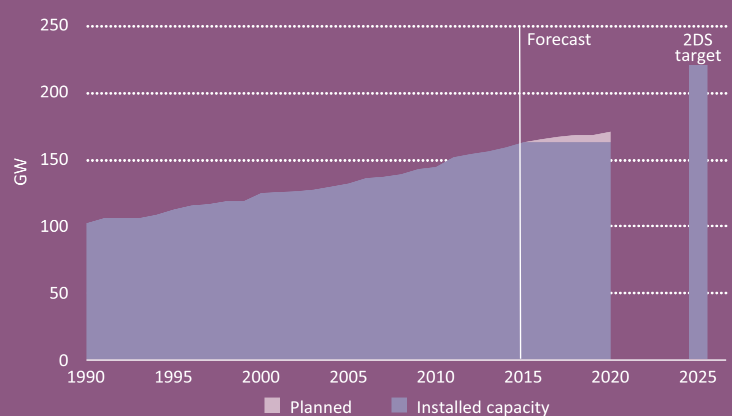
55. Large-scale battery investment cost



56. Large-scale battery storage



57. Pumped hydro storage



1.6 GW

LARGE-SCALE BATTERY STORAGE BUILT OR PLANNED

142 GW

PUMPED HYDRO STORAGE CAPACITY

For sources and notes see page 72

Annexes

Acronyms, Abbreviations, Units of Measure and Regional groupings

Acronyms

4E TCP	Technology Collaboration Programme on Energy Efficient End-Use Equipment
AC	alternating current
AL	aluminum
AMI	advanced metering infrastructure
ASEAN	Association of Southeast Asian Nations
ATAG	Air Transport Action Group
BAT	best available technologies
BEA	Buildings Efficiency Accelerator
BEEP	building energy efficiency policy
BERC	Buildings Energy Research Center
BEV	battery-electric vehicle
BNEF	Bloomberg New Energy Finance
CAES	compressed air energy storage
CCS	carbon capture and storage
CDD	cooling degree days
CEA	Central Electricity Authority (India)
CfD	contract for difference
CFL	compact fluorescent lamp
CHP	combined heat and power
COP21	21st Conference of the parties
CZ	climate zone
DC	direct current
DECC	Department of Energy and Climate Change (United Kingdom)
DER	distributed energy resources
DHC	district heating and cooling
EESL	energy efficiency standards and labelling
EOR	enhanced oil recovery
ESTIF	European Solar Thermal Industry Federation
ETP	*Energy Technology Perspectives*
EU	European Union
EUR	euro
EV	electric vehicle
EVI	Electric Vehicles Initiative
FNR	fast neutron reactor
GBPN	Global Buildings Performance Network

GCC	Gulf Co-operation Council
GDP	gross domestic product
Gen	generation
GHG	greenhouse gas
GCCSI	Global Carbon Capture and Storage Institute
GTM	Greentech Media
FIT	feed-in tariff
HDD	heating degree days
HFT	heavy freight trucks
HTR	high-temperature reactor
HVDC	high-voltage direct-current
IAI	International Aluminum Institute
IAEA	International Atomic Energy Agency
ICAO	International Civil Aviation Organisation
ICCT	International Council on Clean Transportation
ICE	internal combustion engine
IEA	International Energy Agency
INDC	intended nationally determined contributions
IPCC	Intergovernmental Panel on Climate Change
IPEEC	International Partnership for Energy Efficiency Cooperation
ISGAN	International Smart Grid Action Network
ISIC	International Standard Industrial Classification
IT	information technology
ITC	investment tax credit
LBNL	Lawrence Berkeley National Laboratory
LCA	life cycle assessment
LCV	light commercial vehicles
LED	light-emitting diode
Li-ion	lithium ion
LNG	liquefied natural gas
JADC	Japan Aircraft Development Corporation
KfW	Kreditanstalt für Wiederaufbau (German development bank)
MEPS	minimum energy performance standards
MFT	medium freight trucks
MTRMR	*Medium-Term Renewable Energy Market Report*
NaS	sodium sulphur
NBP	National Balancing Point
NDC	nationally determined contributions
NDRC	National Development and Reform Commission of the People's Republic of China
NEA	Nuclear Energy Agency

OECD	Organisation for Economic Co-operation and Development
OLED	organic light-emitting diode
OT	operational technology
PAT	Perform, Achieve and Trade
PHEV	plug-in hybrid-electric vehicle
PLDV	passenger light-duty vehicle
PNNL	Pacific Northwest National Laboratory
Powermin	Ministry of Power India
PP	percentage points
PPA	power purchase agreement
PPP	purchasing power parity
PRIS	Power Reactor Information System
PTC	production tax credit
PV	photovoltaic
R&D	research and development
RD&D	research, development and demonstration
SCC	State Council of China
SHC TCP	Technology Collaboration Programme on Solar Heating and Cooling
SMR	small modular reactor
SPIRE	Sustainable Process Industry through Resource and Energy Efficiency
STE	solar thermal electricity
TCEP	*Tracking Clean Energy Progress*
TCP	Technology Collaboration Programme
TFC	total final energy consumption
TU	Tsinghua University
UAE	United Arab Emirates
UN	United Nations
UN DESA	United Nations Department of Economics and Social Affairs
UN EP	United Nations Environmental Programme
UN FCCC	United Nations Framework Convention on Climate Change
UNSD	United Nations Statistics Division
US	United States
USD	United States dollar
US DOE	United States Department of Energy
USGS	United States Geological Survey
V2G	vehicle-to-grid
VPP	virtual power point
VRE	variable renewables

