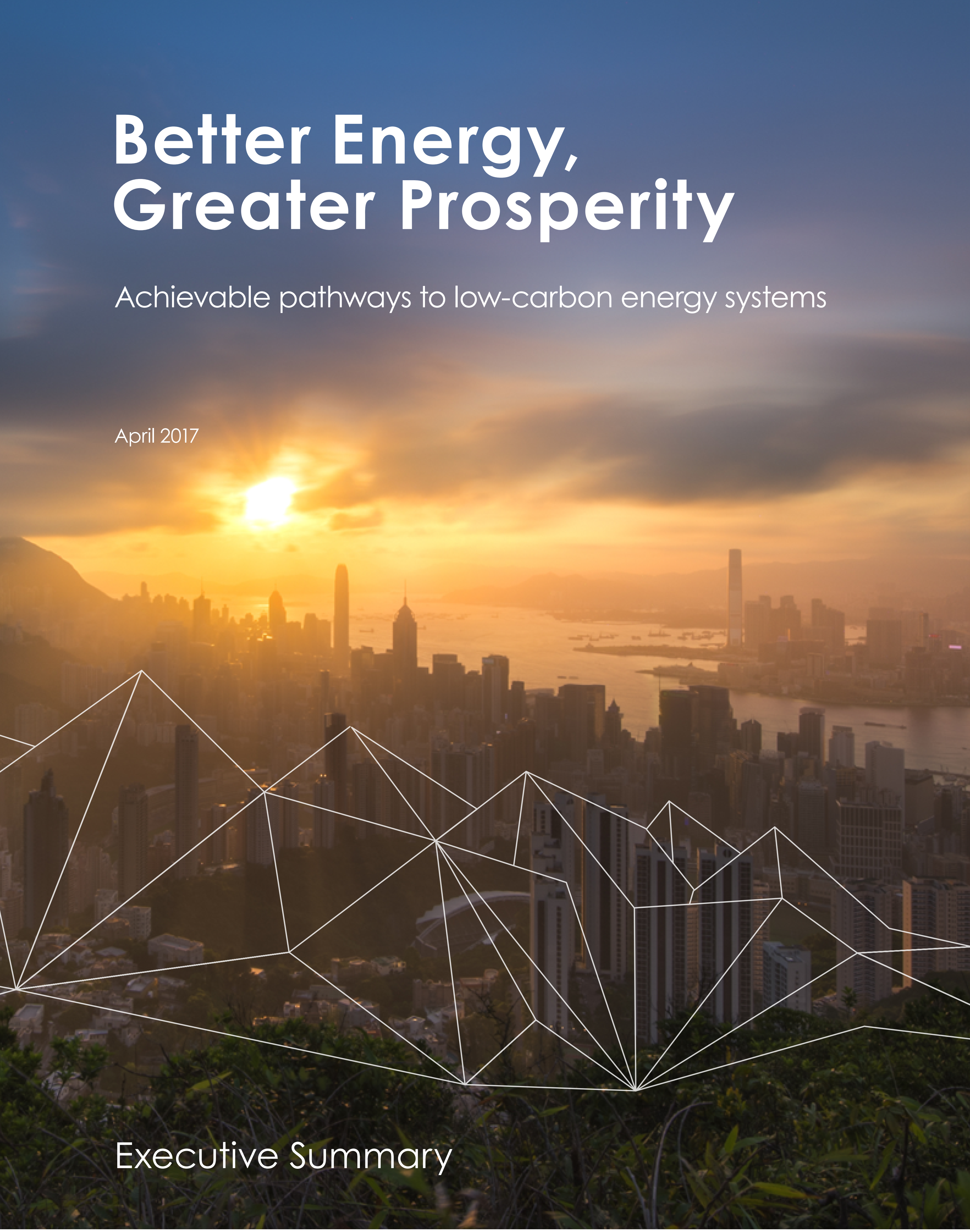
Better Energy, Greater Prosperity

Achievable pathways to low-carbon energy systems

April 2017



Executive Summary

ENERGY TRANSITIONS COMMISSION

The Energy Transitions Commission

The Energy Transitions Commission (ETC) brings together a diverse group of individuals from the energy and climate communities: investors, incumbent energy companies, industry disruptors, equipment suppliers, energy-intensive industries, 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. The ETC is co-chaired by Lord Adair Turner and Dr. Ajay Mathur. Our Commissioners are listed on the next page.

