INTERNATIONAL ENERGY AGENCY

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Real-world policy packages for sustainable energy transitions

Shaping energy transition policies to fit national objectives and constraints

INTERNATIONAL ENERGY AGENCY

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Executive summary

Around the world, many countries are embarking on transitions to sustainable energy systems. Others are already well underway. These transitions will be complex, involving fundamental and interrelated changes in technologies, fuels, infrastructure, policies, markets and institutions. Using the lens of "real-world" policy implementation, this paper unpacks the key elements of policy packages for sustainable energy transitions as well as their application in different timeframes. It also examines in more depth one "real-world" constraint on policymaking – the difficulty in implementing high carbon prices, and focuses on a country case study of Canada. An overarching theme is that in the real world there is no single energy transition policy package that fits all countries – national policy objectives and constraints will shape each jurisdiction's policy mix. Future work will include a substantial examination of policy packages in China, with a particular focus on emissions trading and its fit with other policies in the energy sector.

Real-world energy sector transition policy packages

Given the complexity of energy sector transitions, no single policy can be a silver bullet. Policy packages are needed to achieve a whole-scale shift in energy systems in all sub-sectors with key elements covering three domains:

- **Negative cost opportunities –** Particularly in energy end-use sectors such as transport and buildings, consumers often face non-economic barriers in their decision making. As such, there is significant scope to unlock cost effective opportunities and reduce emissions through incentives that drive improved energy use, such as targeted energy efficiency policies.
- **Optimisation based on pricing –** Optimal energy pricing under efficient market conditions has the potential to play a key role in energy system transformation. Investor confidence in rising future carbon prices can drive investment in low-carbon alternatives in power and industry as well as the phase-out of current high-carbon or polluting assets. If carbon prices are absent or remain only at moderate levels, complemenary policies, such as standards, regulations or other incentives, may be needed to achieve these outcomes.
- **Short-term investment for long-term returns –** Governments can also shift the boundary of what emissions reductions are achievable by supporting the underpinning infrastructure and markets (such as electric vehicle [EV] charging networks, reforming electricity market design) and investing in technology research development demonstration and deployment (RDD&D) to unlock deeper mitigation potential on a larger scale. While these interventions can require additional upfront investment, they can bring down the long-term cost of energy transitions.

Policy packages should address all three domains. The optimal pricing of energy, that includes carbon pricing, is a policy cornerstone for least-cost response. However, supportive policies to remove non-economic barriers to negative cost options and to drive investment in transformational infrastructure and technology RD&D are also required.

The policy package mix in each country will depend not only on what might be ideal, but also on what is possible based on other national policy objectives and constraints. Multiple and varying objectives (such as economic development goals, health considerations from air quality, and energy security issues) and constraints (such as challenges associated with increasing energy prices, existing high-emissions infrastructure or limited investment capital) shape a national policy mix for energy sector transition. As such, real-world policy packages delivering similar greenhouse gas (GHG) outcomes may end up looking quite different in different countries or regions. Nonetheless, countries with similar constraints and objectives can learn from each other's experiences.

Timing of policy interventions is also a critical component for delivering effective and affordable long-term clean energy transitions. Following their own transition trajectory, countries are progressing to first achieve a peak in emissions, then to drive deep emissions reductions and eventually to create net-zero emissions energy systems in the long run. The policy mix at each stage of this process will vary, with an early focus on supporting deployment of energy efficiency and mature clean energy technologies and working towards optimal energy pricing that includes carbon pricing to unlock cost-optimised opportunities. At the same time, it is critical at every stage to have an eye towards the longer-term transition by providing tailored support to bring down the cost of advanced technologies through investment in RDD&D and strategic infrastructure. In other words, current policy packages need to both seize the low-hanging fruit of today and put in place steps to achieve long-term goals.

Policy packages with "moderate" carbon pricing: Lessons from IEA scenarios

This paper looks at the role of carbon pricing as a tool to achieve optimal energy prices and a key element of policy packages for the energy transition. The challenge of implementing robust carbon pricing is also one example of a constraint faced in policy making. IEA model scenarios envisage the use of high carbon prices as a key driver of change, as part of comprehensive policy packages. We explore what "real-world" low-carbon policy packages might look like if implementation of high carbon prices is difficult in the short term.

Examination of two IEA scenarios sheds light on this issue. The *World Energy Outlook Special Report on Energy and Climate Change* (2015) introduced a Bridge Scenario that combines polices already announced (including carbon prices at a moderate level of around USD 40/tCO_2 by 2030 in certain economies) with a further set of GDP-neutral short-term policy interventions that lead to peaking global GHG emissions before 2020. The more ambitious 450 Scenario (consistent with limiting warming to 2°C) went further in two major ways: focusing on early development and deployment of emerging low-carbon technologies, and notably introducing much higher carbon prices of USD 100/tCO_2 by 2030 and USD 140/tCO_2 by 2040 in certain economies.

Understanding where the high carbon prices of the 450 Scenario achieve substantial emissions reductions highlights gaps that could arise if high carbon prices remain challenging to implement in the short-to-medium term in some jurisdictions. It therefore also points towards key elements of alternative policy packages that might be employed to target these outcomes and stay on track with the low-carbon transition. The effect of carbon prices varies depending on the characteristics of specific energy sub-sectors:

- In **power generation and industry**, investment and operational decisions are highly cost-driven. The rising carbon price becomes the principal driver of companies' decisions to deploy low-carbon alternatives (such as deploying renewables on a large scale, retrofitting plants with carbon capture and storage (CCS) or low-carbon industrial production processes), make their operations more efficient and retire high-emissions assets early. Carbon prices at moderate levels can lead to shifts towards lower-carbon options in electricity dispatch and industrial fuel inputs as well as achieving important industrial energy efficiency gains. However, if carbon prices remain moderate, complementary policies would be needed to promote the retirement or CCS retrofit of unabated fossil fuel generation and guide investment decisions to higher-cost, low-carbon technology development.

- Energy end-use sectors dominated by consumer choices show different characteristics in the model. In **transport**, energy policies such as standards, mandates and subsidies lead to improvement in vehicle efficiency, electrification of transport, uptake of advanced biofuels and investments in supporting transport infrastructure. Pricing plays a critical but supporting role: an increase in end-user prices offsets the price reduction that would result from lower global oil prices, thereby avoiding a rebound in transport demand. If a carbon price (or additional fuel tax) is not introduced, strengthened supporting policy measures would be required. In the **buildings** sector, changes in buildings electricity demand are primarily driven by standards and regulation. In these sectors, a high carbon price plays a supportive role, but given lower price elasticities of demand they also require strong and complex packages of regulations and government investment to drive change.

Comparison of the Bridge and 450 Scenarios also reveals the importance of timing of policy interventions across different time horizons. The policy package of short-term interventions in the Bridge Scenario is consistent with the 2°C target into the early 2020s, demonstrating the importance of early action measures within policy packages. They however fail to trigger steep cuts in emissions achieved after 2030 in the 450 Scenario which result not only from the higher carbon price, but also from early investment in the development of innovative technologies and infrastructure. This strengthens the rationale for implementing combinations of complementary policies in the short term that pave the way for greater ambition.

Policy packages in the real world: Low-carbon energy transition in Canada

As a case study of complex policy packages, in Canada a range of measures at the federal and sub-national levels has been implemented or announced to drive the low-carbon energy transition, as reflected in the *Pan Canadian Framework on Clean Growth and Climate Change*. A central component of Canada's policy package is a proposed pan-Canadian approach to carbon pricing to establish pricing in 2018 across all sub-national jurisdictions. Other key federal policies within the *Pan-Canadian Framework* include vehicle emissions standards for light- and heavy-duty vehicles, low-carbon and renewable fuels regulations, emission standards for natural gas and phase-out of coal-fired power plants, and support for clean energy technology and innovation. While GHG emissions reduction has been a primary driver of these policies, Canada's low-carbon policy package has a wider set of objectives, including job creation and economic competitiveness of clean energy sectors, clean air and water, and transition for affected workers and sectors.