Abbreviations

2DS	*ETP 2015* 2°C Scenario
4DS	*ETP 2015* 4°C Scenario
6DS	*ETP 2015* 6°C Scenario
CO_2	carbon dioxide
CO_2-eq	CO_2 equivalent (using 100-year global warming potentials for different GHGs)

Units of measure

bcm	billion cubic metres
EJ	exajoule
gCO_2	grammes carbon dioxide
GJ	gigajoule
Gt	gigatonne
GW	gigawatt
GWh	gigawatt-hour
GW_{th}	gigawatts thermal
km	kilometre
kW	kilowatt
kWh	kilowatt-hour
kW_{th}	kilowatts thermal
kW_{th}/m^2	kilowatts thermal per square metre
L	litres
m^2	square metre
MBtu	million British thermal units
MJ	megajoule
Mt	megatonne
$MtCO_2$	megatonne CO_2
$MtCO_2$-eq	megatonne CO_2 equivalent
MW	megawatt
MWh	megawatt-hour
pkm	passenger kilometre
PJ	petajoule
rpk	revenue passenger kilometre
TJ	terajoule
tCO_2	tonne CO_2
toe	tonne of oil equivalent
TWh	terawatt-hour
tkm	tonne kilometre
U value	W per K per m^2
W	watt
W_{th}	watt thermal

Regional and country groupings

Africa

Algeria, Angola, Benin, Botswana, Cameroon, Congo, Democratic Republic of Congo, Côte d'Ivoire, Egypt, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Libya, Morocco, Mozambique, Namibia, Nigeria, Senegal, South Africa, Sudan,[1] United Republic of Tanzania, Togo, Tunisia, Zambia, Zimbabwe and other African countries and territories.[2]

ASEAN (Association of Southeast Asian Nations)

Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam.

Asia

Bangladesh, Brunei Darussalam, Cambodia, People's Republic of China, India, Indonesia, Japan, Korea, the Democratic People's Republic of Korea, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Chinese Taipei, Thailand, Viet Nam and other Asian countries and territories.[3]

China

Refers to the People's Republic of China, including Hong Kong.

European Union

Austria, Belgium, Bulgaria, Croatia, Cyprus,[4] Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden and United Kingdom.

Latin America

Argentina, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela and other Latin American countries and territories.[5]

Middle East

Bahrain, Islamic Republic of Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates and Yemen. It includes the neutral zone between Saudi Arabia and Iraq.

OECD

Includes OECD Europe, OECD Americas and OECD Asia Oceania regional groupings.

OECD Americas

Canada, Chile, Mexico and United States.

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1 Because only aggregated data were available until 2011, the data for Sudan also include South Sudan.

2 Individual data are not available for: Burkina Faso, Burundi, Cape Verde, Central African Republic, Chad, Comoros, Djibouti, Equatorial Guinea, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Niger, Reunion, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia, Swaziland, Uganda and Western Sahara (territory). Data are estimated in aggregate for these regions.

3 Individual data are not available for: Afghanistan, Bhutan, Cook Islands, East Timor, Fiji, French Polynesia, Kiribati, Lao PDR, Macau, Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga and Vanuatu. Data are estimated in aggregate for these regions.

4 1. Footnote by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

2. Footnote by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

5 Individual data are not available for: Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), French Guyana, Grenada, Guadeloupe, Guyana, Martinique, Montserrat, St.Kitts and Nevis, Saint Lucia, Saint Pierre et Miquelon, St. Vincent and the Grenadines, Suriname and Turks and Caicos Islands. Data are estimated in aggregate for these regions.

OECD Asia Oceania

Includes OECD Asia, comprising Japan, Korea and Israel,[6] and OECD Oceania, comprising Australia and New Zealand.

OECD Europe

Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

Other developing Asia

Non-OECD Asia regional grouping excluding People's Republic of China and India.

Deviating regional definition only used for Figure 53

Asia Pacific: Afghanistan, American Samoa, Armenia, Australia, Azerbaijan, Bangladesh, Bhutan, British Indian Ocean Territory, Brunei Darussalam, Cambodia, People's Republic of China, Christmas Island (Indian Ocean), Cocos (Keeling) Islands, Comoros, Cook Islands, Fiji, French Polynesia, Guam, Heard and McDonald Islands, Hong Kong (China), India, Indonesia, Japan, Kazakhstan, Kiribati, Korea, the Democratic People's Republic of Korea, Kyrgyzstan, Lao People's Democratic Republic, Malaysia, Maldives, Marshall Islands, Mayotte, Federated States of Micronesia, Midway Islands, Mongolia, Myanmar, Nauru, Nepal, New Caledonia, New Zealand, Niue, Norfolk Island, Northern Mariana Islands, Pakistan, Palau, Papua New Guinea, Paracel Islands, Philippines, Pitcairn, Samoa, Seychelles, Singapore, Solomon Islands, Spratly Island, Sri Lanka, Chinese Taipei, Tajikistan, Thailand, Tokelau, Tonga, Turkmenistan, Tuvalu, Uzbekistan, Vanuatu, Viet Nam, Wake Island, Wallis and Futuna Islands.