The *Better Energy, Greater Prosperity* report was developed by the Commissioners with the support of the ETC Secretariat, provided by SYSTEMIQ and McKinsey & Company. It draws upon a set of analyses carried out by Climate Policy Initiative, Copenhagen Economics and Vivid Economics for the ETC, which are available on the ETC's website.

This report constitutes a collective view of the Energy Transitions Commission. Members of the Energy Transitions Commission endorse the general thrust of the arguments made in this report, but should not be taken as agreeing with every finding or recommendation. The institutions with which the Commissioners are affiliated have not been asked to formally endorse the report.

The ETC Commissioners not only agree on the importance of cutting carbon emissions, but also share a broad vision of how the transition to a low-carbon energy system can be achieved. The fact that this agreement is possible between companies and organizations with different perspectives on and interests in the energy system should give decision-makers across the world confidence that it is possible simultaneously to grow the global economy and limit global warming to well below 2˚C, and that many of the key actions to achieve these goals are clear.

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Prosperity depends on access to affordable and reliable energy services*. Across the world today huge differences in prosperity are therefore matched by huge differences in energy use per capita, stretching from over 200 GJ per capita in the USA and Australia to only 20 GJ per capita in much of sub-Saharan Africa [Exhibit 1].

It is essential that developing countries are able to attain the standards of living enjoyed today by the developed world, and this will require big increases in their energy use per capita, especially in low-income countries. Even if we achieve radical improvements in energy productivity* – i.e. increasing income attainable per energy input – something like 80-100 GJ per capita will likely be required to support a good standard of living.

But if major improvements in energy productivity are not achieved, and if increasing energy needs are met by an unchanged energy system, severely harmful climate change will result. In a business as usual scenario*, global energy use could grow by 80% to reach 650 EJ by 2050. Today's global energy system relies on fossil fuels to provide 80% of total primary energy consumption, and is responsible for about 75% of total greenhouse gas emissions*. **The expansion of an unchanged energy system, with anything close to current levels of CO_2 intensity, would likely lead to over 4°C global warming by the end of the century.**

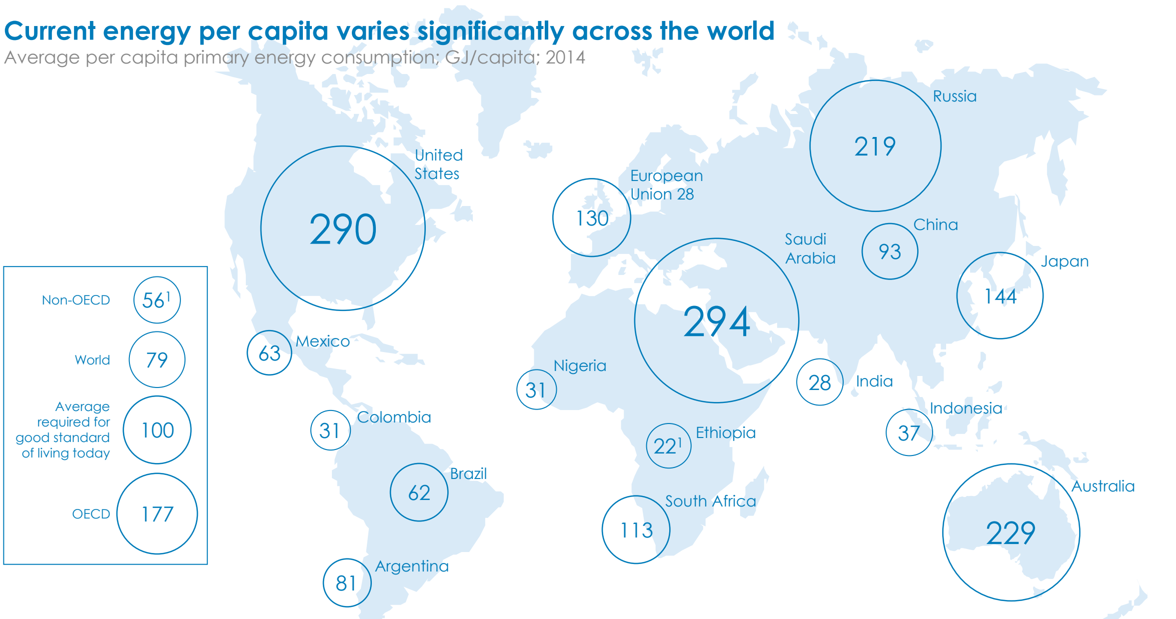
At the 2015 United Nations international climate change conference in Paris (COP21), 195 countries committed to limit global warming to well below 2°C, and national actions to reduce emissions have been ratcheted up. But current plans and pace of progress are still far from sufficient to achieve the well below 2°C objective*. Achieving that objective requires rapid reductions in CO_2 emissions.