Over the previous decade, Canada's provinces have been at the forefront in advancing the low-carbon energy transition. This is partly due to the decentralised nature of Canadian federalism along with unique regional resources, economic structure and political priorities. This has allowed policy packages to be tailored to regional circumstances, for policy to advance in the absence of federal drivers, and for a diverse set of policy experiments to take place across the country, generating lessons to inform policy development including the *Pan-Canadian Framework*. However, federal co-ordination within this provincially-driven policy "patchwork" could create numerous benefits, for example by harmonising marginal emission abatement costs to increase policy cost effectiveness, enhancing policy coherence, minimising emissions "leakage" and enhancing overall ambition. The proposed federal benchmark and backstop approach to carbon pricing illustrates one approach to balancing sub-national autonomy with federal co-ordination: a federal backstop policy would only apply to jurisdictions that do not meet the minimum benchmark; revenues of a federally-imposed carbon price would be recycled back to each jurisdiction; and jurisdictions would have flexibility in carbon-price instrument choice and design.

Sectoral policy packages in Canada illustrate how carbon pricing is central, but alone inadequate – especially at low-to-moderate levels – to drive all the changes required for energy transition. Supportive policies are needed to address non-pricing barriers, meet wider transition objectives and support the function of a moderate, medium-term carbon price. Examples from Canada's transport and electricity sectors highlight how different policies can serve different goals and functions:

- In Canada's transport sector, targeted federal and sub-national policies have been implemented to achieve GHG emissions reductions, as well as deliver air quality improvements, shifting activity to cleaner modes of transport and expand biofuel markets.
- In Alberta's electricity sector, a suite of provincial policies includes a coal phase-out, a renewable electricity tender programme and a tradeable intensity standard using output-based allocations, along with an electricity price cap. These policies are intended to deliver a stable transition towards electricity decarbonisation, while ensuring system reliability and affordability. While the federal policies are common to all provinces and territories, the suite of provincial policies and measures is tailored to the unique circumstances of each province.

These examples illustrate the complexity of policy packages in the "real world", including the issue of policy overlap where policies addressing different objectives cover the same emissions sources. The challenge for policy makers is to map the policy landscape to identify policy interactions, determine whether the benefits of additional policies merit the added costs, and if so, manage interactions by adjusting policy design. For other countries facing similar circumstances or constraints – such as shared governance over energy and climate policy, high regional resource and political diversity and strong energy and fossil fuel sectors – the Canadian case study provides several insights into the design and implementation of policy packages for energy transition:

- Carbon pricing is a critical policy tool in driving the sustainable energy transition. Canada has placed carbon pricing at the centre of the *Pan-Canadian Framework on Clean Growth and Climate Change*. Even at low-to-moderate levels, carbon pricing in Canada is expected to play an important role in driving decarbonisation across the economy.
- Multiple policy objectives require a package of policies, but attention must be paid to interactions amongst policies, which can support or undermine one another.
- Co-ordination and harmonisation of sub-national policies can reduce costs and raise ambition. In a country with strong sub-national authority over energy transition and low-carbon policy making, Canada's benchmark carbon price shows one approach to balancing regional autonomy and flexibility with national policy co-ordination.
- Mechanisms and processes for review and stocktaking are key to ensuring alignment of policies with goals. Review mechanisms are especially important for policy packages with many "moving parts" to identify where policies are not serving their intended function or are undermining one another, but also where they are succeeding.
- Flexibility in policy packages can improve cost effectiveness and enhance alignment with objectives. Countries can incorporate flexibility into policy packages at the compliance level (how agents comply with individual policies) and at the structural level (ability to adjust the policy framework in response to changes).

Future work

This paper provides an initial exploration of an important emerging policy area: how policy packages for energy transitions can be tailored to the real-world constraints and objectives of individual countries. As countries embark on the rapid transitions needed to achieve the Paris Agreement goals, policies that resonate with national priorities are essential.

This paper explores one particular policy example (the implications of carbon prices if they stay at moderate levels in the short-to-medium term) and one country example (Canada). Important work remains to be done to investigate policy packages that can work around various other constraints, for example, whether and how policy packages could be adapted to minimise stranding of assets during the transition to low-carbon energy systems.

A further angle for future work relates to policy packages in varying national contexts, including the differences in policy objectives and national contexts between developed and developing countries. Developing countries need to expand their energy supply to underpin universal energy access and economic growth, while advanced economies often have static or falling energy demand. For developing countries, local environmental issues such as air quality can be a more immediate priority than addressing climate change. As seen in the Canada case study, a country's particular governance structures, energy resource endowments and policy track record will all influence how policy packages can be shaped going forward. Most of the documented experience to date regarding policy packages and policy interactions is in developed countries. There is a need to better understand how the challenges of policy package design, implementation and interaction manifest in the context of developing and emerging countries, so that these countries can learn from, but appropriately adapt, existing experiences.

The world's largest emerging economy – China – presents a particularly interesting and important opportunity to explore policy packages and policy alignment in a country with a strong air pollution and climate change policy agenda alongside other objectives of economic restructuring and continued economic growth. China's implementation of a national emissions trading system presents interesting questions of how carbon price implementation interfaces with various energy policies and different energy governance structures such as China's regulated electricity market. The International Energy Agency (IEA), in partnership with China's National Development and Reform Commission (NDRC) will undertake substantial work in this area in 2018.

Introduction

This paper is an initial exploration of issues surrounding the design and implementation of "real-world" policy packages to support countries' transitions to sustainable energy systems. Energy transition is complex, meaning that packages of policies are needed. These include energy efficiency regulations, accurate pricing of energy (including carbon pricing), support to drive clean energy investments, building up underpinning infrastructure, and research development and deployment of future technologies. At the same time, the details of these policy packages will be strongly shaped by national circumstances. Energy and climate policy packages will be more successful if they are aligned with countries' multiple and varying objectives for the energy sector (e.g. supporting economic development, health, energy security outcomes). Policy packages also need to take into account the various constraints that governments face (e.g. split responsibilities between levels of government, difficulty in implementing carbon pricing policies or phasing out existing high-emissions infrastructure). The policy packages that can realistically be implemented – which we call "real-world" policy packages – will therefore be different in each jurisdiction. From the perspective of real-world policy packages, challenges in implementing low-carbon energy transition need not be seen as reasons to reduce ambition, but rather as invitations to find alternative policy solutions that align more closely with local circumstances.

This report is organised into three main parts as follows:

- The first section lays out the conceptual framework and research base to explain the role of policy packages for a low-carbon energy sector transition. It first explains the domains of policy that should be covered by policy packages, then explores the roles of varying objectives and constraints in shaping national low-carbon transition policies, and finally examines policy alignment needs across different time horizons.
- The second section presents a deep-dive quantitative analysis of the difficulty in implementing ambitious carbon pricing as a key component of a policy package. Being one possible constraint in policy making, it examines the specific roles of carbon pricing in achieving a low-carbon shift in the energy sector in IEA model scenarios. It looks at implications for mitigation if carbon prices remain modest in the short to medium term. It then points towards policy packages with a high carbon price, and also "real-world" alternative policy packages that could potentially play a similar role in terms of achieving a low-carbon energy transition.
- The final section contains a country case study of Canada. As an example of complex policy packages, it examines low-carbon transition constraints of shared jurisdiction over low-carbon and energy policy at the federal and provincial levels, as well as the experience of complementing national carbon pricing with other sectoral energy policies.