Europe: Albania, Andorra, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus,[7] Czech Republic, Denmark, Estonia, Faroe Islands, Finland, Former Yugoslav Republic of Macedonia, France, Georgia, Germany, Gibraltar, Greece, Guernsey, Hungary, Iceland, Ireland, Isle of Man, Italy, Jersey, Republic of Kosovo, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Republic of Moldova, Monaco, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom.

Latin America: Anguilla, Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bermuda Islands, Bolivia, Bouvet Island, Brazil, British Virgin Islands, Cape Verde, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands (Malvinas), French Guiana, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Helena, St. Kitts-Nevis, Saint Lucia, Saint Pierre and Miquelon, St. Vincent and the Grenadines, South Georgia and the South Sandwich Islands, Suriname, Trinidad and Tobago, Turks and Caicos Islands, Uruguay, Venezuela, Virgin Islands of the United States, West Indies.

Middle East/Africa: Algeria, Angola, Bahrain, Botswana, Burkina Faso, Burundi, Cameroon, Central African Public, Chad, Congo, Democratic Republic of the Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, the Islamic Republic of Iran, Iraq, Israel, Jordan, Kenya, Kuwait, Lebanon, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Namibia, Niger, Nigeria, Oman, Palestinian Authority, Qatar, Réunion, Rwanda, Sao Tome and Principe, Saudi Arabia, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Syrian Arab Republic, United Republic of Tanzania, Togo, Tunisia, Turkey, Uganda, United Arab Emirates, Western Sahara, Yemen, Zambia, Zimbabwe.

North America: Canada, Greenland, United States.

6 The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

7 See note 4.

Technology overview notes

Unless otherwise noted, data in this report derive from International Energy Agency (IEA) statistics and *Energy Technology Perspectives* (*ETP*) analysis. The notes in this section provide additional sources and details related to data and methodologies.

Throughout the report, annual averages are calculated as compound average growth rates.

Renewable power (page 18)

Figures 1, 2, 5 and 6: sources: data from IEA (2015a), *Medium-Term Renewable Energy Market Report* and 2°C Scenario (2DS) targets from 2016 *ETP* model.

Figure 4: notes: Values reported in nominal United States dollars (USD) include preferred bidders, power purchase agreements or feed-in-tariffs. US values are calculated excluding tax credits. Delivery date and costs may be different than those reported at the time of the auction.

Nuclear power (page 24)

Figures 8 and 9: sources: data from IAEA (International Atomic Energy Agency) (2015), PRIS (Power Reactor Information System) database, www.iaea.org/pris/; NEA (Nuclear Energy Agency) and IAEA (2014), *Uranium 2014: Resources, Production and Demand (The Red Book)*.

Figure 10: notes: construction spans from first concrete-to-grid connection. Grid connection for projects under construction is estimated based on recent public information. FNR = fast neutron reactor; Gen II = second generation nuclear reactor; Gen III = third generation nuclear reactor; HTR = high temperature reactor; SMR = small modular reactor.

Figure 10: source: realised grid connection data from IAEA (2015), PRIS database, www.iaea.org/pris/.

Natural gas-fired power (page 26)

Figure 11: note: NBP = National Balancing Point (United Kingdom), representative of European gas prices.
Sources: Henry Hub: Intercontinental Exchange; NBP: GasTerra; Japan LNG: Japan Customs.

Figure 12: note: other fossil category comprises coal-fired power and oil-fired power generation. Oil-fired power generation is negligible in Germany and the United States (<1%), but represented 11% in Japan in 2014.

Figure 13: note: the capacity factor describes the output from the plant over a period of time relative to the potential maximum output; it depends on both the running time and the operating load.

Coal-fired power (page 28)

Figure 15: note: other renewables includes geothermal, solar, wind, ocean, biofuels and waste.

Figure 16: note: gCO_2/kWh = grammes CO_2 per kilowatt hour.

Carbon capture and storage (page 30)

Note 1: Enhanced oil recovery (EOR) is a closed-cycle process that involves injecting carbon dioxide (CO_2) into older oil reservoirs to increase or prolong production. The CO_2 is injected into the reservoir, recovered from the produced oil and re-injected. CO_2 is retained and eventually stored through injection for EOR, though additional monitoring and planning is needed to ensure the CO_2 is effectively stored. The IEA has recently defined what it considers as the criteria for planning and monitoring to ensure the efficacy of storage through EOR in IEA (2015c), *Storing CO_2 through Enhanced Oil Recovery*, OECD/IEA, Paris. To date, very few EOR projects meet these criteria.

Figures 17 and 18: note: Large-scale projects are defined in accordance with the Global Carbon Capture and Storage Institute (GCCSI), i.e. projects involving the annual capture, transport and storage of CO_2 at a scale of at least 800 000 tonnes of CO_2 (tCO_2) for a coal-based power plant, or at least 400 000 tCO_2 for other emissions-intensive industrial facilities (including natural gas-based power generation). Advanced stage of planning implies that projects have reached at least the "Define stage" in accordance with the GCCSI Asset Lifecycle Model.