We must therefore transition to a global energy system that can both:

- Ensure everyone has access to affordable, reliable, and modern energy services to support a good standard of living – something like **80-100 GJ* per person per annum** is likely to be required, though this threshold may fall over time as energy productivity improvements are achieved;
- Cut annual carbon emissions* from the energy system from **36 Gt of CO_2 today to 20 Gt by 2040 – i.e. less than half the 47 Gt by 2040 expected in a business as usual scenario* –**, with further cuts to a steady-state of net zero emissions in the second half of the century.

Current energy per capita varies significantly across the world

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

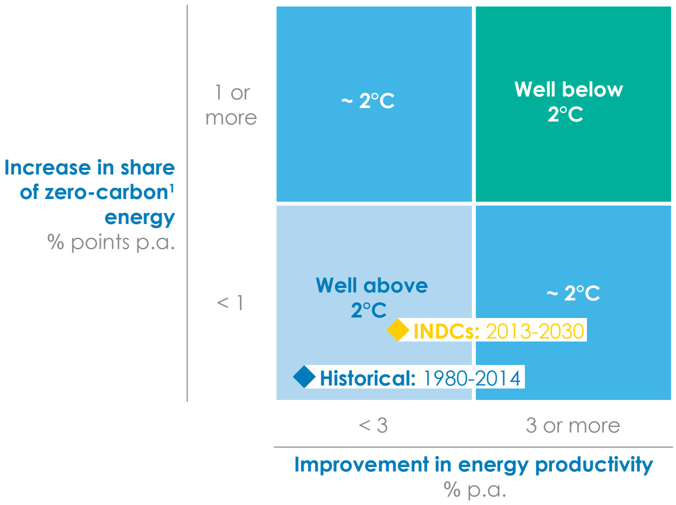


1 2013 due to limited data

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

Exhibit 1

Limiting global temperature rise to 2°C whilst extending energy access requires both the decarbonization of energy supply and improvement in energy productivity



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). However, if a large share of the increase is from the latter, a higher share is required since this does not reduce emissions to zero completely

SOURCE: Enerdata (2015), Historic actuals

Exhibit 2

Achieving these two goals requires rapid progress on two dimensions [Exhibit 2]:

- Energy productivity*, i.e. GDP per unit of energy, must grow by 3% per annum, compared to a historical rate of 1.7% per annum; and
- The share of energy derived from zero-carbon energy sources* (mainly renewables) must grow by at least one percentage point per annum.

These rates of improvement are far higher than achieved over the last 30 years, and much faster than implementation of the current INDCs* would deliver.

"This transition is technically and economically possible"

Despite the scale of the challenge, the Energy Transitions Commission is confident that **this transition is technically and economically possible**, and that **it would deliver important additional social benefits** – with, for instance, dramatically improved local air quality leading to longer and healthier lives – **and economic opportunities** – related to the development of new industries and business models.

Some vital progress is already being achieved, with dramatic falls in the cost of renewable power and recent gains in the rate of energy productivity improvement, but we **need to accelerate the transition.**

This will require rapid but achievable progress along 4 dimensions [Exhibit 3]:

1. Decarbonization of power combined with extended electrification,
2. Decarbonization of activities which cannot be cost-effectively electrified,
3. Acceleration in the pace of energy productivity improvement,
4. Optimization of fossil fuels use within overall carbon budget constraints.