This paper was informed by discussions that took place during a workshop held at the International Energy Agency (IEA) on 27 June 2017,[1] which investigated country experiences with policy packages, the role of "moderate" carbon prices, balancing short- and long-term policies, and policy interactions. It is intended as an initial scoping exercise: further analysis and modelling of other types of policy constraint is planned, and the Canada case study offers a framework that can be applied to other countries. As a next step, China's policy mix will be explored, including interactions and alignment of energy policies with China's national emissions trading system.

[1]https://www.iea.org/workshops/implementing-real-world-low-carbon-policy-packages--in-the-energy-sector-unders.html

Sustainable energy transition

Energy is an essential underpinning of the social and economic activities of modern societies. The transition to sustainable energy systems[2] is therefore intertwined with the simultaneous need to address wider challenges, illustrated for example by the Sustainable Development Goals adopted in 2015. To be successful, a sustainable energy transition needs to address the interlinked challenges of climate change, air pollution, economic competitiveness and energy security, as well as overcoming the current widespread lack of energy access in large parts of the world. (IEA, 2016a; IEA, 2017e).

An energy system transition consistent with the collective global goal of the Paris Agreement to keep temperature rise to "well below 2°C" implies a peak in global GHG emissions by around 2020, with rapid reductions thereafter. This entails massive changes in both fuels (e.g. renewable and nuclear power) and technologies (e.g. carbon capture and storage, energy efficiency, energy storage and smart grids), which in turn will require different infrastructure, urban planning, consumer products, consumption patterns, built environments, business models, professional training programmes, investments and policies. Policies will need to address energy supply and energy demand as well as changes in systems and processes (IEA, 2017b).

Given the multi-faceted nature of the energy transition challenge, there is a need for coherent packages of policies to achieve a whole-scale shift in energy systems in all sub-sectors, impacting all key actors, and ensuring that transition can occur at the pace necessary to meet climate and other socioeconomic objectives. At the same time, the most effective policy levers for producing this suite of changes will differ across sectors and countries. As will be discussed in further detail below, the details of "real-world" policy packages can be tailored to local socioeconomic contexts and priorities, recognising the multiple objectives and constraints embedded in a sustainable energy transition.

Domains of policy for sustainable energy transition

Within the energy sector, one way to frame the elements of policy packages for energy transition is to characterise them as falling into three domains, illustrated in Figure 1. Because the three domains address different and complementary aspects of energy sector transition, policy packages should address all three domains, not just focus on policy elements that appear least costly in the short term.

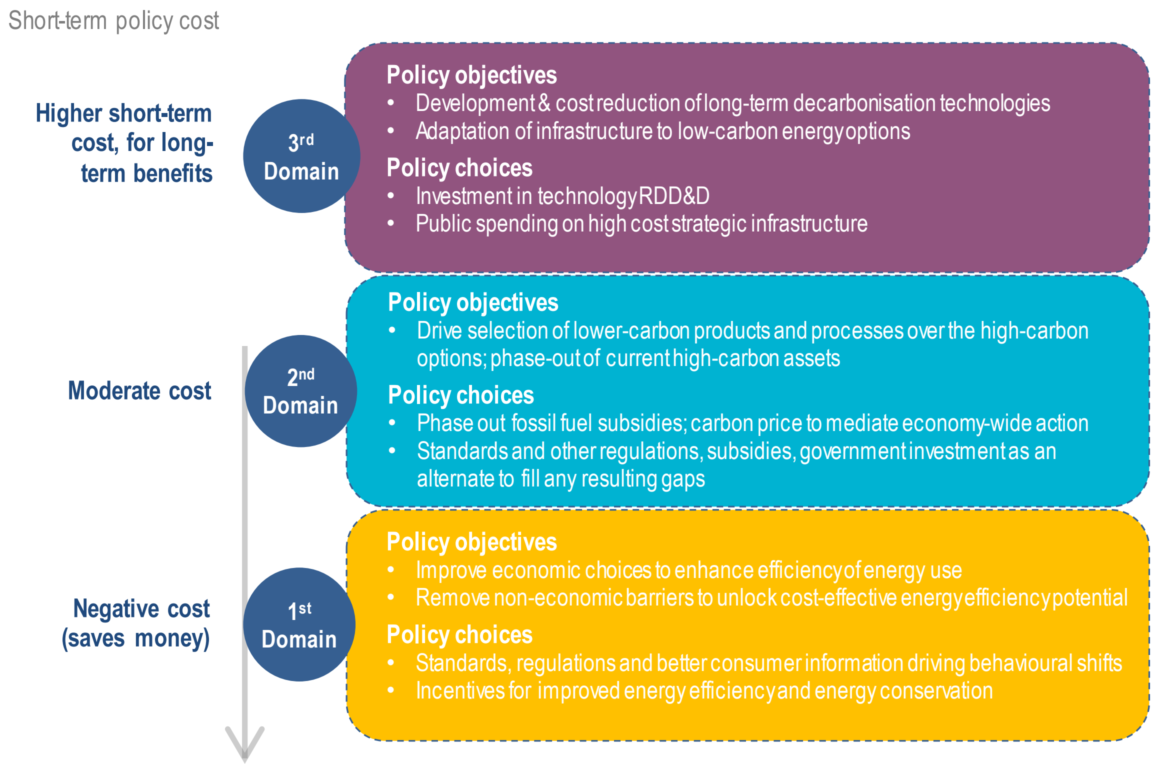
- The first domain covers the parts of the energy system (particularly in demand sectors) which are characterised by consumer and business choices that are not economically optimal, often leading to inefficient use of energy that costs consumers money and increases emissions. In this domain, supportive policy frameworks (such as standards and/or better consumer information) are essential to steer better choices, and move the system closer to cost-effective outcomes. Correct energy pricing (via subsidy reform and carbon pricing) also plays an important supporting role, to give added impetus to consumers and reduce rebound effects.[3] There is significant potential for negative-cost (i.e. money-saving) emissions reductions in this domain. Complementary energy

[2] Van den Bergh and Kemp (2006) explore the concept of "transition" in the wider context of sustainable development.

[3] The rebound effect describes the phenomenon that improving energy efficiency may save less energy than naively expected, due to behavioural changes of consumers and market responses. For example, falling demand for oil (due to tighter fuel economy standards or greater diversity in the fleet with EVs and biofuels) might decrease oil prices, in turn triggering increased transport demand.

efficiency interventions to reduce market barriers and aid consumer decisions should therefore have high priority in policy packages, particularly since this domain may be characterised by several market failures which make pure price signals less effective (Ryan et al., 2011).

Figure 1 • Three domains of policy are each required to address energy transition objectives



Source*:* Based on concepts discussed in Grubb et al. (2014), *Planetary Economics*, and Hood, C. (2013), *Managing interactions between carbon pricing and existing energy policies,* http://www.iea.org/publications/insights/insightpublications/managinginteractionscarbonpricing_final.pdf.