Figure 17-18: source: GCCSI (2015), *The Global Status of CCS 2015*.

Figure 19: note: data are in USD 2014 prices and purchasing price parity (PPP).

Industry (page 32)

Note 2: Industry energy consumption includes energy use in blast furnaces and coke ovens and as petrochemical feedstock.

Note 3: In IEA modelling, five energy-intensive sectors are considered: chemicals and petrochemicals, cement, iron and steel, aluminium, and pulp and paper.

Figure 21: note: chemicals and petrochemicals includes fuel use as petrochemical feedstock.

Figure 22: note: Direct energy-related CO_2 emissions are those from fuel combustion. In chemicals and petrochemicals, there is a slight increase in direct energy-related CO_2 intensity in 2025 primarily due to the effect of existing and planned coal-based methanol-to-olefins capacity in the short term in China, with a greater overall energy footprint than steam cracking. Emissions from electricity generation are accounted for in the electricity sector, making electricity-intensive industrial processes appear less CO_2-intensive.

Aluminium (page 34)

Note 4: This represents aluminium produced from new and old scrap. Internal scrap has been excluded for consistency with published statistics.
Source: IAI (International Aluminium Institute) (2015b), *Global Mass Flow Model – 2013 (2014 draft)*, www.world-aluminium.org/publications/.

Note 5: This represents the share of production based on new and old scrap. Internal scrap has been excluded for consistency with published statistics.
Source: IAI (2015b), *Global Mass Flow Model – 2013 (2014 draft)*, www.world-aluminium.org/publications/.

Note 6: These data are reported by IAI member companies and associations to IAI, and capacity not covered by members is accounted for via IAI estimates. Alumina refining energy intensity does not include alternative (non-Bayer) processes.
Source: IAI (2015a), *Current IAI Statistics*, www.world-aluminium.org/statistics/ (accessed 7 December 2015).

Note 7: Of which aluminium is a major part. Not all of the increase in energy consumption can be attributed to aluminium. Defined in the IEA Energy Balances as ISIC Group 242 (manufacture of basic precious and other non-ferrous metals) and Class 2432 (casting of non-ferrous metals).
Sources: IEA (2015e), *Energy Balances of OECD Countries*, OECD/IEA, Paris; United Nations Statistics Division (2008), *International Standard Industrial Classification of All Economic Activities (ISIC)*, Rev. 4, Series M No. 4, UNSD, New York.

Note 8: These data are reported by IAI member companies and associations to IAI, and capacity not covered by members is accounted for via IAI estimates. Best available technology (BAT)

level for primary aluminium smelting is given as 49 gigajoules per tonne (GJ/t) aluminium (Al) (13 611 kilowatt hours per tonne [kWh/t] Al), and BAT level for Bayer process alumina refining is 7.6 GJ/t alumina.
Sources: IAI (2015a), *Current IAI Statistics*, www.world-aluminium.org/statistics/ (accessed 7 December 2015); LBNL (Lawrence Berkeley National Laboratory) (2008), *World Best Practice Energy Intensity Values for Selected Industrial Sectors*, LBNL, Berkeley.

Note 9: A recent estimate put overall average energy intensity of alumina refining in China at 18.53 GJ/t.
Source: Rock, M. and M. Toman (2015), *China's Technological Catch-up Strategy: Industrial Development, Energy Efficiency, and CO_2 Emissions*, Oxford University Press, Oxford.

Note 10: This could be commercially available by 2030, by some estimates, though this depends on research progress in creating an economically and technically viable inert anode. Intergovernmental Panel on Climate Change (IPCC) literature estimates availability by 2020. Note that in IEA modelling, inert anodes are assumed to be commercially available from 2030 in the 2DS, and 2035 in the 4°C Scenario (4DS).
Source: IPCC (2007), *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.

Note 11: Refer to IEA (2015f), *World Energy Outlook 2015,* OECD/IEA, Paris, for additional discussion of material efficiency in the aluminium sector.

Textbox: note 12: this represents the share of production based on new and old scrap in 2025 in the 2DS. Internal scrap has been excluded for consistency with published statistics.

Figure 23: note: GCC = Gulf Co-operation Council. These data are reported by IAI member companies and associations to IAI, and capacity not covered by members is accounted for via IAI estimates. For regional definitions see source website.
Source: IAI (2015a), *Current IAI Statistics*, www.world-aluminium.org/statistics/ (accessed 7 December 2015).

Figure 24: note: Bubble size refers to primary aluminium production in millions of tonnes (Mt). These data are reported by IAI member companies and associations to IAI, and capacity not covered by members is accounted for via IAI estimates. For regional definitions see source website. Alumina refining energy intensity includes only Bayer process refining, which means some regions' refining energy intensities are underestimated in this graph, particularly China. BAT level for alumina refining energy intensity is 7.6 GJ/t alumina, and for smelting electricity intensity is 13 611 kWh/t Al. BAT levels refer to an average size capacity, and the achievable performance level not considering particular characteristics at specific sites, such as high capacity sites with high levels of process integration, and varying qualities of raw materials and feedstocks.
Source: IAI (2015a), *Current IAI Statistics*, www.world-aluminium.org/statistics/ (accessed 7 December 2015).