These 4 transition strategies in turn imply the need for and will crucially depend on:

1. A major shift in the mix and financing of energy system investment,
2. A coherent and predictable policy framework.

Accelerating energy transitions requires to simultaneously implement 4 transition strategies by leveraging two sets of enablers

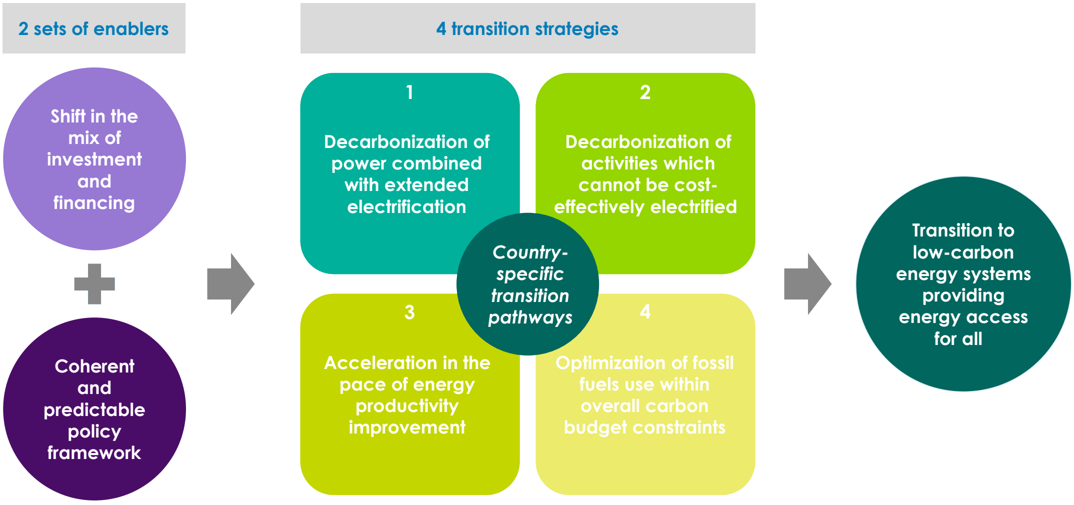


Exhibit 3

4 TRANSITION STRATEGIES

The 4 energy transition strategies are interdependent and we must pursue them all simultaneously. But their likely contribution to emissions reductions differs, as does our degree of confidence that we are on a path to achieve what is required. Exhibit 4 **presents the ETC's estimate of the feasible contribution of each transition to CO_2 emissions reductions over the next 15-20 years**. If achieved, these reductions would put the world on a path compatible with a well below 2˚C warming pathway. But realizing this potential will require strong action from public and private decision-makers.

- Energy transition 1 – decarbonization of power combined with extended electrification could account for the largest share of emissions reductions between now and 2040. Zero-carbon sources (mainly renewables) could account for up to 80% of the global power mix by 2040, while coal-fired power need to decline steeply as soon as possible.

- Energy transition 2 – decarbonization of activities which cannot be cost-effectively electrified – will probably account for only a small share of emissions reductions over the next 20 years, but will become absolutely vital as the potential for electrification is exhausted. Major work is still required to define the path to success.

- On Energy transition 3 – energy productivity – considerable progress is being achieved, but a further acceleration is required. This is technically and economically feasible, but will required more forceful public policies.

- Energy transition 4 implies falling fossil fuels use, even if carbon capture and sequestration* is developed on a very large scale. However, at the moment, progress on all forms of carbon sequestration (including natural carbon sinks*, underground storage* and CO_2-based products*) is too slow and requires supportive policy frameworks in order to progress.

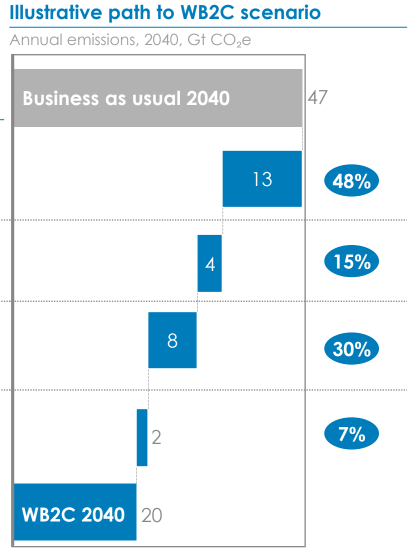
Energy transition 1 – **Decarbonization of power combined with extended electrification**

By 2040, half of the potential CO_2 emissions reductions compared to a business as usual scenario (48% or 13 Gt per annum) could come from the combined impact of decarbonization of power and extended electrification.