- The second domain applies to parts of the energy system that operate by optimising costs, for example dispatch of electricity generation, or private investment decisions in energy infrastructure, industrial plant processes and efficiency improvements. Here, optimal energy price levels that are visible to investors play a key role, as decisions are dispersed among a large range of actors throughout these sectors, each with their own interests. Phase-out of fossil fuel subsidies is an essential first step towards rational decision making in this domain. If carbon prices are present and there is investor confidence in their future increases to levels consistent with low-carbon transition, these can drive investment decisions in deployment of new low-carbon alternatives as well as phase-out of current high-carbon assets. If carbon prices are absent or at low levels (and/or there is no anticipation among investors that carbon prices will increase), other types of policy (standards and other regulations, subsidies, government investment) may be needed to compensate for missing price signals. An understanding of the role of pricing in delivering GHG mitigation, bearing in mind the potential constraints around the implementation of carbon pricing (Box 1), will help governments put together such "real-world" policy packages.
- The third domain relates to policies extending the scope of what emissions reductions are achievable. Investment in technology research, development, demonstration and

deployment (RDD&D) falls within this domain, as it aims to bring down the costs and improve the performance of advanced technologies (such as carbon capture and storage, and batteries) to lower long-term costs. Support for underpinning infrastructure (such as power market reform to enable integration of variable renewables, or build-out of public transport and EV charging infrastructure) also contributes here. These options may appear much more costly if taking a short-term view, but their development leads to a lower-cost transition in the long run, justifying strategic investment.

Not all policy effects will be intentional or foreseeable, and policies may unintentionally affect more than one objective (Ürge-Vorsatz et al., 2014). Poorly designed policy packages can create duplication, increase cost, lower efficiency, and reduce policy clarity and certainty. They can even work against their intended objectives. In general, care needs to be taken to understand the precise policy goals: in many cases, policy co-existence can be justified if policies are aimed at different specific outcomes within an overall strategy. For instance, one policy can be set to achieve short-term environmental targets and another policy for longer-term targets (CARISMA, 2017), given the complementary nature of the three domains.

Layering of policy incentives to ensure achievement of a certain target could be another reason to justify multiple policies in a situation where constraints do not permit a single policy. For instance, a carbon price could be combined with a minimum performance standard over the short term in a situation where the carbon price level is not sufficient, or the price signal is not visible enough, to deliver a particular policy outcome. While these policies would overlap, and would be less efficient economically than a strong carbon price, multiple policies may be necessary in real-world settings. Where complex policy packages involve many policies, careful mapping of the policy landscape may be needed to identify overlaps, along with review processes that aim to maintain policy alignment over time (Hood, 2013).

Box 1 • Carbon pricing implementation: An example of constrained policy making

Carbon prices are an integral part of a comprehensive policy package to deliver the challenging goals of clean energy transition. Carbon prices can influence the economic choices of investors, consumers and technology developers in favour of clean energy technology and energy efficiency. Confidence in rising future carbon prices can also be a strong driver for investment in long-lived, low-carbon infrastructure and clean energy technology RD&D. Coupled with targeted policies to deliver energy efficiency actions and policies to bring forward and reduce the cost of advanced technologies (renewables, CCS, industry, buildings), carbon pricing forms part of a policy mix that can minimise decarbonisation costs over the long term (Stern et al., 2006; Matthes, 2010; Grubb et al., 2014; Hood, 2013; Burtraw and Palmer, 2013).

However for many countries, economically efficient “first-best” policy elements such as high carbon prices may be difficult to implement in the short term, and low-to-moderate carbon price levels may be all that is achievable. Policy package choices can nonetheless drive significant change. Since 2013, for instance, the UK government has required power generators using fossil fuels to pay a carbon fee which acts as a price floor for GHG emissions, alongside the EU ETS price (Ares and Delebarre, 2016). This, coupled with energy efficiency policies, contracts to support new low-carbon generation and shifts in fossil fuel prices, has been widely credited for driving switching from coal to gas in the United Kingdom (IEA, 2016c). Carbon pricing policies can also be designed to be more politically feasible, though at the cost of some economic efficiency. For example, the use of output-based obligations in an emissions trading system (ETS) can minimise price rises to end-consumers and industry (Hood, 2013), though significant care is needed to prevent weakening of incentives for clean investment.

Packaging of climate policies can also help to overcome implementation constraints by mitigating negative impacts, for example through the use of revenues raised by the carbon pricing policy. Carbon pricing can impact certain parts of the population and economy by increasing energy prices, with lower income household groups and energy intensive industries generally facing higher impact.

For low-income households, governments can introduce complementary policies to fund social assistance and reduce inequalities, reduce distortionary taxes or provide other fiscal instruments for short-term impact mitigation. In this light, there is a parallel between carbon pricing and fossil fuel subsidy removal, with both requiring complementary policies to accommodate the public interest. The effectiveness of a carbon price in changing behaviour is also much higher when complementary policies provide alternative options. For instance, shifting behaviour in the transport sector is more effective when public transport options exist, particularly in the short term (Vogt-Schilb et al., 2014).

Competitiveness concerns are of particular importance to energy-intensive, trade-exposed (EITE) sectors of the economy as they often have limited possibilities to deliver carbon reductions from their operations (CPLC, 2017). Governments introducing carbon pricing have generally paid specific attention to the EITE sectors, for example providing free allocation of emissions permits.

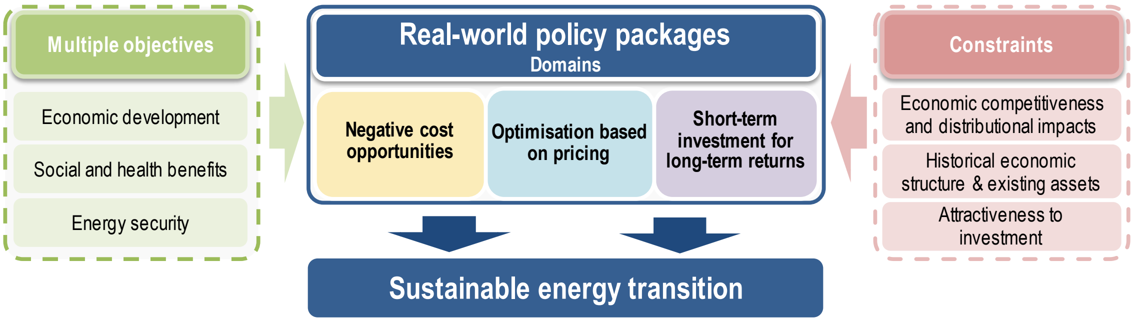
Even with such complementary policies, high carbon price levels may not be feasible in some jurisdictions in the short term. A suite of other policies can still keep sustainable energy transition objectives on track until the environment for carbon pricing improves. They can be targeted, for example, at the deployment of low carbon power generation and the phase-out of high-carbon intensive assets, standards and sustainable infrastructure in the transport and buildings sectors, as well as technology development, including CCS. The potential for second-best policy packages to substitute for high carbon prices will be explored in more detail in the next section.

Integrating wider policy objectives and constraints to create "real-world" policy packages

Energy transition policy packages will need to address all the three domains discussed above, but different country contexts will shape how policy is formed in detail, depending on each country's multiple and varying objectives and various constraints faced in policymaking. This introduces the concept of "real-world" policy packages: there is no one "right" policy package as national objectives and constraints differ, but countries may nonetheless be able to learn from others that have similar circumstances to their own. The sequencing of policy actions may also vary depending on national contexts: creating and maintaining momentum in easily-agreed-upon policy areas can enable a country to get started in moving along a transition pathway, and create opportunities for further high-potential options at a later stage (Pahle et al., 2017). Figure 2 illustrates the concept of how domains of sustainable energy transition policy packages are shaped by different national objectives and constraints that influence policy choices and implementation.

The range of objectives being pursued by any individual government, and their prioritisation over time, will shape the scope and depth of its sustainable energy policies, as the energy transition is directly linked with broader economic, social and environmental policy objectives. Improving socioeconomic well-being is an overarching objective of the highest priority in all countries and the energy transition needs to support it. Energy security,[4] energy access and improved health are important enablers of economic activity and social progress as well as key elements of energy transition. Energy considerations are therefore at the heart of nearly all socioeconomic objectives, including fiscal and distributive. The alignment of wider policies across the economy also matters: there is a range of policies across different sectors that will facilitate or hinder the ability to meet overall climate objectives and other related objectives, such as air quality. For example, fiscal policy and financial regulations will have a significant impact on low-carbon investments, and may inadvertently hinder these depending on their design (OECD/IEA/NEA/ITF, 2015).