Figure 25: note: includes top six primary aluminium producing regions. CO_2 intensities of electricity production are based on national averages, not electricity provided specifically to the aluminium sector. In the 2DS, as global electricity supplies become increasingly decarbonised, several of these regions' CO_2 intensities of electricity production reach nearly zero. In 2025, Canada reaches 73 grammes CO_2 per kilowatt hour (gCO_2/kWh), Brazil reaches 26 gCO_2/kWh and Norway reaches 6 gCO_2/kWh. Norway also starts from a very low level, 8 gCO_2/kWh, due to the large share of hydropower in its primary energy supply.
Sources: IEA analysis; USGS (United States Geological Survey) (2015), *Minerals Yearbook: Aluminum*, www.minerals.usgs.gov/minerals/pubs/commodity/aluminum/index.html#myb.

Transport (page 36)

Note 13: Well-to-wheel refers to the energy use and greenhouse gas (GHG) emissions in the production of a fuel and its use in a vehicle. Well-to-wheel energy use and GHG emission estimates exclude the production and end-of-life disposal of the vehicle and fuel production/distribution facilities. As such, they provide a partial view of energy use and emissions resulting from a life-cycle assessment (LCA) of fuel and vehicle production, use and disposal. LCA is a broader concept, requiring more information than the well-to-wheel energy and GHG emissions estimates. LCA is used to account for all the environmental impacts (not only energy and GHG, but also many kinds of pollutants and water requirements) resulting from the consumption of all the materials needed for the production process.

Figure 26: note: $MtCO_2$-eq = million tonnes of carbon dioxide equivalent; HFTs = heavy freight trucks; LCVs = light commercial vehicles; MFTs = medium freight trucks; pkm = passenger kilometres; tkm = tonne kilometres.
Source: IEA (2016a), *Mobility Model*, January 2016 version (database and simulation model), www.iea.org/etp/etpmodel/transport/.

Figure 27: note: this map is without prejudice to the sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.
Source: Population data sourced from UN DESA (United Nations Department of Economic and Social Affairs) (2014), *World Urbanization Prospects: The 2014 Revision*, CD-ROM edition, www.esa.un.org/unpd/wup/CD-ROM/ (accessed 10 October 2015); calculations derived from IEA (2015g), "World energy balances", *World Energy Statistics and Balances 2015* (database), www.iea.org/statistics (accessed 4 February 2016).

Electric vehicles (page 38)

Figure 28: note: BEV = Battery Electric Vehicle; PHEV = Plug-in Hybrid Electric Vehicle.

Figures 28 and 29: source: IEA (forthcoming), *Global EV Outlook 2016*.

Figure 30: note: reflects a share of electric driving for plug-in hybrid electric vehicles of 30%.
Source: IEA (forthcoming), *Global EV Outlook 2016,* OECD/IEA, Paris; IEA (2015h), *CO_2 Emissions from Fuel Combustion* (database), www.iea.org/statistics; IEA (2016a), *Mobility Model*, January 2016 version (database and simulation model), www.iea.org/etp/etpmodel/transport/.

Aviation (page 40)

Note 15: Unless otherwise noted, all references to energy use are expressed in terms of final energy.

Note 16: In aviation, the common activity metric is RPK: revenue passenger-kilometres. This corresponds to the number of passengers transported, multiplied by the kilometres they fly. It is equivalent to passenger-kilometres (pkm) in other transport modes.

Note 17: Air Transport Action Group (ATAG) represents a broad industrial consortium in aviation, including airport operators, aircraft and aircraft engine manufacturers, airlines, and civil aviation services, among others.

Figure 31: source: Calculations derived from IEA (2015g), *World Energy Statistics and Balances 2015*, www.iea.org/statistics; ICAO (International Civil Aviation Organization) (2013), "Appendix 1", *Annual Report of the ICAO Council: 2013*, www.icao.int/annual-report-2013/Documents/Appendix_1_en.pdf.

Figure 32: note: GDP = gross domestic product.
Source: IEA (2016a), *Mobility Model*, January 2016 version (database and simulation model), www.iea.org/etp/etpmodel/transport/; population calculations from UN DESA (2014), *World Urbanization Prospects: The 2014 Revision*, www.esa.un.org/unpd/wup/CD-ROM/.

Figures 32 and 33: source: IEA (2016a), *Mobility Model*, January 2016 version (database and simulation model), www.iea.org/etp/etpmodel/transport/.

Biofuels (page 42)

Note 18: Sustainably produced biofuels offer a lower-carbon intensity alternative to petroleum-derived fuels. Conventional biofuels include sugar- and starch-based ethanol and oil crop-based biodiesel. Advanced biofuels include biofuels based on non-food agricultural residue and waste feedstocks such as cellulosic ethanol, renewable diesel and bio-synthetic gas. The category also includes other novel technologies that are mainly in the research and development and pilot stages.

Flexible-fuel vehicles, or flex-fuel vehicles, have suitable engine modifications to use higher ethanol blends (e.g. E85) or as is commonly found in Brazil, pure hydrous ethanol (E100). As of February 2016, ten commercial-scale advanced biofuels plants have been commissioned in Brazil, China, Europe and the United States; annual production capacities for these plants range from 30 to 120 million litres per year. Nine of these plants produce cellulosic ethanol from biomass wastes and agricultural residues.