- **By 2035, it will be feasible in many geographies to build a near-total-variable-renewable power system* providing electricity at a maximum all-in cost of $70 per MWh***. This will make renewables fully competitive with fossil fuels, allowing for all necessary flexibility and back-up costs. This estimate

4 transition strategies need to be pursued simultaneously to achieve a well below 2°C scenario

Transition strategy	Major components
1 Decarbonization of power combined with extended electrification	▪ Zero-carbon sources reaching ~80% of power mix ▪ Electrification of transport, buildings, industry: electricity reaching ~30% of final energy mix
2 Decarbonization of activities which cannot be cost-effectively electrified	▪ Fuels substitution (bioenergy, hydrogen…) ▪ CCS and CO_2-based products for industry ▪ District heating and cooling
3 Acceleration in the pace of energy productivity improvement to 3% per annum	▪ Spillovers from extended electrification ▪ End-to-end energy efficiency improvement ▪ Structural shifts (service-based economy, digitization, circular economy, urban infrastructure)
4 Optimization of fossil fuels use within overall carbon budget constraints	▪ Coal to gas transition ▪ Methane leakage management ▪ Phasing out of routine flaring



SOURCE: Ad hoc analysis developed by Copenhagen Economics for the Energy Transitions Commission

Exhibit 4

reflects predictable reductions in the cost of renewables such as wind and solar and rapid cost reductions now being achieved in batteries. This all-in cost could be further reduced if a wider set of flexibility options such as demand management and better grid integration were deployed.

- Renewables deployment will therefore play a key role in decarbonization in all countries, but actual renewables penetration as a percentage of total electricity supply will reflect the feasible and economic pace of investment. **By 2040, intermittent renewables (solar and wind) could reach 45% of the global power mix, with other zero-carbon power sources representing about 35%, and unabated fossil fuels the remaining 20%.** The need for carbon capture in the power sector is likely to be limited to specific countries. A meaningful carbon price* would help drive a faster and more certain transition.

- As power is decarbonized, electricity could then be extended to a wider range of economic activities. The ETC's conservative scenario suggests that around **10-20% of all fossil fuels use could be eliminated through electrification by 2040, delivering CO_2 emissions reductions of at least 2-4 Gt per annum.** Initial opportunities are greatest in light vehicle transport and building heat services. Bigger reductions may well result from faster electric vehicle penetration than our conservative scenario envisages, and in the long-term, innovation will potentially enable significant electrification of industrial processes.

Energy transition 2 – **Decarbonization of activities which cannot be cost-effectively electrified**

While transition 1 will be the most important driver of emissions reductions to 2040, **decarbonization beyond power, e.g. from transport or industrial activities that cannot be electrified at reasonable cost, will be crucial to achieve full decarbonization of the global economy after 2040.** So, while decarbonization beyond power will likely deliver a relatively small share of total emissions reductions over the next 10-20 years (15% or 4 Gt per annum), urgent action, including the introduction of appropriate carbon pricing*, is required to ensure that more extensive decarbonization becomes achievable in subsequent years.

- **Multiple possible decarbonization routes are possible.** On the energy supply side, fossil fuels could be replaced with various forms of bioenergy; hydrogen could be used as an energy carrier; and carbon capture and sequestration (including CO_2 conversion into valuable products that sequester carbon over the long term) could be deployed. On the demand side, circular economy* value chains could reduce the need for virgin energy-intensive products and alternative less energy/carbon-intensive products could be used.

- However, **these supply-side technologies have not experienced the rapid cost reduction and huge scale deployment** seen in renewable power – although (first-generation) biofuels are more advanced than other options. They also face significant barriers to development, such as competition for land use (bioenergy) and large infrastructure requirements (hydrogen, CCS). At present, there is no clarity on which technology will be most appropriate in different industrial and transport applications.

- **This high level of uncertainty generates an unfavorable environment for investment.** Ensuring rapid progress will require substantial R&D expenditures plus large-scale deployment to drive cost reductions. Governments and private industry coalitions should together develop roadmaps to define a clearer way forward; and Governments should adopt infant industry policies similar to those that drove wind and solar industries to self-sustaining scale.

Energy transition 3 – **Acceleration in the pace of energy productivity improvement**

If the world is to enjoy continued economic development while keeping global warming well below 2°C, **a step change in energy productivity, i.e. economic output per unit of energy, must be achieved**. The rate of energy productivity improvement globally must rise from 1.7% to close to 3% per annum to deliver the 8 Gt per annum of CO_2 emissions reduction required from these levers by 2040. For this energy productivity revolution to happen, rapid progress on two dimensions is essential:

- **Improvements in the efficiency with which energy-based goods and services* are delivered** (e.g., reduced kWh* per lumen of light or per kilometer travelled), which would deliver two-thirds of the prize if historic trends continue. Electrification will itself deliver large benefits, and there are multiple opportunities to continue the efficiency improvements already observed in building insulation, household appliances, transport equipment and industrial processes. Performance standards, procurement process principles and appropriate regulation are the key policy tools to drive further improvement.