Figure 2 • Real world energy transition policy packages with different objectives and constraints



Policy actions aimed at reducing GHG emissions as well as delivering other environmental sustainability goals have the potential to significantly support social and economic development (Khosla et al., 2015; OECD/IEA/NEA/ITF, 2015; Ryan et al., 2011). For instance, energy efficiency policy can help lower industrial energy consumption and thereby enhance economic competiveness as well as directly improve individual welfare through reduced energy spending for households. A sustainable energy transition also has direct impacts on investment and job creation, which underline most energy, climate and economic policy objectives. A country may emphasise specific low-carbon or energy efficiency technologies as areas to develop industrial capacity. For example, it may emphasise rooftop solar energy if the job impacts are greater than ground-mounted solar or wind energy (and if the technology cost differential make this worthwhile) as seen in an Indian context (CEEW, 2017). Some energy transition policies (for example carbon pricing) have the potential for creating winners and losers, so upfront analysis is essential to ensure that social and economic objectives are met, including through decisions on how revenues from carbon pricing are used.

The integration of the goal of GHG emissions reductions with additional socioeconomic objectives, such as energy security and affordability, could equally enhance policy synergies. The European Union's Clean Energy Package, for instance, justifies investment in clean energy technologies by the creation of new jobs and the reduction of energy imports at the same time as delivering decarbonisation objectives (EC, 2016). Similarly, enhancing the use of renewable energy and low-carbon transport modes can significantly contribute towards improving air quality as well as delivering health benefits and improved economic productivity. The IEA World Energy Outlook Special Report 2016: Energy and Air Pollution demonstrates areas of cross-benefit in achieving GHG emissions reductions as well as air quality improvement. Early

[4] The IEA defines energy security as "the uninterrupted availability of energy sources at an affordable price".

peaking in GHG emissions can be achieved at the same time as reduction of black carbon, a major component of particulate matter (PM) emissions, and methane emissions (IEA, 2016b; IEA, 2017e). China's 13th Five Year Plan and Energy Supply and Consumption Revolution Strategy equally see air quality and climate objectives as a way to support health objectives and economic productivity growth. Similarly, evidence from India shows that increased deployment of renewable energy offers greater energy access and therefore improved living standards, compared to conventional energy, with GHG emissions reductions as an additional benefit (Khosla et al., 2015).

Clear articulation of a country's range of objectives can help enable identification of synergies between policies that may work well together to meet one or more objectives, but it can also help identify tensions and trade-offs. If objectives are considered in isolation, policy decisions may impact each other. For instance, scale up of variable renewables can pose grid integration challenges if other accompanying policies are not in place, or the uptake of biomass combustion technologies for decarbonisation reasons without appropriate local air pollutants capture technology might impact local air quality targets. Similarly, policies that aim to improve disposable income for poor households by controlling the prices of energy may skew incentives and lead to reduced energy-sector investment, increased GHG emissions and air pollutant emissions, thus having a limited impact on poor households compared with more targeted income support measures (OECD, 2017b; OECD, 2015).

Real-world policy decisions can often face numerous constraints. For instance, in many countries introduction of carbon pricing policies that visibly increase energy prices provides implementation challenges (Box 1). The implications of policy making where carbon prices are constrained will be explored in greater detail in Section 2. As another example, in formulating climate policies a country could be faced with decisions over the retirement or refurbishment of high carbon assets, such as coal-based power generation without CCS or outdated industrial installations. As a result of historical economic structure, industry and power sectors can have considerable political influence over the legislative process (MacNeil, 2013). As these installations are often major contributors to local employment and economic activity, such decisions can also have consequences for governments' social and economic development priorities. For current policy making, this might imply difficulties in enacting policies that would lead to the retirement of assets before the end of their economic lifetime, raising the need to address the challenge of transitioning existing assets explicitly as part of the energy policy package.

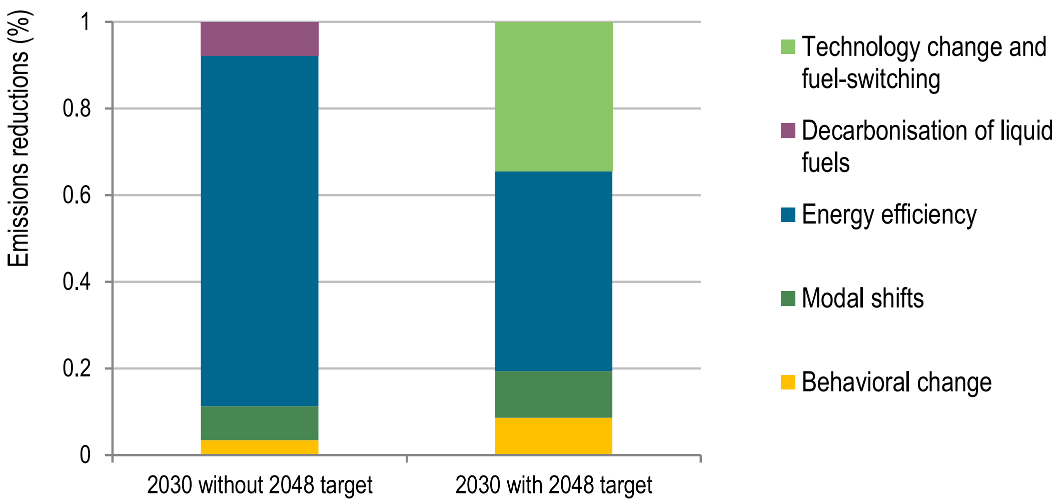
Another common and important constraint is the often-limited attractiveness of clean energy technologies as an investment proposition. This is particularly the case for public funding that is often thinly stretched to meet different objectives. Allocation of private finance, including shifting finance from other parts of the energy sector to clean energy, as well as attracting new sources of finance, could be stifled in certain markets. Clean energy could be seen as a less mature area of investment especially in markets where return on investment is not sufficient, technology risks are too great, expertise in specific infrastructure investment is limited, there is a lack of clarity around environmental and climate policies or penetration of specific technology in a market is too low. The risk involved also stems from a lack of clarity around current and future environmental and climate policies, which adds to the passive mentality towards new investments. However, access to finance will vary across different countries, with developing countries suffering most acute private and public finance shortages due to the lack of maturity of their clean energy policy and market environment.

The time dimension of policy packages

Policies are needed to both seize immediate GHG mitigation opportunities (primarily in the first and second domains described above) and put in place steps for longer-term transition (the third domain). Policies with a short-term impact include support for the deployment of energy efficiency and mature clean energy technologies. Preparing for the future involves paying attention to investment patterns, providing support for early stage clean energy technology deployment, developing a strategic approach to underpinning infrastructure and investment in technology RDD&D (e.g. battery technologies, advanced biofuels).

A variety of policy mixes can achieve the same objectives, but a policy package that aims to deliver shorter-term goals without taking into account longer-term transition needs might leave the energy sector ill-prepared for the future. Marginal abatement cost curves – which show the cost of additional emissions reductions and are sometimes used to "rank" mitigation options – can usefully depict the short-term cost and abatement potential of all technically available mitigation options. They are however not sufficient to design long-term emissions reduction strategies on their own (Vogt-Schilb and Hallegatte, 2014). As some technologies needed to achieve deep mitigation potential (such as CCS or transport electrification) may not be available at scale immediately, the optimal strategy to reach a short-term target should be consistent with longer-term targets. Moreover, consideration of long-term objectives will aid in devising a transition pathway that limits the risk of carbon lock-in (Hood, 2011; IEA, 2015c; Vogt-Schilb and Hallegatte, 2017). As one concrete example, a policy mix to deliver 2030 objectives modelled by the French government for its transport sector looks drastically different if long-term objectives are also taken into consideration (Figure 3). If optimisation only considers the 2030 target, energy efficiency policies could constitute the majority of the transport sector policy package. However, with a mid-century target in mind, the policy mix places much greater emphasis on energy technology changes and fuel shift to unlock deeper decarbonisation options.