Examples of ambitious and long-term transport sector targets include Finland's aim to provide a 40% share of renewable transport fuels and Sweden's goal of a vehicle stock independent of fossil fuels, both by 2030. Examples of policies to establish defined reductions in the life-cycle carbon intensity of transportation fuels include the Low Carbon Fuel Standard in California and the Climate Protection Quota in Germany. These policies take into effect the different levels of carbon reduction achieved by biofuels due to specific feedstock and production process combinations. Specific advanced biofuels quotas are included in the Renewable Fuel Standard in the United States, will be introduced in Italy from 2018 and are under consideration within several other European countries.

Both conventional and advanced biofuels' contributions to the 2DS have been revised down from previous projections due to slower market growth and lower than anticipated commercialisation, respectively. This reduction is offset by updated transport assumptions regarding journey avoidance and switching to alternative public transport modes in urban areas, in addition to a slower assumed GHG emissions reduction profile and updated vehicle efficiency assumptions.

Figure 34: sources: IEA (2016b), *Medium-Term Oil Market Report 2016*; 2DS targets from the 2016 *ETP* model.

Figure 35: source: Biofuels production data from IEA (2016b), *Medium-Term Oil Market Report 2016*.

Figure 36: source: Bloomberg New Energy Finance (BNEF) (2015), *Funds Committed* (database), www.bnef.com/FundsCommitted/search.

Buildings (page 44)

Figure 38: notes: the year 1995 has been used for the Russian Federation to account for the dissolution of the Former Soviet Union. MWh = megawatt hours.

Figure 39: note: kWh/m^2 = kilowatt hours per square metre; ASEAN = Association of Southeast Asian Nations.

Building envelopes and equipment (page 46)

Figure 40: note: this map is without prejudice to the sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.
Source: IEA building code analysis and IEA (2015i), *IEA Building Energy Efficiency Policies (BEEP) Database,* www.iea.org/beep/.

Figure 41: note: heating and cooling degree days are based on average heating degree days (HDD) over the heating region within a large country and average cooling degree days (CDD) over the cooling region within a large country. CZ = climate zone, as defined by Ministère de l'Environnement, de l'Énergie et de la Mer [Ministry of the environment, energy and the sea] (2013) and Pacific Northwest National Laboratory (PNNL) (2015).
Source: IEA building code analysis and Global Buildings Performance Network (GBPN) analysis; Ministère de l'Environnement, de l'Énergie et de la Mer [Ministry of the environment, energy and sea] (2013), *La répartition des départements par zone climatique [The distribution of departments by climate zone];* PNNL (2015), *High-Performance Home Technologies: Guide to Determining Climate Regions by County*, Building America Best Practices Series.

Figure 42: note: fuel boilers are not compared with gas heat pumps in this figure. HDDs and CDDs are based on average HDD over the heating region within a large country and average CDD over the cooling region within a large country.
Source: IEA technology policy mapping analysis.

Appliances and lighting (page 48)

Figure 43: note: CFL = compact fluorescent lamp; LED = Light emitting diode; OLED = organic light emitting diode.

Figure 43 (left): source: 4E TCP (Technology Collaboration Programme on Energy Efficient End-Use Equipment) (2015b), "Mapping & benchmarking of the impact of 'phase-out' on the lighting market (updated)", www.iea-4e.org/document/351/policy-brief-mapping-benchmarking-of-the-impact-of-phase-out-on-the-lighting-market-updated.

Figure 43 (right): source: adapted from US-DOE (United States Department of Energy) (2012), *Solid-State Lighting Research and Development: Multi-Year Program Plan*.

Solar heating (page 50)

Note 20: Data for total installed global solar thermal collector capacity are estimated, with a considerable amount of uncertainty over the coverage in some markets. For this report, several data sources were used including official IEA statistics, Technology Collaboration Programme on Solar Heating and Cooling (SHC TCP), the European Solar Thermal Industry Federation (ESTIF), and national administrations. Data for 2014 deployment are preliminary and may differ from when historical data sources are updated.

Solar thermal collector capacities are represented in gigawatts thermal (GW_{th}) using the conversion factor of 0.7 kilowatts thermal per square metre (kW_{th}/m^2) to derive the nominal capacity from the area of installed collectors in order to make solar thermal collector capacity comparable with that of other energy sources. The conversion factor was agreed by representative associations from member countries, the ESTIF and the IEA SHC programme in a 2004 joint meeting between the SHC TCP and major solar thermal trade associations.

Figures 46, 47 and 48: sources: data from IEA (2015j), *Renewables Information 2015* www.iea.org/statistics/; SHC TCP (2015), *Solar Heat Worldwide*; ESTIF (2015), *Solar Thermal Markets in Europe;* and 2DS targets from 2016 *ETP* model.

Figure 48: note: this map is without prejudice to the sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Co-generation and district heating and cooling (page 52)

Note 21: Cogeneration is also commonly referred to as combined heat and power (CHP). This report uses the term “cogeneration” to refer to the simultaneous generation of heat and electricity.

Efficiency for a district cooling system refers to the ratio of final thermal energy provided to primary energy input for generation. These efficiencies can be especially high in the case of systems that use surplus heat and natural cooling sources as inputs.