- **Increased GDP productivity of energy-based services** (e.g., reduced kilometer travelled per unit of GDP). Structural shift towards more service-based and information-intensive economies could itself drive significant improvement, but to achieve the full potential requires: (i) increased progress towards more efficient and dense urban design than is currently being achieved – without this, rapid urbanization in developing economies could lock the world into unsustainable emission pathways; and (ii) the development of economies which are both "circular"* (closed loop supply chains with near total recycling) and based on "sharing"* (more efficient ownership models of assets such as vehicles).

Energy transition 4 – **Optimization of fossil fuels use within overall carbon budget constraints**

To achieve a cost-effective transition to a carbon-constrained economy, the use of fossil fuels needs to be optimized and fossil fuels treated like a scarce resource, even if there is an abundant supply. **Efficient management of fossil fuels use optimizing carbon productivity* could contribute 7% of required CO_2 emissions reduction up to 2040** (or 2 Gt per annum).

- To put the world on a pathway to a 2°C rise in global temperature, **total CO_2 emissions from the energy system between now and 2100 must be at most 900 Gt**.

- Even if different forms of carbon sequestration (CCS, CO_2-based products and natural carbon sinks) were able to remove up to 8 Gt of CO_2 emissions per annum by 2040 (versus less than 50 MT today), fossil fuels use would still need to fall by around one third by that date to make it possible to stay within the carbon budget. This carries different implications for the three main fossil fuels:
  - **Unabated coal use must begin immediate decline** and be eliminated as rapidly as possible from developed country power systems to make space for unavoidable use in some developing countries. Total coal consumption (including both thermal and metallurgical coal) would need to decline by 70% from today's level by 2040. Thermal coal consumption would need to decline even faster, leaving space for continued use of metallurgical coal.

- **A limited increase in gas production is possible, but with a flat profile beyond the 2020s**, and with a total volume in 2040 only 2% higher than today – provided methane leakages are drastically reduced;
- **Oil must peak in the 2020s**, falling about 30% below today's volumes by 2040.

- **These trajectories can be achieved** through the combination of clean electrification, energy productivity improvements and decarbonization beyond power, as illustrated by Exhibit 4.

- The amount of CO_2 that must be sequestered (in products, storage or natural sinks) to ensure that the world is on a well below 2˚C trajectory will depend on the pace at which we decarbonize power, expand electrification and improve energy productivity, as well as on the uptake of alternative solutions for industrial decarbonization. The distribution between different forms of capture and sequestration* can also vary. **The ETC illustrative pathway shown on Exhibit 4 assumes only 3-4 Gt of carbon capture on fossil fuels* per annum, primarily in industry.**
  - Even to achieve 3-4 Gt of carbon capture on fossil fuels would require **a step-change in the development of CCS***, with major public and private investment. This should include greater focus on **CO_2 conversion into products** with an estimated potential of 1-6 Gt of carbon sequestered per annum by 2040.
  - **Greater focus on natural carbon sequestration is also needed**. Up to 11 Gt per annum could potentially be sequestered in natural carbon sinks, including 7 Gt through natural forest management, reforestation and avoided reforestation. In some cases, this sequestration could enhance agricultural productivity through boosting soil health, but competing demands for land between food/feed, fiber production, bioenergy, renewable energy and carbon sequestration will require careful management.

- **Increased renewables penetration, greater energy productivity and declining fossil fuels use means that fossil fuels prices could fall (relative to a business as usual scenario).** Overall, this combination could lower energy costs as a share of household budgets, creating a net welfare gain for society. However, it could also undermine the energy transition by slowing renewables investment and generating demand rebound effects. **A carbon tax wedge is therefore essential.**

2 SETS OF ENABLERS

The 4 energy transition strategies described above require a major shift in the pattern of investment and types of finance needed. They must also be supported by a range of public policies.