Figure 3 • Modelled French transport sector policy package with and without longer-term objectives



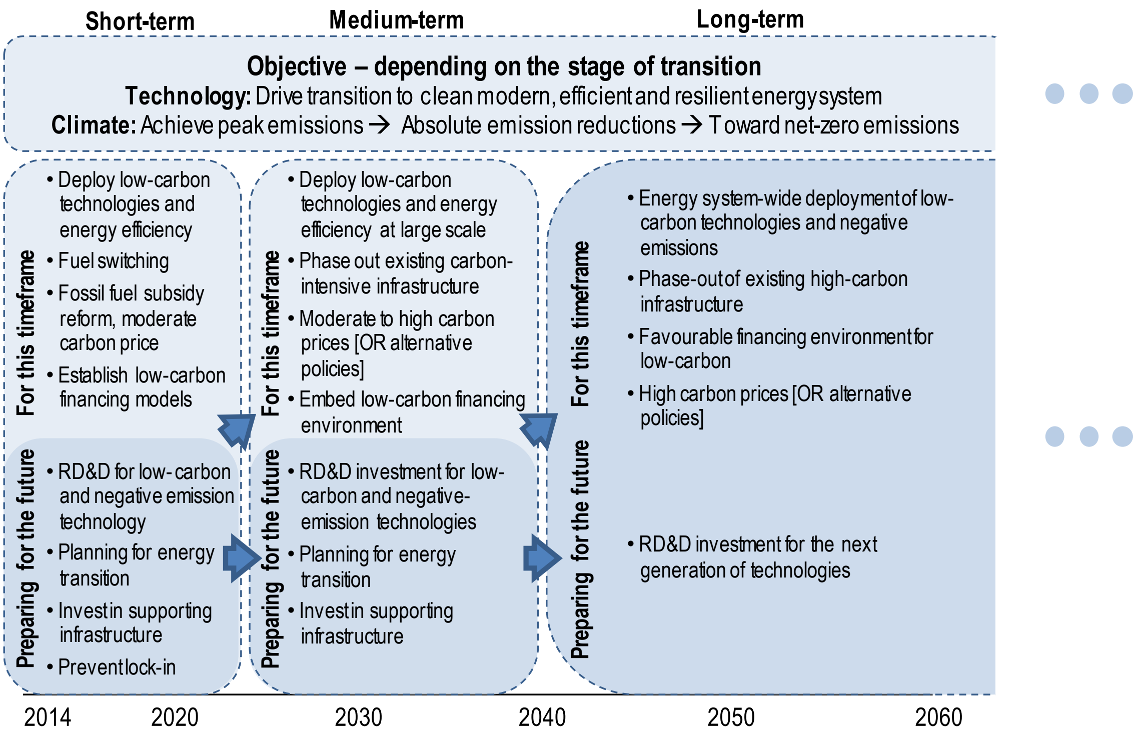
Note: Figure shows the difference in the share of total emissions reductions in the transport sector optimised for 2030 as a medium terms target (left) and 2050 as a long term target (right).

Source: Adapted from Perrissin Fabert and Foussard (2016), *Trajectoires de transition bas carbone en France au moindre coût*, https://www.tresor.economie.gouv.fr/Ressources/File/431005.

The timing of policy interventions is an additional component for delivering upon multiple targets and objectives in different phases of the long-term clean energy transition. Although the temporal boundaries of when different policies are needed are not clearly identified, policies need to be sequenced. In the context of individual country transitions, sequencing of policies can enable one policy to create the preconditions for further policies to take root (Pahle et al., 2017).

Figure 4 depicts different phases of global clean energy transition in line with the agreed goal of the Paris Agreement. From the short to the long term, indicative policies are shown for each phase. Distinct objectives form a trajectory that will achieve global peak in emissions in the short term by 2020 (noting that individual developing countries take longer to peak), turning to steep emissions reductions in the medium term in the 2020s to 2040s, and a decline to net-zero emissions from the energy sector in the long run in the second half of this century. As already discussed, the success in implementing individual policies in the context of a particular country will depend on how well they can be designed to align with broader objectives, and be tailored to be sensitive to policy-making constraints.

Figure 4 • Indicative policy packages pathways



Policy packages in the short term

There are many opportunities for immediate short-term emissions reductions, including deployment of mature clean energy technologies, energy efficiency policies, fossil fuel subsidy reform and modest carbon pricing that can drive fuel switching to less carbon-intensive energy supply options. Establishment of low-carbon finance frameworks is also essential to begin the large-scale roll out of these options.

Energy efficiency offers immediate, cost-effective options. Depending on the nature of the sector and country specific challenges, the tools used to improve energy efficiency may include fiscal instruments (such as tax incentives or explicit subsidies), regulatory policies (such as minimum energy performance standards [MEPs]), fuel economy standards, or voluntary measures (such as assistance with energy management). Energy efficiency interventions are generally seen as a "win-win" situation, providing wider social and economic benefits, and therefore are generally well supported by governments. Deployment of clean technologies to support power sector decarbonisation is an important early focus, as it supports emissions reductions across other sectors through electrification (IEA, 2016d; IEA, 2017b). Renewable energy support policies are well established around the world and generally publicly popular, partly due to co-benefits in air quality and reduced fuel import-dependence. Concerns about the impact of subsidy schemes on electricity prices to consumers and industry are a challenge to be managed in the short term (IEA, 2017f).

Effective price signals – achieved through phase-out of fossil fuel subsidies and introduction of carbon pricing, can encourage switching to lower-carbon options in the short term. While the level of carbon prices is predicted to progressively increase over time, in most jurisdictions carbon pricing is currently at a level of less than USD 30/tCO_2e (World Bank, Ecofys and Vivid Economics, 2017). However, moderate pricing can begin to drive the switch to lower-carbon technologies in areas where it is cost effective, such as switching from coal to gas in the power sector. This could be complemented with additional measures, such as dispatch rules that favour lower-emissions plants (IEA, 2017b). The phase-out of fossil fuel subsidies is aligned with many domestic economic benefits, but will not be successful unless the challenges of addressing the social objectives of the original subsidy (generally energy access for the poorest consumers) can be achieved through other more targeted policies. The introduction of carbon pricing (Box 1) can be designed to align with national economic and social objectives if revenues are used to replace more unpopular or inefficient taxes.

Strong policies are also needed in the short term to lay the groundwork for longer-term, deeper emissions reductions. This includes support for RD&D, with technology support tailored to different points of the technology development cycle (IEA, 2017b): cost reduction or performance enhancement of existing technologies will require different support than early-stage piloting of new low-carbon technologies. Global public funding for clean energy RD&D was over USD 19 billion in 2015, but statistics from IEA countries show that it has stagnated since 2010. It has therefore so far proven challenging to significantly scale up RD&D funding from public budgets, which has led to the launch of the Mission Innovation initiative to double public funding for clean energy RD&D. Through RD&D support, governments guide their economies towards activities they value as important and should be in line with their broader socioeconomic objectives. While knowledge produced from clean energy RD&D is a public good employable by economic competitors, clean energy innovation offers countries economic opportunity by positioning them as global technology market leaders. Technology RD&D support also needs to be co-ordinated across public and private sectors, each of which will respond to different policy levers. Technologies with lower unit costs of production require a lower share of RD&D funding from public sources. Technologies that are highly adaptable and differentiated are able to raise finance more easily due to their ability to fulfil the needs of other sectors. Improving battery performance, for instance, is being driven by the electronics, military and transport sectors.

