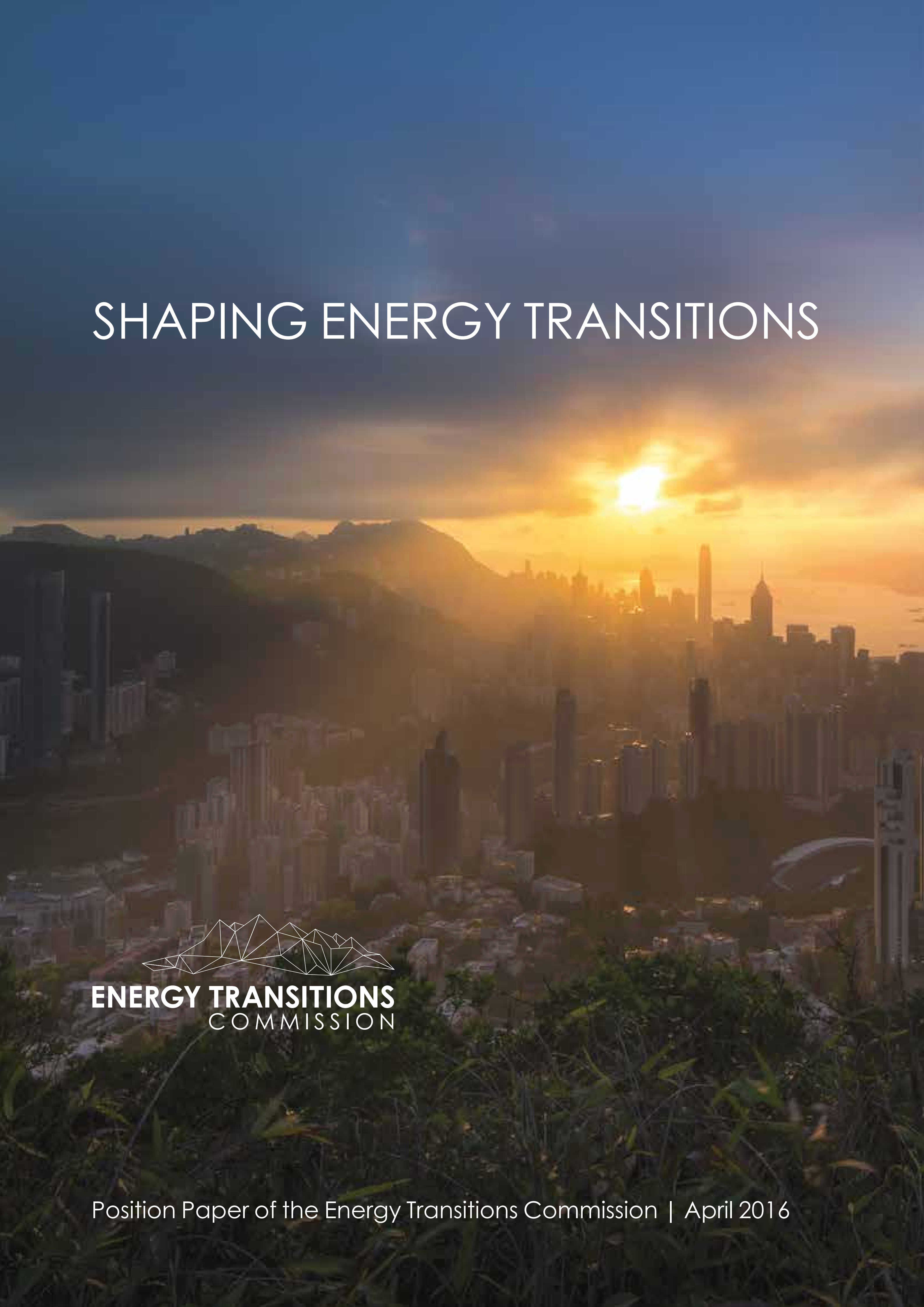

SHAPING ENERGY TRANSITIONS

ENERGY TRANSITIONS COMMISSION

Position Paper of the Energy Transitions Commission | April 2016

This communication is a collective view of the ETC, and may not represent the individual viewpoints of Commissioners and/or their respective organizations.

For an up to date list of all the ETC Commissioners please visite our website energy-transitions.org

EXECUTIVE SUMMARY

Over the course of this century, humanity has to solve an immensely complex problem that requires all of our ingenuity and creativity: we must achieve net zero greenhouse gas emissions[1] at some point between 2045 and 2060 to keep the global average temperature to well below 2°C and pursue efforts to limit the increase to 1.5°C[2]. At the same time, we have to expand the total supply of energy services – currently the main source of carbon dioxide (CO_2) emissions[3] – to meet the rising demand from the world's growing population. The need for more energy services is urgent in low- and middle-income countries. This is where most of the world's poorest live now, and where most of the expected expansion in the world's population to almost 10 billion by 2050[4] is expected to take place.

There is a two-part solution to this energy challenge: reducing emissions stemming from energy supply by increasing the share of zero-carbon energy[5] in the supply mix and moderating growth in demand for energy by radically increasing energy productivity (the economic output generated from each unit of energy used).

Doing both these things should enable us to satisfy future demand for energy without overheating the planet because energy supply will be cleaner and people's needs will be met more efficiently. To limit global warming to well below 2°C, we have to do both these things faster than any historic precedent.

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1 Net zero emissions implies that any man-made emissions are fully offset by negative emissions – i.e., the active removal of carbon from the atmosphere through sustainable carbon sinks. Greenhouse gas emissions include carbon dioxide (CO_2) but also other emissions such as methane, nitrous oxide and fluorinated gases.

2 Or 4°F; relative to pre-industrial levels, as agreed on at the COP21 2015 in Paris.

3 IPCC (2014), "Contribution of Working Group III to the Fifth Assessment Report of the IPCC".

4 United Nations, Department of Economic and Social Affairs, Population Division (2015). World Population Prospects: The 2015 Revision. New York: United Nations.

5 Renewables, nuclear, biomass, and fossil fuels if their use can be decarbonized through carbon capture and storage or carbon capture and usage (CCS/CCU). However, if a large share of increase results from the latter, a higher share is required given CCS/CCU does not reduce emissions to zero completely.

Decarbonizing the power sector is essential, and decarbonized power can be used in an increasing range of economic activities. However, we also need to decarbonize other sectors and value chains. This will require reshaping transport systems, building and urban design, industrial processes, and agricultural activities to enable either cost-effective zero-emissions electrification or a zero-carbon non-power energy supply. In both cases, radical improvements in energy productivity are also required.

incumbent energy companies, industry disruptors, equipment suppliers, non-profit organizations, advisors, and academics from across the developed and developing world. Our aim is to accelerate change towards low-carbon energy systems that enable robust economic development and limit the rise in global temperature to well below 2°C.

We believe that these are compatible goals. They can also be mutually reinforcing as innovations in clean technology create new

> Putting these deceptively simple solutions into practice requires big decisions in every area of human activity, from the international and national policies shaping incentives for public and private investment to the social and individual behaviors shaping patterns of demand.

competitive markets, increasing the pace of innovation. There will be transition costs, given the pervasive role of carbon-intensive energy sources throughout our economy, and any transition will involve winner and loser effects. However, those costs must not be overstated and can be reduced through policies that provide more predictability for investors.

Achieving this will require the widespread use of new energy technologies, more circular production systems using recycled materials and more re-usable components, pervasive digitization to reduce energy waste, as well as more integrated strategies for land, energy, and water use. It will only be possible if technological and design change is complemented and enabled by changes in individual behavior, by new business and financing models, and by predictable policies and regulations which send a strong, clear signal to markets.

Although complex, this creates opportunities to build energy systems that deliver multiple other social and environmental benefits at the same time as achieving dramatic CO_2 emissions reductions. Transformed energy systems can deliver cleaner cities, greater resilience and energy security, and affordable energy for all.

We, the Energy Transition Commission (ETC), are a diverse group of individuals and organizations from energy and climate communities: investors,

This paper introduces the ETC's work program. Beyond identifying what needs to be done, we are committed to clarify how to do it by answering three questions:

- What are the priorities for an efficient acceleration of energy transitions?
- Which decisions could lock in high-carbon energy infrastructure and should be avoided?
- How can transition costs be reduced?