Note 22: According to IEA energy balance conventions, for auto-producer cogeneration plants, which produce some heat and electricity for their own use, only heat generation and fuel input for heat sold are considered, whereas the fuel input for heat used within the auto-producer’s establishment is not included, but accounted for in the final energy demand of the appropriate consuming sector. Transmission and distribution losses are not included.

Note 23: More information is available at www.stratego-project.eu/project-brief/.

Figure 49: notes: share of population served by district heat in China accounts only for populations in north urban China. Estimates provided by the Tsinghua University Buildings Energy Research Center (BERC).
Sources: Euroheat & Power (2015), *District Heating and Cooling: Country by Country Survey 2015*; TU (Tsinghua University) (2015), *2015 Annual Report on China Building Energy Efficiency*.

Figure 50: notes: non-OECD CHP shares have not been included for 1990-93 due to the dissolution of the Former Soviet Union. Heat generation includes heat sold and does not include heat used on-site.

Figure 51: note: decarbonisation of district heating accelerates in the medium- to long-term time frame given the volumes of infrastructure already in place to 2025 and the typical lifetimes of heat generation investments.

Smart grids (page 54)

Figure 52: note: DER = distributed energy resources; V2G = vehicle to grid; VRE = variable renewables.
Source: ISGAN (International Smart Grid Action Network) (2015), *Global Smart Grid Inventory*.

Figure 53: note: see page 65 for deviations from regional groupings associated with this figure.
Source: Navigant (2014), *Smart Grid Technologies*.

Figure 54: source: IEA analysis and NRG Expert (2015), *Electricity Transmission and Distribution Report and Database*, www.nrgexpert.com/energy-market-research/electricity-transmission-and-distribution-report-and-database/.

Energy storage (page 56)

Note 25: The technology learning rate refers in this case to the reduction in investment costs for every doubling of cumulative (historical) installed capacity.

Note 26: “Balance-of-system costs” refers to costs related to additional equipment and operations required to monitor, manage and connect batteries to power grids.

Figure 56 and top row textbox: source: IEA analysis and US-DOE (2016, *Global Energy Storage Database*, www.energystorageexchange.org/.

Figure 56: note: NaS = sodium sulphur; Li-ion = lithium ion; CAES = compressed air energy storage.

Figure 57: source: Platts (2015), *World Electric Power Plants Database*.

Bottom row textbox: source: GTM (Greentech Media) (2016), *US Energy Storage Monitor*.

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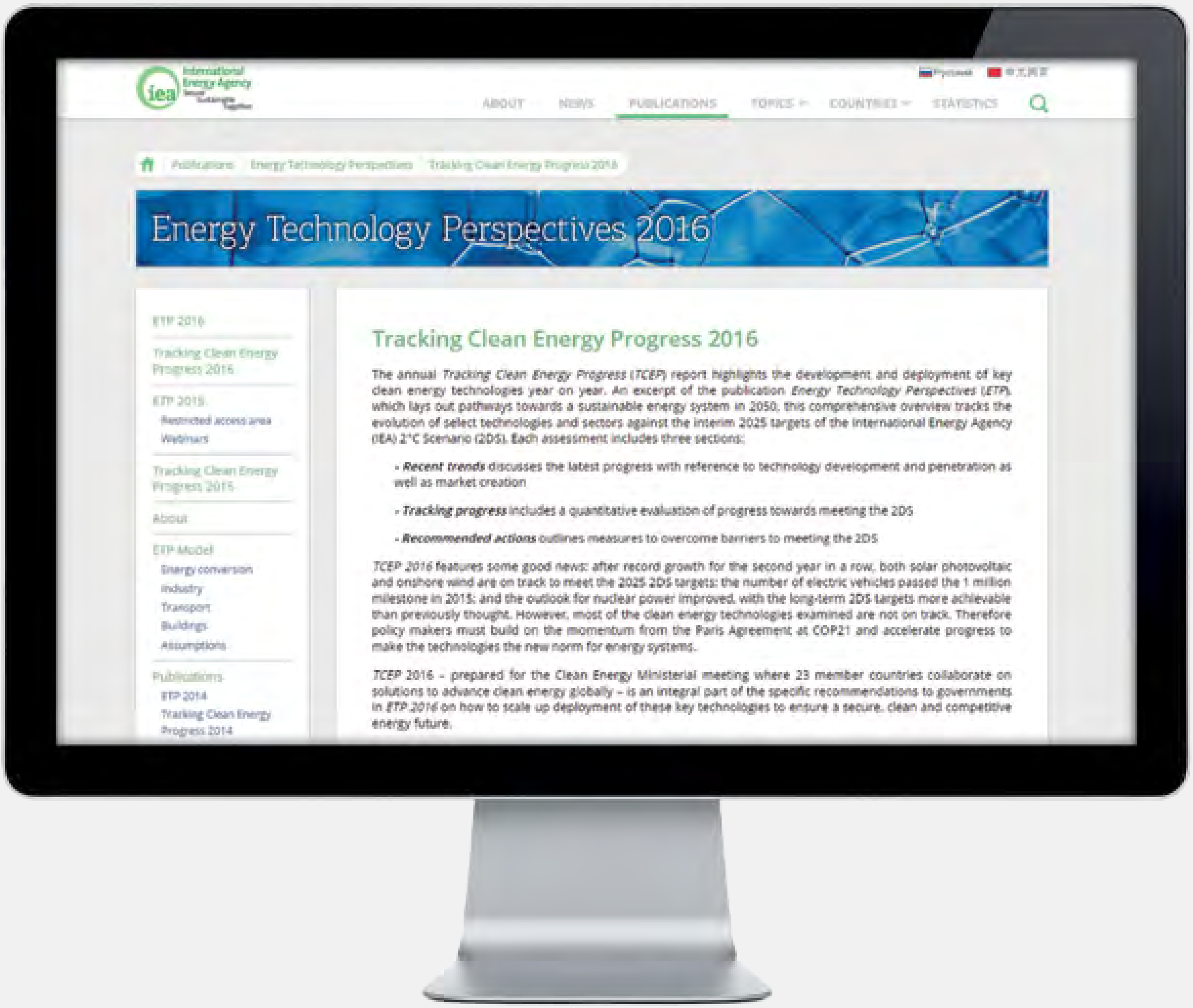