Low or moderate carbon prices may be insufficient on their own to prevent investment in new high-emissions infrastructure, so additional policy attention may be required in the short-term to preventing lock-in of high-emissions infrastructure that is not well suited for the longer term.

Policy packages in the medium and long term

Policies implemented in the medium term have the immediate challenging task of delivering accelerated absolute emissions reductions after countries peak their emissions. Certain low-cost mitigation options (such as fuel switching and fossil fuel subsidy reform) can be achieved early, leaving policy in this phase to focus on more challenging aspects such as phase-out of existing high-emissions assets and technologies. Here, social and economic tensions will need to be addressed in policy making, for example addressing the employment concerns of coal-dependent communities. Another significant challenge will be the scale-up of carbon pricing to the high levels needed to drive structural energy sector change (see section 3 for more detailed discussion). However if carbon prices remain at moderate levels over the medium term, a well-structured set of policies could be employed to supplement the carbon price signal, including regulatory minimum performance standards or market-based backstopping options for different energy technologies. RD&D must also continue at scale if advanced technologies such as CCS, and later negative emissions technologies, are to be ready for scaled-up deployment towards mid-century.

Decarbonisation of electricity sets the scene for the electrification of end-uses. In transport, deployment of EVs follows this trend in combination with liquid biofuels use (IEA, 2017b). The industry sector can equally benefit from electrification within technical limitations and deliver a certain level of flexibility to electricity grids when implemented in tandem with demand-side management. Implementation of new technological solutions across the energy sector will pose challenges for energy system security. Maintaining a reliable and secure energy system requires sound management of potentially disruptive changes. The introduction of a very high share of variable renewables in the power sector, electrification of the transport sector and use of smart appliances in the buildings sector, will change the nature of energy systems. Improvements to energy access will expand and potentially increase dependency on electricity systems. These developments could also foster greater potential for digitalisation, with the scale and scope of potential impacts more apparent in the medium term.

In the long term, the key challenge is to accomplish ever-deeper emissions reductions at a large scale across the entire energy sector. While the energy transition will never reach a definite end point, the agreed goal of the Paris Agreement provides one benchmark: the achievement of a balance between emissions and removals (i.e. net-zero emissions) in the second half of this century. A pathway to deliver the required scale of emissions reductions in industry, power, buildings and transport will require a mix of new technologies in addition to cost and performance improvements, and full deployment of existing technologies. Energy system transformation is possible with known and anticipated technologies (IEA, 2017e), but there will be other solutions that might not be available or even known at present. For instance, negative emissions technologies in the power sector may be required in order to compensate for emissions from sectors where zero emissions are not yet possible, including the transport or industry sector. Maintaining a focus on optimising for the long term, while keeping the flexibility to adjust to changes such as those that will be brought by digitalisation of the energy sector, will be a primary challenge for policy makers.

The roles of carbon pricing in policy packages for sustainable energy transition: Lessons from IEA scenarios

The previous section has described why complex packages of policies are required to deliver sustainable energy transition. Over the years, the IEA has built an extensive modelling capacity to unpack the complexity of the energy sector and devise pathways to achieve sustainable energy transitions. The resulting model scenarios envisage the use of high carbon prices, which drive a considerable part of the technological and behavioural changes needed for energy sector transformation. At the same time, they show that a high carbon price alone does not address all aspects of energy transition: comprehensive policy packages are needed. This section explores the role that carbon pricing plays within the policy packages modelled in the IEA's low-carbon scenarios. An enhanced understanding of the specific roles of carbon pricing can shed light on the policy gaps that could arise if it is not politically feasible to raise carbon prices significantly in the short-to-medium term, and point towards "real-world" policy packages targeting these outcomes in the meantime.

Policy packages and carbon pricing in IEA scenarios

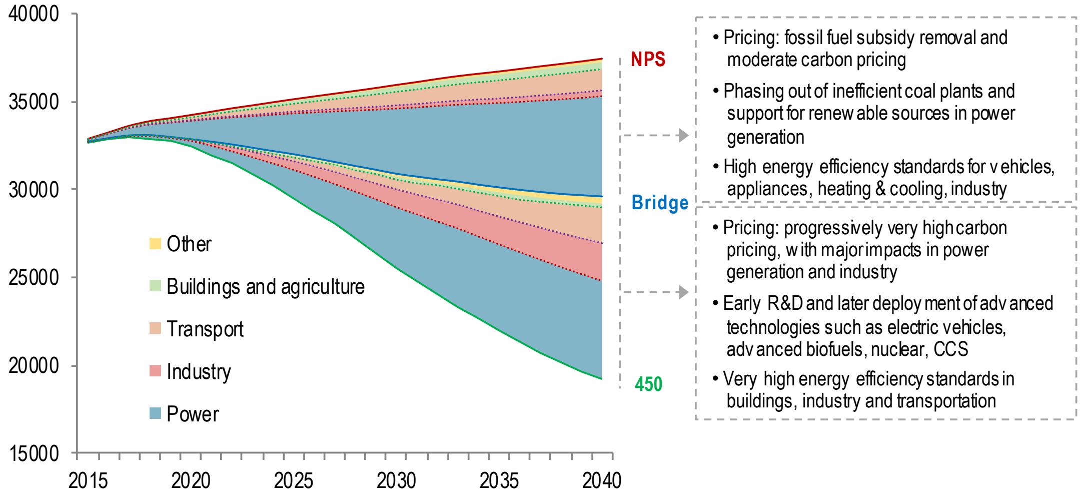
Given the complexity of climate and energy goals along with other economic and political constraints, none of the IEA low-carbon scenarios is based on a single policy driver, but rather on packages of policies to most effectively and efficiently unlock emissions reductions as introduced in section 1. They vary by sector and region, depending on economic and political specificities as well as abatement potentials. This section compares two IEA scenarios – the 450 Scenario and the Bridge Scenario[5] – to explore the role of carbon pricing in policy packages, and the effects of moderate and high carbon prices (Figure 5):

- The 450 Scenario is consistent with limiting warming to 2)C by 2100. Its policies target both short- and long-term savings, and pave the way for economy-wide carbon neutrality by the end of the century. The 450 Scenario offers a long-term pathway in which increasing carbon prices are an important driver of change. Standards and regulations are used as well (e.g. energy efficiency standards), coupled with support for technology development and deployment to make emerging low-carbon technologies competitive.
- The Bridge Scenario is a step part way from today's trends (reflected in the New Policies Scenario [NPS]) towards the 450 Scenario. It starts from currently announced energy and climate policies, and adds many of the same policies as the 450 Scenario, but notably excludes high carbon prices. It was designed to unlock cost-effective, short-term emissions reductions to peak global emissions by 2020, through policies such as standards, targets, subsidies and regulation. The Bridge Scenario is designed around five core pillars:
    - increase energy efficiency in the industry, buildings and transport sectors
    - progressively reduce the use of the least-efficient coal-fired power generating plants and ban the construction of new ones

[5] The Bridge Scenario was developed for the 2015 World Energy Outlook Special Report on Energy and Climate Change. It is compared with the 450 Scenario from World Energy Outlook 2015. These 2015 scenarios (rather than the most recent WEO 2017 scenarios) are used here as they better illustrate the policy implications of carbon pricing.