If radical change is not achieved within the next fifteen years, it will become close to impossible to meet the well below 2°C goal. Therefore, the ETC's focus is on those changes that are particularly required in this time-frame. Decisions and action prior to 2030 will not provide all of the answers needed, but getting the next fifteen years right "buys an option" on an energy abundant, climate-secure future; get the next fifteen years wrong, and that option is lost. And: there are still more radical changes needed over the next fifty years.

To answer the questions mentioned above, we will take diverse and sometimes conflicting perspectives into account. In 2016, the ETC will bring that diversity to bear on four critical issues:

- **How fast can energy productivity be improved and what is required to achieve rapid improvement?** What explains the massive gaps between different projections of energy demand for the next 15 to 35 years? What factors could lead to a step-change in energy productivity? How could they be accelerated?

- **How to accelerate growth in the market share of zero-carbon energy?** How can we accelerate the growth of zero-carbon sources of power supply, overcoming possible problems such as variability of supply? How big is the potential to drive wider decarbonization by applying zero-carbon power to an increasing range of economic activities? Are there other technologies that are essential to achieve adequate decarbonization of the total energy system? In which specific applications are they likely to be feasible and economic?

- **How could different countries accelerate their energy transitions?** What ways to reduce greenhouse gas emissions do countries prioritize in their Intended Nationally Determined Contributions (INDCs)? Given that the INDCs in aggregate would still commit us to global warming well above 2°C, what opportunities are there to drive significantly lower emissions, while still delivering increased energy supply and economic growth especially in low- and middle-income countries?

- **What role will fossil fuels play in the transition to a world where warming will remain well below 2°C?** How do different assumptions, including those relating to carbon capture and storage or carbon capture and use (CCS/CCU), lead to different patterns of fossil fuel use and supply in well below 2°C pathways? What are the implications for key markets and stakeholders?

WHY ETC: MISSION AND CORE BELIEFS

Energy demand and energy-related CO_2 emissions have been growing continually for the past 25 years[6]. This has sparked a debate about a potential tradeoff between economic growth and climate change action. Some argue that we must accept the dominance of carbon-intensive energy sources for the next three to five decades as an unavoidable price for economic development. This would imply that climate action should be back-ended, with radical reductions achieved later in the century, when technological development has massively reduced the cost of zero-carbon energy. Others believe in quite the opposite: that energy system transformation must speed up dramatically over the next 15 years if we are to have any chance of staying well below 2°C. They point to rapid progress already being made in new energy technologies and stress that an estimated USD 90 trillion[7] investments in infrastructure required over the next 15 years create an opportunity to build a zero-carbon system.

Our mission: We aim to accelerate change towards zero-carbon energy systems that enable robust economic development and limit the rise in global temperature to well below 2°C.

The ETC has been designed to force these tough energy transition questions onto the table by bringing together leaders from all parts of the energy industry and surrounding ecosystem. We have different views about the feasible pace and optimal design of potential energy transition pathways. We have different beliefs about the costs of transition and the risks of

6 PBL (2015), "Trends in Global CO_2 Emissions 2015 Report".

7 The Global Commission on the Economy and Climate (2014), "New Climate Economy Technical Note: Infrastructure Investment Needs of a Low-Carbon Scenario".

different pathways. However, we share a sense of urgency and a belief that if we are able to develop reliable facts, actionable options and transparency around trade-offs together, then these will gain traction and enable better energy decision making in both public and private sectors. If the diverse members of the ETC can all agree on essential features of what is required, we could make a material contribution to accelerating better energy transitions across the world.

Our mission:
We aim to accelerate change towards zero-carbon energy systems that enable robust economic development and limit the rise in global temperature to well below 2°C.

We believe that:

- There is an affordable, practical set of solutions to the challenge of energy system transitions, which can enable both more energy services in low- and middle-income countries and emissions reductions sufficient to keep global warming well below 2°C. Climate goals and economic growth are interdependent and must be achieved together – we are facing not one energy transition, but a series of interconnected transitions.

- Energy policy and business decisions made over the next 15 years are critical because they will determine whether we can achieve this transitions without prohibitive later cost. Getting the next 15 years right is necessary, but not sufficient for achieving that goal.

- Nonlinear change is needed – significant innovation in technology, financing, and business models is required on both the supply and demand side of energy systems to spark exponential progress towards the goal.

- There are hidden costs and cross-subsidies in existing energy systems and transition costs that need to be addressed. Managing costs and benefits across time and space will be critical for successful transitions.

- We can add most value by focusing on solving the "how" rather than the "what" – recognizing that each "how" requires an approach tailored to its context, and must often overcome some difficult dilemmas. To do so, our diversity is a huge asset. We aim to build an open and diverse learning community anchored in high-quality information, tools, and analytics. We need to learn from the past, and challenge and learn from each other.

THE DIMENSIONS OF THE CHALLENGE

Over the next decades, the world needs to expand energy services to meet growing demand and at the same time reduce energy-related CO_2 emissions rapidly to ensure that global warming remains well below 2°C.

“100 GJ per capita has been historically required per year to achieve a good standard of living”

CO_2 emissions from energy systems have risen from 20 Gt in 1990 to over 30 Gt in 2012, and about 70% of all CO_2 emissions[8]. This is due to two developments over this period:

- First and primarily, an increase in primary energy consumption of more than 50%,[9] driven largely by economic growth in middle-income countries, and
- Second, because the carbon intensity of energy supply has not decreased[10]. For example, the share of coal in primary energy use actually increased from about 26% to 29%[9], largely to satisfy growing power demand in emerging economies.

However, the typical per capita energy consumption of middle-income countries is still well below that of high-income countries: on average, these still consume three times more energy per capita than non-OECD countries (Exhibit 1). Further increases in energy supply are necessary in low- and middle-income countries to achieve increased prosperity. Comparing per capita energy consumption and the Human Development Index (HDI) across countries and time reveals that about 100 GJ primary energy per capita has been historically required per year to achieve a good standard of living. Below this, the HDI declines, while above the 100 GJ level, it increases on a limited basis with diminishing marginal returns (see Appendix

8 IEA (2015), “CO_2 Emissions From Fossil Fuel Combustion Highlights”.
9 Enerdata (2015), World primary energy consumption.
10 IEA (2016), “CO_2/TPES”, World Indicators for 1990 and 2012.

EXHIBIT 1

Current energy per capita varies significantly across the world

Average per capita primary energy consumption; GJ/capita; 2014

1 2013 due to limited data

SOURCE: Enerdata (2015), Historic actuals; UN Population Division (2015), World Population Prospects: The 2015 Revision

I). In the future, this threshold level of energy consumption may decrease because of energy efficiency. China, India, and other emerging markets are building energy systems to power the factories and cities where they expect an additional 1 billion middle-class consumers to work and live by 2025[11]. On the sametime, 1.1 billion people in low-income countries still lack power and 2.9 billion people do not have clean cooking facilities[12]. About 800 million people, mainly in Africa, may still be without power in 2030[13].

Some of the increase in emissions arising in middle-income countries, meanwhile, derives from household consumption in the high-income world. In its Fifth Assessment Report, the IPCC recognizes that the shift in energy-intensive manufacturing to China and other middle-income countries has enabled high-income countries to offshore a significant percentage of their domestic emissions (up to 48% according to some estimates[14]). Future offshoring of energy-intensive industrial activity to more developing countries may therefore lead to increased global CO_2 emissions.