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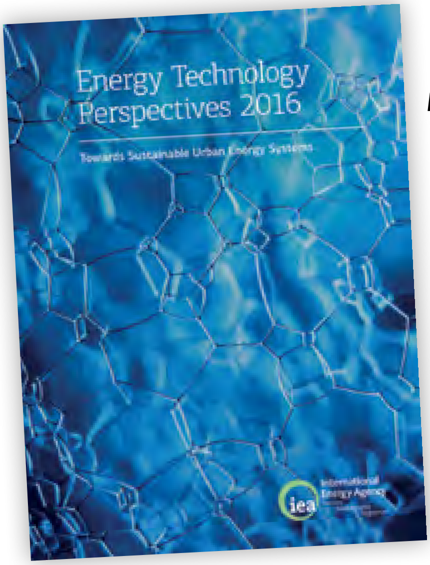

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Four decades ago, the IEA founders had the foresight to create a multilateral mechanism for governments and industry to accelerate energy technology innovation worldwide that has stood the test of time. Today, it is more relevant than ever to delivering solutions to global energy challenges. The publication ***Technology Collaboration Programmes: Highlights and Outcomes*** provides an overview of the activities and recent accomplishments of these experts groups. www.iea.org/tcp/

The ***IEA Policies and Measures Databases*** contain information on policies and measures to reduce greenhouse gas emissions, improve energy efficiency and support renewable energy. This online service complements the policy analysis carried out by the IEA and covers all IEA member countries as well as many non-member countries. Delegates from IEA member countries are given the opportunity to review the information twice a year. www.iea.org/policiesandmeasures

IEA Technology Roadmaps help set the agenda for development and deployment of key low-carbon energy technologies. These free publications identify pathways and priorities to support technological advances and uptake in alignment with ETP scenarios of energy system decarbonisation. Twenty-one different technologies have been covered, embracing energy supply, energy demand, integration, industry sectors and mitigation. These are complemented by the ***How2Guides*** – a series of manuals for policy and decision makers to plan and implement technology roadmaps that are tailored to national or regional frameworks. www.iea.org/roadmaps

Nordic Energy Technology Perspectives 2016 goes beyond the 2 Degree Scenario and assesses pathways to a carbon-neutral Nordic energy system in 2050. The report assesses how the five Nordic countries can build on their pioneering efforts in decarbonisation, with a special focus on urban transport and buildings, high penetrations of variable renewables, and the role of a more interconnected and flexible cross-border electricity grid. www.iea.org/etp/nordic

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Tracking Clean Energy Progress 2016

Energy Technology Perspectives 2016 Excerpt
IEA Input to the Clean Energy Ministerial

The annual *Tracking Clean Energy Progress* (*TCEP*) report highlights the development and deployment of key clean energy technologies year on year. An excerpt of the publication *Energy Technology Perspectives* (*ETP*), which lays out pathways towards a sustainable energy system in 2050, this comprehensive overview tracks the evolution of select technologies and sectors against the interim 2025 targets of the International Energy Agency (IEA) 2°C Scenario (2DS). Each assessment includes three sections:

- **Recent trends** discusses the latest progress with reference to technology development and penetration as well as market creation.
- **Tracking progress** includes a quantitative evaluation of progress towards meeting the 2DS.
- **Recommended actions** outlines measures to overcome barriers to meeting the 2DS.

TCEP 2016 features some good news: after record growth for the second year in a row, both solar photovoltaic and onshore wind are on track to meet the 2025 2DS targets; the number of electric vehicles passed the 1 million milestone in 2015; and the outlook for nuclear power improved, with the long-term 2DS targets more achievable than previously thought. However, most of the clean energy technologies examined are not on track. Therefore policy makers must build on the momentum from the Paris Agreement at COP21 and accelerate progress to make the technologies the new norm for energy systems.

www.iea.org/etp/tracking

Visit our website for interactive tools, additional data, presentations and more.

TCEP 2016 – prepared for the Clean Energy Ministerial meeting where 23 member countries collaborate on solutions to advance clean energy globally – is an integral part of the specific recommendations to governments in *ETP 2016* on how to scale up deployment of these key technologies to ensure a secure, clean and competitive energy future.

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