Enabler 1 – **Investment shift**

The transition to a low-carbon global economy* will require significant additional energy system investments – around $300-$600 billion per annum – compared with a business as usual scenario. In the context of global GDP running at around $80 trillion in 2017, and global annual investment at $20 trillion, additional investments of around $300-$600 billion per annum **do not pose a major macroeconomic challenge**. Clean energy investments with predictable long-term returns could be attractive to a range of institutional investors in the current low interest rate environment.

> ***"A well below 2°C pathway requires a major change in the mix of investment"***

However, a well below 2˚C pathway requires a major change in the mix of investment. Total fossil fuels investment between now and 2030 could be some $3.7 trillion ($175 billion per year) lower than in a business as usual scenario; investment in renewables and other low-carbon technologies some $6 trillion higher ($300 billion per year); while the largest required increases – of almost $9 trillion ($450 billion per year) – will be in more efficient energy saving equipment and buildings.

These shifts raise important financing issues:
- **The cost structure of low-carbon power**, with high upfront capital and low operating cost, makes the cost of capital, and therefore the perception of risks, particularly important. If required returns can be reduced by 100-300 basis points, the levelized cost of renewable energy would fall by 10-20%. Policies which increase the predictability of long-term cashflows (e.g. delinking low-carbon energy prices from volatile fossil fuels markets) will spur more rapid deployment and reduce prices for energy consumers.

- **"Atomized" energy efficiency* investments**, involving decisions by multiple individual households and companies, make appropriate regulation and, in some cases, temporary fiscal investment incentives vitally important.

- **High investment needs in developing economies** imply a major role for multilateral and national development banks and for global concessional financial flows.

- Fossil fuels companies and investors face complex challenges arising from the fact that **although total fossil fuels investment must decrease, large investments in some fossil fuels are still required** over the next 15 years to meet global/regional energy needs.

Enabler 2 – **Integrated public policy framework**

Public policy must ensure that private stakeholders face credible and reliable market signals and incentives. This requires the following:

- **Carbon pricing*** – an explicit, predictably rising, forward price curve for carbon, resulting from policy, reaching approximately $50 per tonne in the 2020s and rising to around $100 per tonne in the 2030s – is essential to drive decarbonization beyond power, to reinforce regulatory-driven improvements in energy productivity and to prevent falling fossil fuels prices from undermining the pace of the energy transition. Extensive fossil fuels subsidies, which create powerful incentives for wasteful consumption and often primarily favor middle and high income groups, should be phased out.

- While carbon pricing levers are important, they are not sufficient by themselves. Other crucial public policy levers include:
  - **R&D and focused deployment support** for a range of low-carbon technologies, in particular those which will enable decarbonization beyond power;
  - **Market redesign and pricing mechanisms, especially in the power market** to encourage the most efficient integration of large-scale renewables coupled with stronger flexibility management and phase-out of old coal plants;
  - Continued implementation of **performance standards and other regulations** to drive energy efficiency improvement;
  - **Transport systems and urban planning** which make it possible to grow GDP rapidly while limiting the growth of energy-based services;
  - **Integrated energy system planning** to ensure adequate coordination across a diversity of sectors (e.g. enabling much greater use of electricity across multiple sectors).

- In addition, **policy needs to entail a strong focus on the distributional implications of specific national energy transitions**, especially the implications for jobs and end-user consumer energy costs. If potential downsides for specific groups are not recognized and addressed, political resistance will make progress slower and increase the eventual costs.

COUNTRY-SPECIFIC TRANSITION PATHWAYS

All four energy transitions will be important in every country, and **INDCs should identify how to secure progress along each dimension. Action over next 15 years is critical**. But important differences between countries must also be recognized:

- **Some developing countries, especially low-income countries, face a significant energy access challenge**, which they may have an opportunity to meet by leapfrogging to new and better technologies, avoiding unnecessary investments in fossil fuels and centralized power systems, although progress to date is insufficient.

- **Some densely populated and low-income countries, such as India, might find it more difficult to meet electricity energy needs with zero-carbon power in the short term**; while rich and lightly populated countries such as the US or Australia face far easier challenges in this respect.

- **Conversely, many developing economies have an opportunity to get energy productivity "right first time"** avoiding the lock-in effects that have made it more challenging for some high-income countries to reduce energy use per capita to the 80-100 GJ "benchmark".

- **Fossil fuels exporters, meanwhile, face major adjustment challenges and economic diversification**, which will be most urgent for countries with large and rapidly growing populations.

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