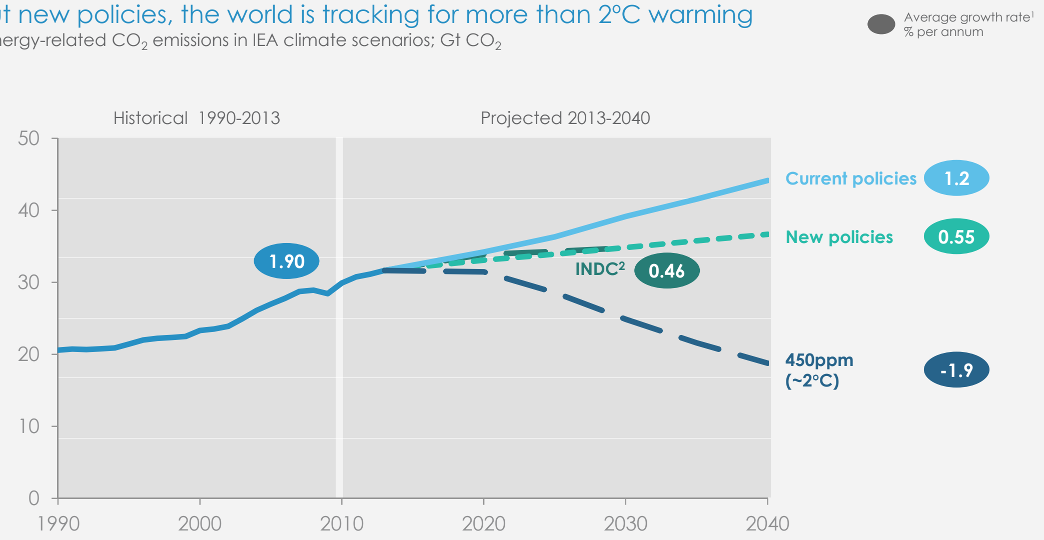
Yet, the rise in CO_2 emissions needs to be reversed. The climate objective agreed at the COP21 is to keep any increase in global temperature versus pre-industrial levels well below 2°C and to pursue efforts to limit it to 1.5°C[15]. To achieve this, energy-related CO_2 emissions would need to fall by nearly 70% by 2050 compared to 2010 levels[16]. At the same time, CO_2 would need to be actively removed from the atmosphere to reach net zero emissions between 2045 and 2060, followed by decades of net negative emissions[16]. In theory, net zero emissions allow for a modest level of

11 McKinsey Global Institute (2012), "Urban World: Cities and the rise of the consuming class".
12 SE4All (2015), "Progress Towards Sustainable Energy 2015", Global Tracking Framework.
13 IEA (2015), "World Energy Outlook: New Policies Scenario.
14 Xu, M., Li, R., Crittenden, J. C., & Chen, Y. (2011). CO_2 emissions embodied in China's exports from 2002 to 2008: A structural decomposition analysis. Energy Policy, 39, pp. 7381-7388.
15 IEA ETP (2015): 2DS described as a pathway that yields at least a 50% chance to limit the mean global temperature increase to 2°C compared to pre-industrial levels. It is largely in line with the IEA World Energy Outlook 450 ppm (parts per million of CO_2 in the atmosphere) scenario.
16 Rogelj, J. et al., (2015), "Energy system transformations for limiting end-of-century warming to below 1.5°C", Nature Climate Change 5, pp. 591-527.

EXHIBIT 2

Without new policies, the world is tracking for more than 2°C warming

Global energy-related CO_2 emissions in IEA climate scenarios; Gt CO_2



1 Intended Nationally Determined Contributions to CO_2 emission reductions for COP21. Average growth rate 2013-2030

SOURCE: IEA (2014), CO_2 Emissions from Fuel Combustion; IEA (2015) World Energy Outlook; IEA (2015) World Energy Outlook Special Report on Energy and Climate Change

emissions, provided there are ways to remove an equivalent number of gigatons from the atmosphere, through sustainable natural sinks (e.g., forests and soil), leak-free storage systems (e.g., saline aquifers) and/or other CO_2 removal techniques. Staying within the 1.5°C requires further halving aggregate CO_2 emissions over the 21st century compared to 2°C scenarios and global emissions reach a net zero level 10 to 20 years earlier[17].

The INDCs submitted ahead of the COP21 show that given current national intentions, emissions growth would be slowed down. Yet, this would not be nearly sufficient to reach the well below 2°C goal. And, to realize current plans would, in many countries, require financial flows (including greater concessional flows to developing countries), which are not certain to occur.

The ETC has, therefore, analyzed in detail the specific assumptions, proposed policies, and categories of change which underpin the INDCs. Based on this analysis, we will identify: (i) the scale and specific nature of the energy transitions challenge, overall and by specific major country, (ii) the required changes in approach, policy, and financial flows required to make more radical reductions feasible, and (iii) the scope to ratchet up the ambition of countries before they submit the next round of INDCs to the United Nations Framework Convention on Climate Change (UNFCCC) in 2018. The findings of this analysis are available in the paper:

- Renewable power capacity to expand four times as much as fossil fuel power, and 70% of the growth to occur in developing countries;
- Limited growth in natural gas power generation in developed economies and continued growth in coal-generated power in developing countries;
- Very limited measures to decarbonize energy supply beyond the power sector;
- Limited specificity and large variation in energy productivity ambitions;
- One fifth of the total emissions reductions depends on international financial support and technology transfer.

17 Rogelj, J. et al., (2015), "Energy system transformations for limiting end-of-century warming to below 1.5°C", Nature Climate Change 5, pp. 591-527.

To remain well below 2°C, greenhouse gases would need to be actively removed from the atmosphere to reach net zero emissions by 2045-2060, followed by decades of net negative emissions.

MAKING THE TRANSITION

The ETC's Energy Transitions Matrix (Exhibit 3) presents in simple terms what needs to be done to both expand energy supply and reduce emissions (see Appendix II for its derivation). Globally, we need to do two things well. First, drive increases in energy productivity – measured by economic output achieved per unit of energy consumed – much faster than in the past. World energy productivity increased on average 0.9% per year between 1980 and 2014[18], a period spanning decades of both low and high energy prices[19]. To limit global warming to well below 2°C a 3% annual improvement in the average global energy productivity is needed up to 2050[20].

Second, we need to radically reduce the average carbon intensity of the global energy supply, increasing the percentage that comes from zero-carbon sources. Included here are renewables, nuclear, biomass, and fossil fuels if and when their use can be decarbonized through CCS/CCU. However, if a large share of the increase is from the latter, a higher share is required given CCS/CCU typically does not reduce emissions to zero.

To keep warming well below 2°C would require the share of zero-carbon energy in the global energy system to increase by at least 1 percentage point per annum between now and 2050. Achieving such a rapid share increase will be difficult: it has increased by only 0.1 percentage points per annum between 1980 and 2014[18], mainly due to recent increases in the share of renewables in power generation. However, power makes up just 18% of total final energy consumption[21]. The shift towards zero-carbon energy sources needs to accelerate dramatically not only in the power sector (where we have seen greatest progress so far), but in particular in other sectors and activities: transport, heating, and industry.

18 Enerdata (2015), Historical actuals, "World Primary Energy Demand (PJ)"; World Bank (2015), Databank. "World GDP (constant 2005 US$)".

19 Latest IEA results indicate stronger energy productivity performance in 2014, but it is not clear whether this is a short-term response to higher energy prices in the previous five years or the start of a structural performance shift.

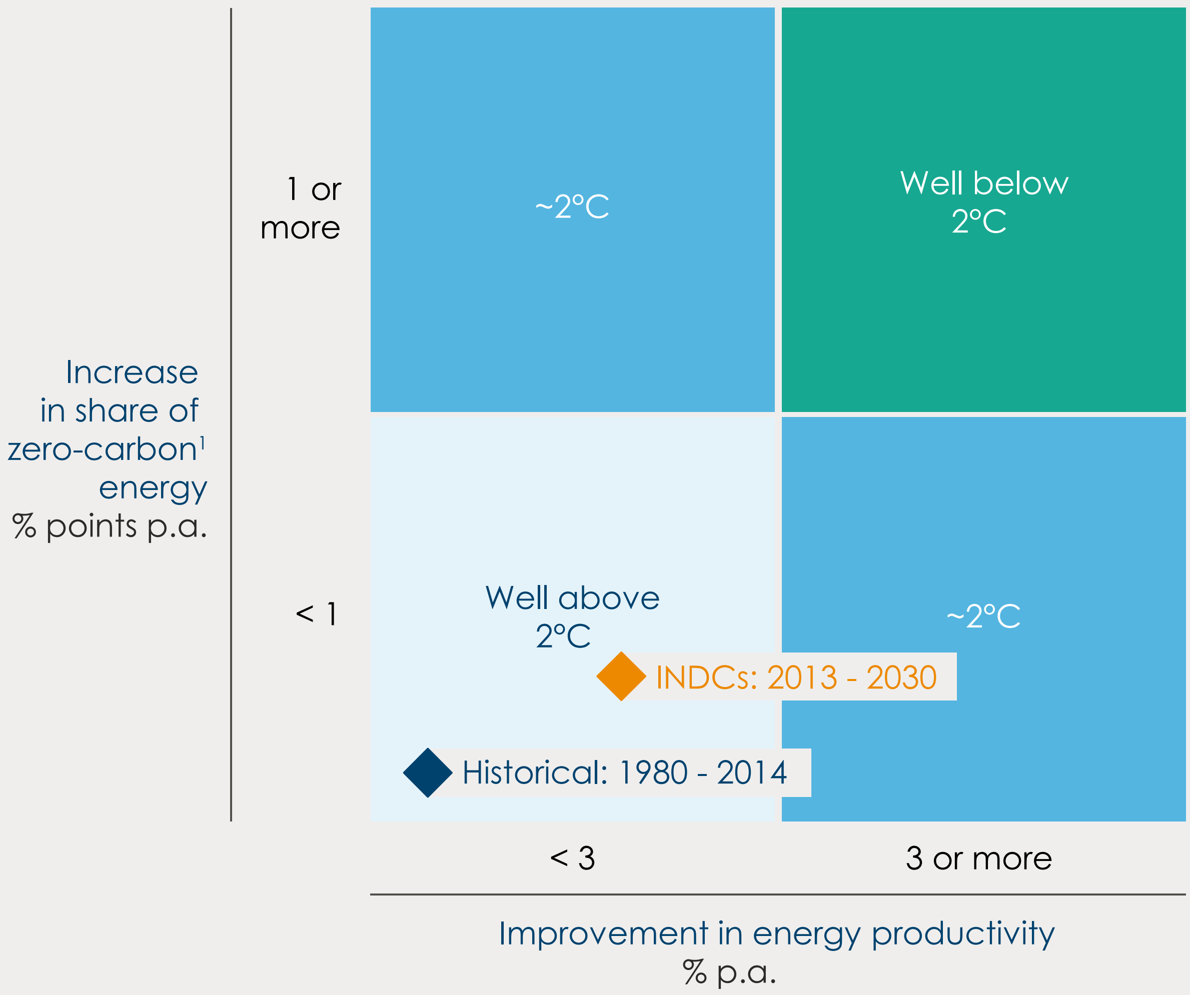
20 IIASA (2016), 450 ppm scenarios; IEA ETP (2015), 2DS.

21 Enerdata (2015), Historical actuals.

Exhibit 3

Energy productivity and the share of zero-carbon energy will drive overall system change

Global primary energy demand, 2012-2050



1 We include here renewables, nuclear, biomass and fossil fuels if and when their use can be decarbonized through carbon capture and use or storage (CCS/CCU). However, if a large share of the increase is from CCUS, a higher share is required since this does not reduce emissions to zero completely

SOURCE: Enerdata (2015), Historic actuals

CAN IT BE DONE?

The Energy Transitions Matrix illustrates the scale of the energy transitions challenges we face. However, the questions it raises point to equally important opportunities for beneficial change and innovation.

What would it take to increase energy productivity by more than 3% per year?

The challenges are undoubtedly great, but we are confident that they can be faced by a mix of changes:

- Major improvements in energy and material efficiency with which unchanged consumer preferences are met or even exceeded, as we have seen, e.g., in the development of new lighting technologies which are cheaper, more energy efficient, and (increasingly) more versatile than incandescent light bulbs;
- Adjustments in consumer behavior which change the energy intensity of specific products and services, such as a shift in preferences of an ever more urban population towards hybrid models of mobility service;
- Radical changes in business processes, e.g., through the widespread application of better, digitally-enabled information management and more circular production systems.

Whilst a shift in the pattern of growth towards less energy-intensive, often higher value-added sectors and forms of consumption can improve energy productivity at a national level, this is not necessarily the case at the global level and, thus, requires careful international coordination. Together, these changes may have profound systemic effects in for example:

Transport: Energy productivity of personal transport systems can undoubtedly be increased by continued improvements in vehicle efficiency and design (e.g., ultralight electric vehicles). Thus, CO_2 emissions can be largely reduced, that is if consumer behavior does not generate a "rebound effect," for example by demanding vehicles that are technically more efficient, but at the same time also larger. Additional savings can be achieved through greater use of public transport and car-sharing – enabled by a combination of better information management, changes in consumer preference, driverless vehicles, and new patterns of urban design. These would not only be direct savings from lower energy demand, but also through an indirect effect on demand for energy-intensive steel. Some scenarios suggest that such changes could allow the same fundamental demand for "transport services" to be met with 30 to 50% less capacity in the automotive industry by the 2030s. That in turn would translate into a 10 to 20% reduction in steel demand relative to more conventional linear projections[22].

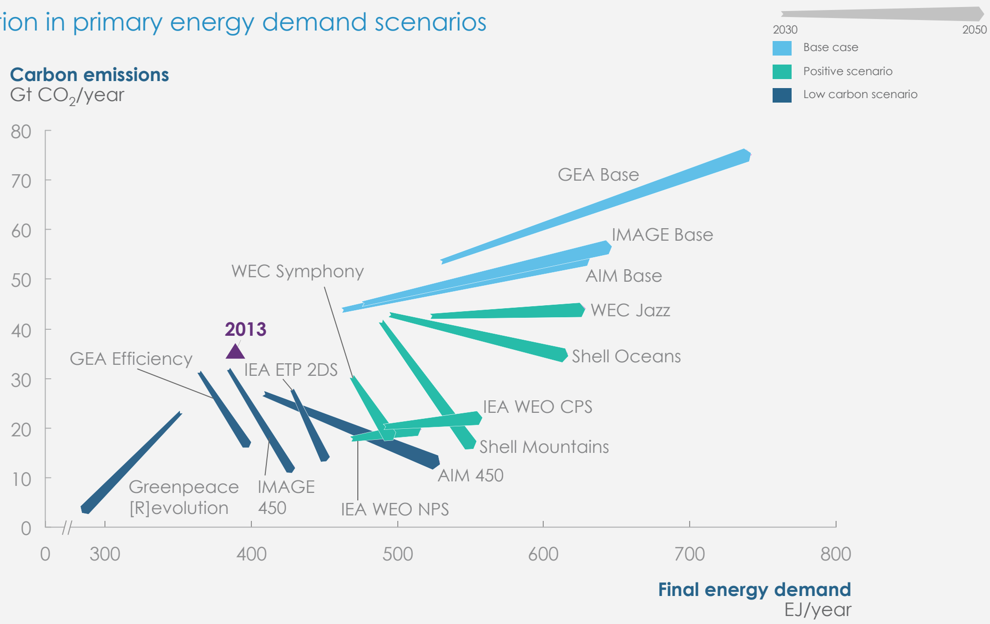
More electrification of personal transport, meanwhile, would not only enable decarbonization of energy supply (provided that power came from increasingly low-carbon sources). It would probably also go hand in hand with greater residential use of energy storage and distributed generation capacity. This blurs the line between energy supply and demand (the so-called "prosumer" model), enhancing grid value and helping to integrate renewables.

Buildings and urban design: Until 2050, the world's urban population will likely grow by 6 billion[23]. This will generate massive investment in residential housing as well as in offices and other commercial space. The way in which new buildings are constructed will, therefore, hugely influence emission: first, by the energy and carbon intensity of the building materials used, and second, by the requirements of building insulation, shell, equipment, and operational efficiency (e.g., heating and/or cooling). In addition, overall urban design, e.g., the choice between dense high-rise cities and spread-out suburban development, can have a major impact on the energy requirements of both transport and building sectors.

The resulting wide range of possible energy productivity paths is reflected in the very large variations found in different projections of energy demand produced by different organizations (Exhibit 4). A key starting point for the ETC analysis will, therefore, be to explore the assumptions behind the different projections, and identify where the application of new technologies and innovations, or changed policies and behaviors, have the greatest potential to constrain or reduce energy demand.

EXHIBIT 4

Large variation in primary energy demand scenarios



22 Ellen MacArthur Foundation (2015), Growth within: A circular economy vision for a competitive Europe.

23 United Nations, Department of Economic and Social Affairs, Population Division (2015). World Population Prospects: The 2015 Revision. New York: United Nations.

Is it possible to shift towards zero-carbon energy sources in time?

The crucial challenge here is to accelerate the change already occurring in the power sector and to find ways to decarbonize energy supply that is delivered in a non-power form (Exhibit 5).

Power: The pace of change in the power sector is already speeding up and there are now credible technical and economic pathways towards zero-emissions power systems. The last decade has seen accelerating technological progress, with growth in solar PV and onshore wind running much faster than anticipated[24]. Most new investment in power generation capacity is now going into renewables.

However, this acceleration needs to be maintained and still further intensified. Despite significant progress, wind accounted for only 2.9% of total power generation in 2014, while solar energy (photovoltaic and concentrated solar power) accounted for just 0.7%[25]. Hydropower remains the biggest source of renewable energy at around 17% of total power supply, while nuclear accounts for 11%[25]. While there is still potential for some further hydropower growth especially in developing countries provided that local environmental and community concerns can be addressed, rapid progress in other zero-carbon technologies is essential to decarbonize the power sector.

The potential for large-scale CCS and CCU also needs to be carefully assessed. In the short term, these are the continued use of carbon in enhanced oil recovery, chemicals, and plastics. However, in the mid- and long-term, cement, algae-based fuel, and carbon fiber could be high-volume uses. These emerging technologies and applications potentially create a commercially market for CO_2 emissions and, at the same time, drive down CO_2 capture costs. This may help to overcome some of the barriers, which so far have made it hard to scale and replicate more traditional CCS in the power sector.

Moreover, these measures can be complemented by a shift towards cleaner fossil fuels such as natural gas, provided that actions are taken to tackle the risks of methane leakage, infrastructure lock-in and crowding out of renewables. Other measures such as the combination of afforestation and CCS/CCU with biomass-fired power[26] will also be needed to further reduce emissions in the second half of this century, to reach the goal of net zero and subsequently negative emissions. Indeed, terrestrial carbon sinks such as forests (and other forms of soil carbon) together with other storage systems (e.g., saline aquifers) will be essential to complement the necessary increases in energy productivity and the share of zero-carbon energy sources outlined above.

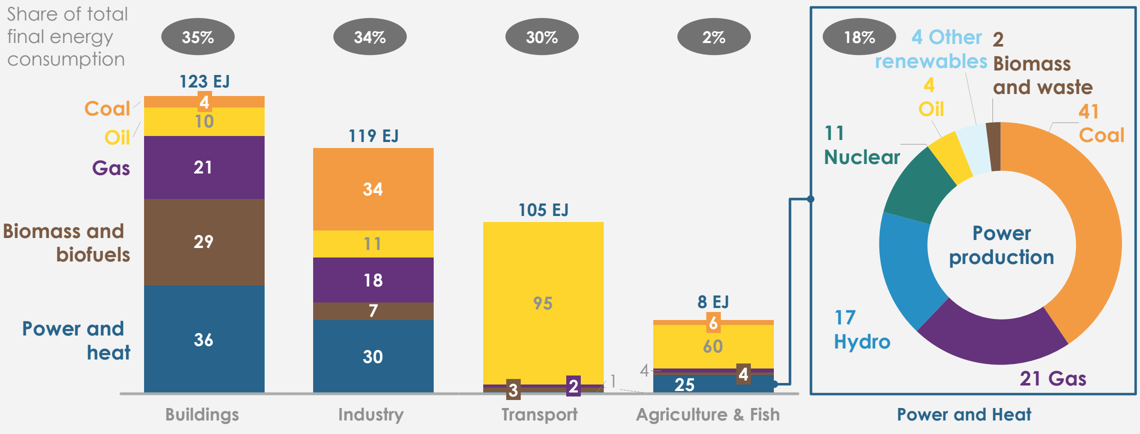
Energy currently supplied in non-power form: As importantly, we now need to accelerate progress in decarbonizing those energy-intensive processes and activities that are not electrified. While zero-carbon sources now account for about one third of power generation, they account for only 8 to 10% of total global primary energy consumption, and that share has been constant since 1990[27]. Other forms of energy such as those required for high-temperature processes, and carbon inputs to primary heavy industry applications (e.g., steel, iron, cement, chemicals, and plastics), are at the heart of the modern global economy, but also the most challenging to decarbonize. As is also the case in the transport and buildings sectors, encouraging the necessary churn of capital

24 IEA (2005, 2010, 2015), "World Energy Outlook".
25 Enerdata (2015), Electricity Production by Source.
26 IPCC (2014), Summary for policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, US.
27 Enerdata (2015), "Electricity Production by Source" and "World Primary Energy Consumption".

EXHIBIT 5

Each sector has different energy transition challenges

Global final energy use by sector and source; Percent, 2014



Note numbers may not add due to rounding

SOURCE: Enerdata (2015), "Global final energy consumption" and "Electricity production by source" – historical actuals

stocks and developing new technologies, skills, and supply chains will require long-term policy and price signals. Actions need to be taken now for those industrial, transport and building/urban transitions to complement and feed off the shorter-term "easier" decarbonization priorities such as in the power sector.

Reviewing different 2°C energy scenarios[28] reveals that 30 to 50% of global primary energy consumption needs to come from zero-carbon energy (noncombustible renewables and nuclear) by 2050 even if another 30% can come from biomass and CCS/CCU[29].

The crucial question is, therefore, what combination of strategies can ensure the required decarbonization. Two complementary routes are possible:

- Achieve greater electrification of sectors and/or applications such as in surface transport and heat supply within buildings and industry, now that we know in principle how to decarbonize power generation;
- Deploy other technologies such as hydrogen derived from zero-carbon sources or modern bio-energy (provided they do not compete with food production), or use CCS/CCU to make fossil fuel use potentially zero-carbon and decarbonize non-power energy sources.

The ETC is convinced that some combinations of these strategies can deliver the required results. However, the optimal balance is currently unknown, and it is clear that relying on market forces alone will not produce sufficiently rapid transition, especially in the absence of robust, government-led carbon pricing (together with more stringent regulations on other greenhouse gases, such as HFCs and methane). Studying previous energy transitions shows that the market shares of traditional fuels – coal, oil, and natural gas – increased slowly over time (Exhibit 6), driven largely by market forces. The later technologies of nuclear, liquid natural gas, and first-generation biofuels took up to 30 years to reach a share in the total primary energy market greater than 1%[30]. Once they reached 1%, all these energy sources increased

28 IIASA (2016), 450 ppm scenarios (corresponds to less than 2°C warming).

29 IEA ETP (2015), 2DS; GEA (2014), Riahi, K. et al. (2012), Energy Pathways for Sustainable Development. In Global Energy Assessment - Toward a Sustainable Future, Cambridge University Press, Cambridge, UK, and New York, US and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 1203-1306.

their market shares by 0.3 to 0.9 percentage points a year over the next 25 to 50 years, as did oil, growing its share of primary energy consumption from around 10% in 1920 to 40% by 1970[31]. However, if zero-carbon energy sources grow this slowly, emissions will not fall rapidly enough to make the well below 2°C target anywhere near feasible. Adequately rapid progress will require a significant role for policies such as a predictably rising carbon price (still the first-best instrument in any decarbonization policy package), substantial funding for early-stage research, vastly improved urban planning, stronger self-ratcheting efficiency standards, and other interventions that support rapid deployment of a range of different technologies.

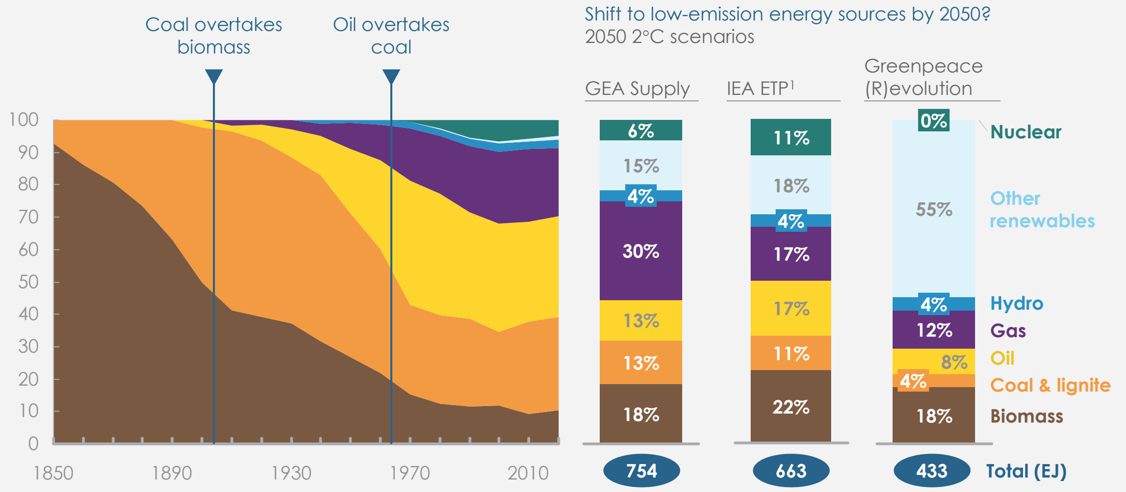
Structural shifts in relative shares of fossil fuels and renewable energy sources will have profound implications on infrastructure (e.g., the grid), market structures, producers, and consumers. For example, more renewables will mean more variable power supply, raising questions of how future energy systems can match supply and demand every day (and every minute). The ETC will explore how to overcome the resulting challenges, comparing different flexibility options including an enhanced grid, storage technologies, conversion to other forms of energy, as well as supply and demand management.

We will also investigate what well below 2°C scenarios imply for the extent to which fossil fuels can be used within the energy system, how this is achieved, their evolution over time and how this will impact markets and key stakeholders. The answer will depend crucially on the realistic potential for CCS/CCU and is likely to be significantly different for oil, natural gas, and coal. It will also necessarily be different for high-, medium-, and low-income countries; however, it is unlikely that even low-income countries can build out their energy systems on a traditional carbon-intensive basis if the world is to stay well below 2°C of global warming.

EXHIBIT 6

Diverging scenarios of shifts to low-emission sources

Share in total primary energy demand; Percent

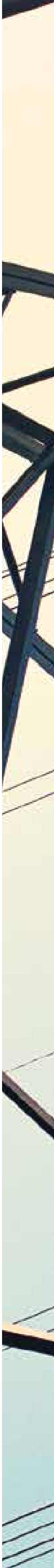


1 Energy Technology Perspectives, similar to IEA World Energy Outlook 450ppm scenario

SOURCE: Smil, V. (2010), "Energy transitions: history, requirements, prospects"; Enerdata (2015), Historical actuals 1971-2014
IEA (2015), Energy Technology Perspectives; GEA (2012), MESSAGE Scenario database (Version 2.0.2); Greenpeace (2015), Energy Revolution

30 Kramer, G. and M. Haigh (2009), "No quick switch to low-carbon energy", Nature 462.3, pp. 568-569.

31 Energdata (2015), Historical actuals.



"Big changes in the relative shares of fossil fuels and renewable energy sources, when they come, will have profound and complex implications on infrastructure (e.g., the grid), market structures, producers and consumers."

ACCELERATING THE TRANSITION

Energy systems need to achieve faster transitions – towards both higher energy productivity and falling carbon intensity – than has been achieved over the last several decades. There are strong reasons for believing that this acceleration is possible.

capacity to direct financial resources towards future opportunities, when the surrounding policy, technological direction, and risks are clear, both globally and locally. And the rate at which policy innovations and effective policy practices spread internationally is increasing.

"One of the key roles of the Commission is to identify where discontinuities might arise and how these could be addressed both to speed up the transition and reduce its costs."

There are already more energy supply and demand technologies to choose from than ever before and the number is likely to expand rapidly over the coming 15 years. Global markets are able to take technologies to scale at an unprecedented rate. Pervasive digitization has the potential to substitute information for energy across multiple sectors of the economy, and is likely to do so at exponentially increasing rates given the growing "digital mindset" among consumers and the rise in digital business models. Today's capital markets have immense

For these reasons, we should not be surprised by the speed at which energy systems may change, with potentially disruptive social and economic consequences. But in practice, we will be surprised. One of the key roles of the ETC is to identify where discontinuities might arise and how these could be addressed to both speed up the transition and reduce its costs.

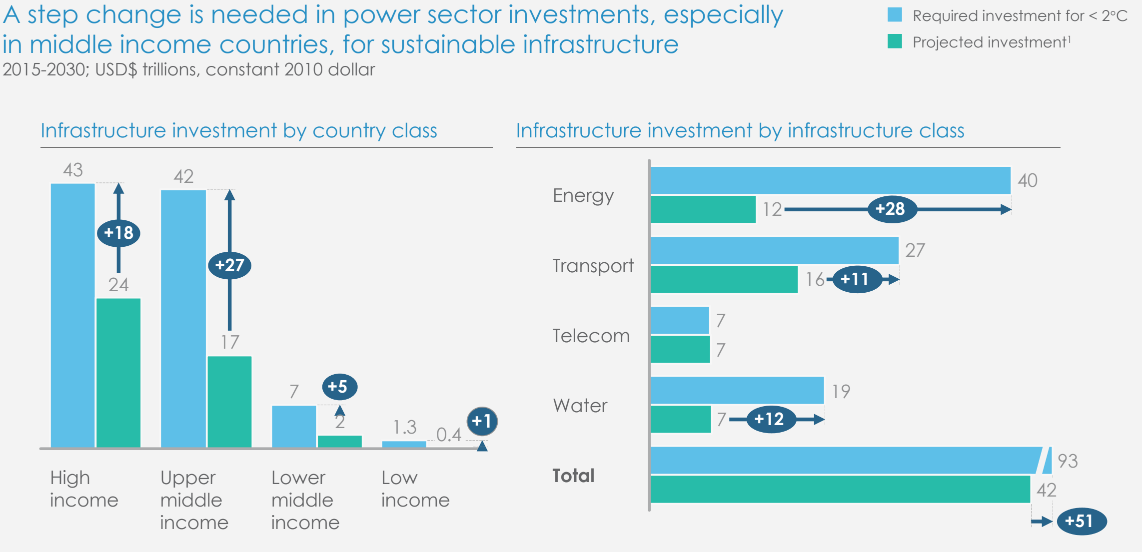
That said, the factors that could slow down change are also considerable. The sheer scale of required investment is very large, and both private asset owners and society at large have legitimate interests in avoiding inefficient value destruction. Policy inertia and distortions that create false price signals such as fossil fuel subsidies[32] can slow technically feasible progress. There is some evidence of rebound effects that can reduce net emissions benefits of more efficient use, though they also increase consumer welfare. Then there is the need for system stability to "keep the lights on", general risk-aversion, and policy uncertainty unfavorable for the long planning horizons of renewable investments. More recently, lower energy prices have limited the direct economic incentives for energy efficiency and low-carbon investments. In some countries, there may also be practical problems arising from weak institutions and ongoing corruption. In others, systemic short-termism in both political institutions and capital markets make it hard to drive long-term change and settle questions about the inevitable transition costs: how to allocate them, when to bear them, and how to minimize them. In all countries, structural shifts in market design that have the potential to create new winners and losers always generate political resistance.

Securing finance in an appropriate form at reasonable prices across the multitude of new business models and technologies will be essential to delivering the energy systems we need. It will not be easy to mobilize the required scale of finance. An estimated USD 3 trillion per year in infrastructure investments will be required up to 2030 for energy transitions worldwide, or just under half of total worldwide infrastructure financing requirements (Exhibit 7)[33]. Middle-income countries will account for the majority of this investment. If this finance can be secured, it represents a huge opportunity to transform energy systems. However, if misdirected, it could lock countries into a high-carbon economy for years to come. So new policies and regulations are needed to allocate transition costs fairly, send the right market signals and create a more predictable environment for long-term investors. ETC members recognize that designing

EXHIBIT 7

A step change is needed in power sector investments, especially in middle income countries, for sustainable infrastructure

2015-2030; USD$ trillions, constant 2010 dollar



1 Extrapolated from historical spending and assuming a continuation of real investment growth (assumes China maintains current investment but does not continue growth in investment at current rate)

SOURCE: McKinsey Center for Business and Environment (2016), "Financing Change: How to mobilize private sector financing for sustainable infrastructure"

32 Coady, D., et al. (2015), "How Large Are Global Energy Subsidies?", IMF Working Paper.

33 The Global Commission on the Economy and Climate (2014), "New Climate Economy Technical Note: Infrastructure Investment Needs of a Low-Carbon Scenario".

predictable, long-term investment environments is easier said than done, especially given volatility in today's energy markets.

The next 15 years are not the "finals", but they are the critical phase in which to establish the drivers of system change until 2050. We will, therefore, focus in particular on these 15 years, but within the contexts of the still more radical changes needed over the next 50. In 2016, we will address four of the tough, undecided systemic questions that will benefit from our diversity of perspective:

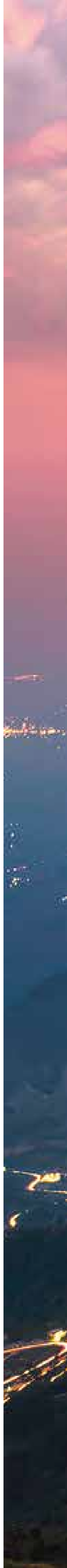
- **How fast can energy productivity be improved and what is required to achieve rapid improvement?** What explains the massive gaps between different projections of energy demand for the next 15 to 35 years? What factors could lead to a step-change in energy productivity? How could they be accelerated?

- **How to accelerate growth in the market share of zero-carbon energy?** How can we accelerate the growth of zero-carbon sources of power supply, overcoming possible problems such as variability of supply? How big is the potential to drive wider decarbonization by applying zero-carbon power to an increasing range of economic activities? Are there other technologies that are essential to achieve adequate decarbonization of the total energy system? In which specific applications are they likely to be feasible and economic?

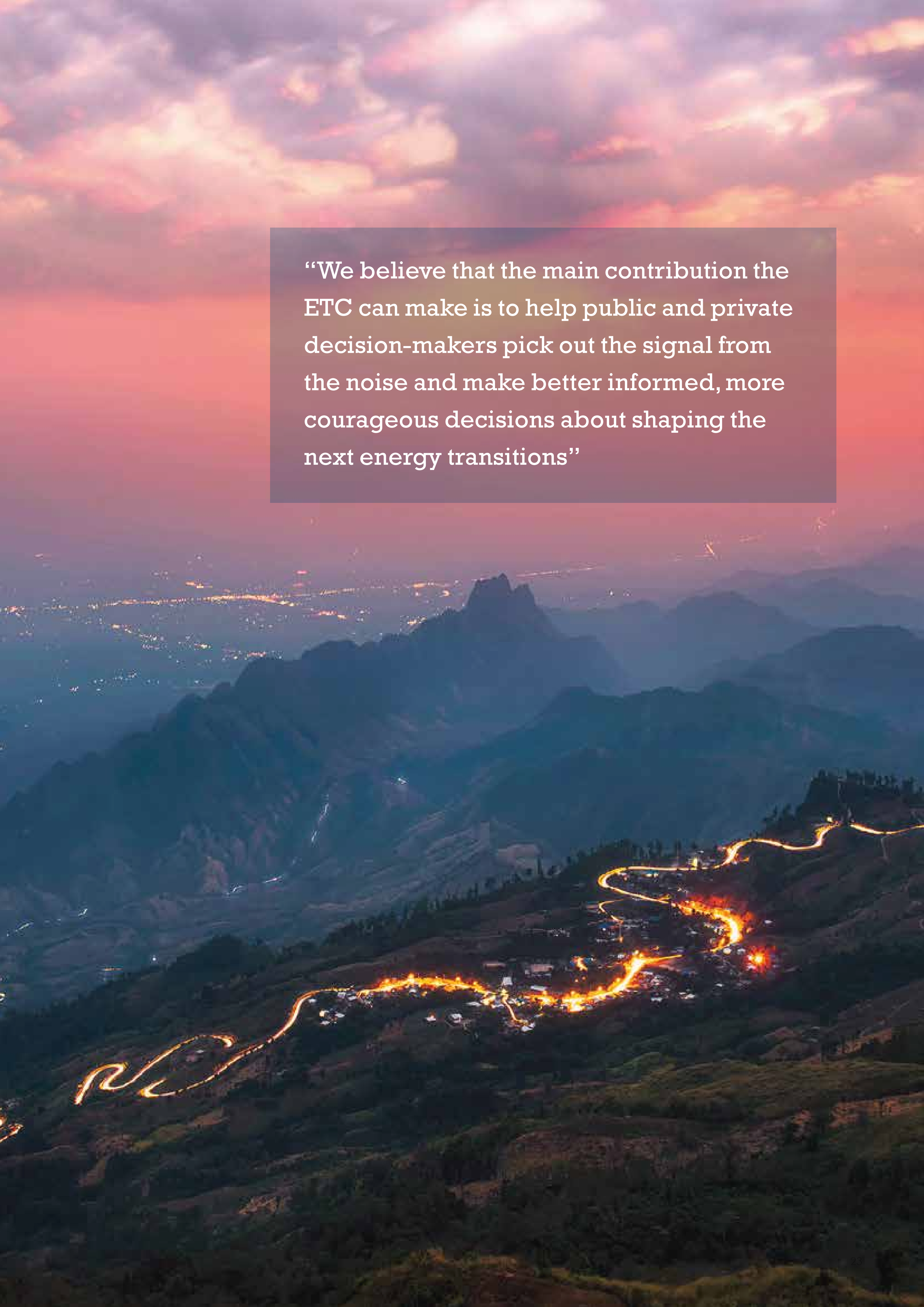
- **How could different countries accelerate their energy transitions?** What ways to reduce greenhouse gas emissions do countries prioritize in their INDCs? Given that the INDCs in aggregate would still commit us to global warming well above 2°C, what opportunities are there to drive significantly lower emissions, while still delivering increased energy supply and economic growth especially in low- and middle-income countries?

- **What role will fossil fuels play in the transition to a world where warming will remain well below 2°C?** How do different assumptions, including those relating to carbon capture and storage or CCS/CCU, lead to different patterns of fossil fuel use and supply in well below 2°C pathways? What are the implications for key markets and stakeholders?

We believe robust answers to some of these questions are already emerging. However, we also recognize inherent uncertainties that make retaining options good strategy. We know that every country and situation is different and decision makers will rightly weigh up their priorities differently. We believe that the main contribution the ETC can make is to help public and private decision makers pick out the signal from the noise and make better informed, more courageous decisions about shaping the next energy transitions.



“We believe that the main contribution the ETC can make is to help public and private decision-makers pick out the signal from the noise and make better informed, more courageous decisions about shaping the next energy transitions”



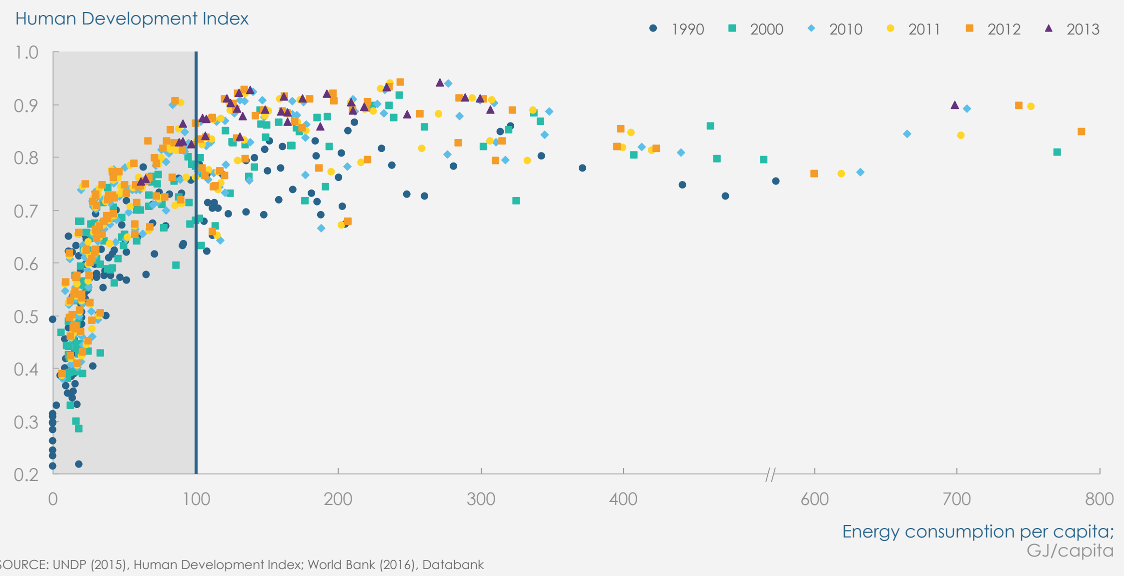
APPENDIX I: THE HUMAN DEVELOPMENT INDEX (HDI) AND ENERGY CONSUMPTION PER CAPITA

In order to determine the average amount of energy required for a good standard of living, we compared per capita primary energy consumption and the Human Development Index (HDI) for 143 countries and six years (the six years are not available for all countries). The HDI stabilizes, despite an increase in energy consumption per capita, around 100 GJ per capita. Energy consumption below this level results also in lower levels of the HDI, while energy consumption beyond 100 GJ per capita barely increases the HDI. There is rather a remarkable range in energy consumption per capita at similar levels of human development.

As improvements in energy efficiency are made and production becomes more circular, the 100 GJ may decrease over time, as less energy is required for production and consumption. This implies that the 100 GJ historically required for a good standard of living may become an energy demand ceiling, which could decrease over time. It is also possible that new energy requirements will emerge, which could result in greater demand for a given standard of living (e.g., as the economy becomes ever more digitized or as CCS/CCU requirements push up energy inputs for a given output), changing historical parameters.

EXHIBIT 8

About 100 GJ per capita required for a decent standard of living



SOURCE: UNDP (2015), Human Development Index; World Bank (2016), Databank

APPENDIX II: DERIVATION OF THE ENERGY TRANSITIONS MATRIX

The Energy Transitions Matrix (Exhibit 3) is based on a mapping of global 450 ppm and 550 ppm scenarios from IIASA and the IEA ETP 2DS (see Exhibit 9). Based on this, we find that to remain well below 2°C global warming energy productivity needs to grow by 3% per year and the share of zero-carbon energy needs to increase by about 1% percentage point per year. In zero-carbon energy we include renewables, nuclear, biomass, and fossil fuels if and when their use can be decarbonized through CCS/CCU. However, if a large share of the increase is from the latter, a higher share is required given CCS/CCU does not reduce emissions to zero completely.

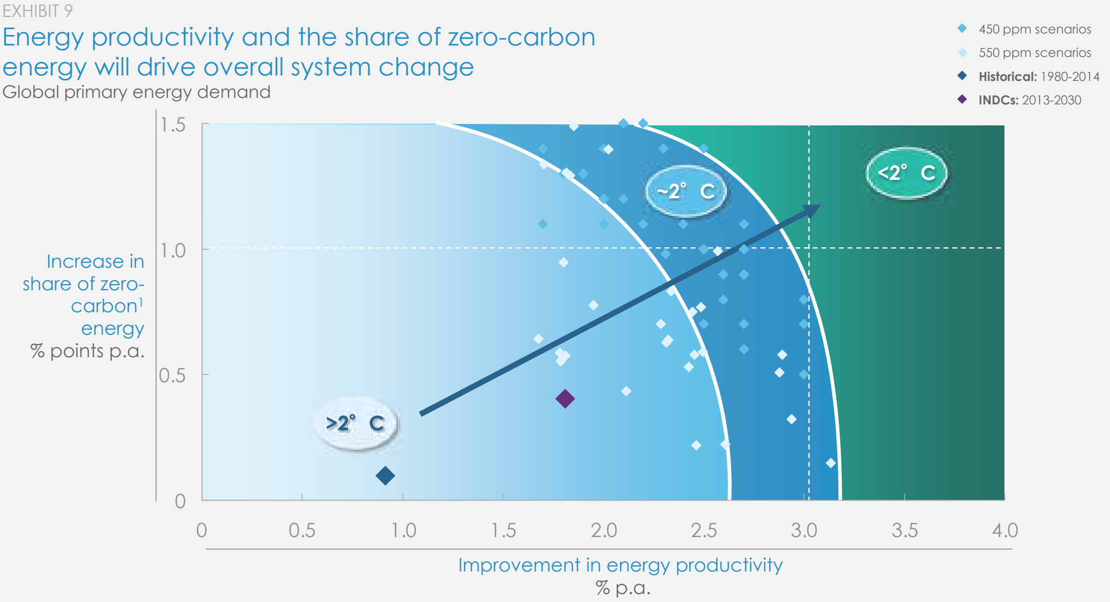
We find that most 2°C scenarios rely on a large increase in the share of zero-carbon energy in supply (top-left quadrant of the matrix). Few if any scenarios focus on energy productivity as the main driver (bottom-right quadrant of the matrix). However, most 450ppm scenarios do have energy productivity improvements beyond 2% per annum, also when the share of zero-carbon energy increases beyond the required 1 percentage point per year. Delivering more on energy productivity has the benefit of reducing the investments required to decarbonize energy supply, which is particularly helpful given the relatively high capital-intensity of low- and zero-carbon energy supply sources.

We find that different combinations of the two options to reduce emissions can yield 2°C pathways. Depending on model and scenario GDP assumptions, the fossil fuel mix (i.e., shift from carbon-intensive to less carbon-intensive sources) and assumptions around carbon sinks, similar levels of energy productivity can be associated with different levels of the share of zero-carbon energy. Outliers in the scatterplot below have more extreme assumptions around one of these variables. In high-growth scenarios, e.g., a much larger increase in the share of

EXHIBIT 9

Energy productivity and the share of zero-carbon energy will drive overall system change

Global primary energy demand



1 We include here renewables, nuclear, biomass and fossil fuels if and when their use can be decarbonized through carbon capture, use and storage (CCUS). However, if a large share of the increase is from the latter, a higher share is required given CCUS does not reduce emissions to zero completely.

SOURCE: IIASA MESSAGE and IMAGE scenarios; IEA (2015), ETP 2 degrees scenario; Enerdata; INDCs of 17 countries representing ~80% of global emissions in 2012 zero-carbon energy is required to remain well below 2°C, so an increase in the share of zero-carbon energy does not guarantee a decline in absolute emissions in the short run.

The simple nature of the matrix is very valuable; however, it has three main limitations. First, the required annual improvement calculated for both axes is based on a linear analysis, while the development of the decarbonization of supply and improvement in energy productivity will likely occur in a nonlinear fashion, compounding over time. There is also not a simple trade-off between the two axes, because an energy system that is 100% based on zero-carbon energy would not require further improvements in energy productivity.

Second, the matrix focuses on the climate challenge ahead, and does not include the challenge of ensuring sufficient energy services across the world, in terms of both energy access and the energy required for economic growth. The ETC, therefore, considers the provision of energy access and sufficient energy for a good standard of living as an assumed minimum requirement together with climate ambitions.

Third, one could incorporate "carbon sinks" (e.g., afforestation) and a shift away from carbon-intensive fossil fuels in the supply axis, defining these as "equivalent to" an increase in the share of zero-carbon energy. This solution space exists, but is not made explicit in the matrix. All the scenarios which have been used to populate the matrix include major "sink" assumptions, especially given the degree of carbon overshooting likely to occur by 2050.

This framework is derived from world primary energy demand and GDP. Every individual country will have different minimum levels of energy productivity growth and the share of zero-carbon energy, dependent on their starting position today. Determining these per country would be useful way to track progress towards a well below 2°C world.