- increase investment in renewable energies in the power sector from USD 270 billion in 2014 to USD 400 billion in 2030
- gradually phase out fossil fuel subsidies to most end-users by 2030
- reduce methane emissions in upstream oil and gas production[6]

Figure 5 • Global CO_2 emissions and CO_2 abatement by sector over 2015-2040 ($MtCO_2$)



Source: Analysis builds on data from the IEA (2015a), *World Energy Outlook Sepcial Report : Energy and Climate Change*, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf.

Carbon pricing in the 450 Scenario reaches the high level of USD 100/tCO_2 by 2030 and USD 140/tCO_2 by 2040 in certain developed economies (Table 1). In the Bridge Scenario, carbon prices reach moderate levels of around USD 40/tCO_2 by 2030 in these economies. In the following sections, this analysis will explore what role carbon prices and other policies play within each energy sub-sector. In particular, there will be a focus on where high carbon prices achieve substantial emissions reductions in the 450 Scenario, and where "real-world" policy packages could use a combination of moderate carbon prices (as in the Bridge Scenario) plus additional policies.

As discussed above in this paper, policy packages should be coherent across time, addressing short- and long-term priorities. The Bridge Scenario's set of short-term interventions manages to nearly keep CO_2 emissions on track with those of the 450 Scenario into the early 2020's, demonstrating the tremendous opportunity for cost-effective early action. However, the gap between the two scenarios nearly doubles over 2030-2040 compared to 2015-2030. The steep cuts in emissions achieved over 2030-2040 in the 450 Scenario rely on high carbon prices, but also on early actions geared for the long term. For example, investing in emerging technologies in the short term may only pay off a decade or more after early commercial pilot projects are initiated. This strengthens the rationale for implementing combinations of complementary policies in the short term that pave the way for future greater ambition.

Breaking down the emissions reductions between the Bridge and 450 Scenarios on a regional basis (Figure 6) provides more detail on abatement opportunities, and hints at the most important focus areas for local policy packages. The power sector is universally the biggest area of abatement opportunity. In the OECD countries, transport emissions reductions play a significant role as the secondary opportunity compared to the power sector, whereas in non-

[6] Box 3 provides insights on the role of energy and carbon pricing in methane emissions reductions from oil and gas sector

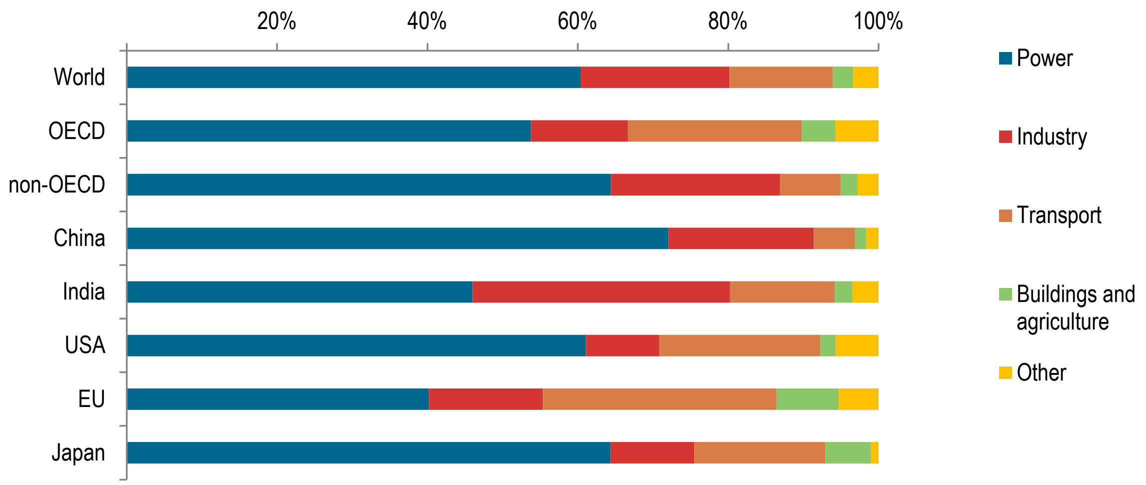
OECD countries, nearly 90% of these additional reductions come from the power and industry sectors. These three sectors – power, industry and transport – will be explored in more detail in the following sections.

Table 1 • Carbon prices in IEA Bridge Scenario and 450 Scenario, in 2014 USD/tCO_2

	Region	2020	2030	2040
NPS and Bridge Scenario	European Union	22	37	50
	Chile	6	12	20
	Republic of Korea	22	37	50
	China	10	23	35
	South Africa	7	15	24
450 Scenario	United States and Canada	20	100	140
	European Union	22	100	140
	Japan	20	100	140
	Republic of Korea	22	100	140
	Australia and New Zealand	20	100	140
	China, Russia, Brazil and South Africa	10	75	125

Source: IEA (2015a), *World Energy Outlook Sepcial Report : Energy and Climate Change*, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf.

Figure 6 • Cumulative CO_2 abatement in the 450 relative to the Bridge Scenario by sector in selected areas, over 2015-2040



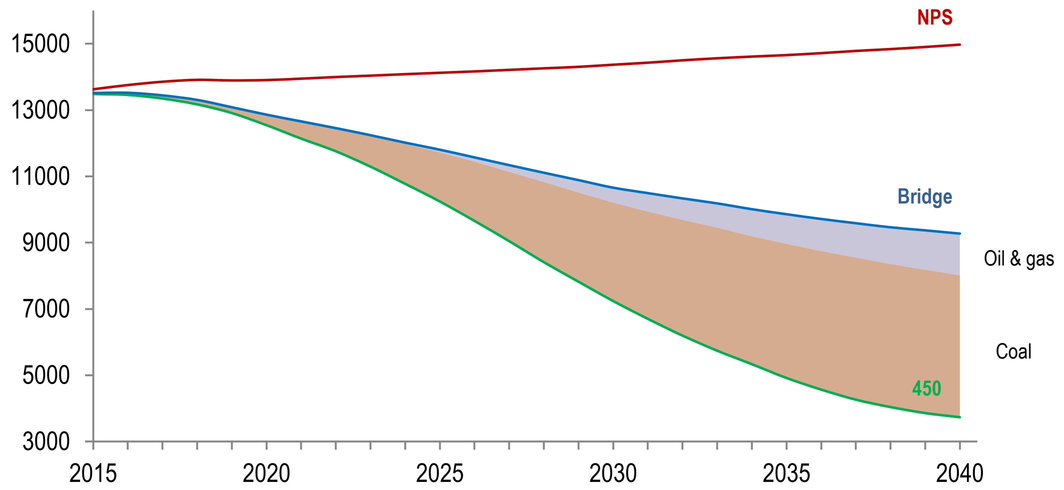
Source: Analysis builds on data from IEA (2015a), *World Energy Outlook Sepcial Report : Energy and Climate Change*, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf.

Policies to support transition in the power sector are likely to be relatively similar across countries, as they mainly aim at reducing electricity demand through efficiency, and replacing unabated coal generation with renewable sources and/or CCS technology over the medium term. Countries will differ on which specific source is most strategic and transitional lower-carbon alternative fuels, such as natural gas, will also play an important role in certain markets. Policies in industry, transportation and buildings are more likely to vary with the structure of the economy (natural resources, industry specialisation, etc.) and local specificities (density of urban areas, car-use profiles, local demand for air conditioning or heating, etc.). For example, more rapid development of EVs could be relevant in a country with high power-sector decarbonisation potential, while advanced biofuels could be of interest where large amounts of biomass are easily available. This section aims to unpack these key opportunities on the sectoral level and provide key policy elements in each sector.

Policy packages for power sector transition

Power generation is the largest source of energy-related CO_2 emissions, with 70% of emissions attributable to coal-fired generation. The incremental emissions reductions in moving from the Bridge to the 450 Scenario are largely a matter of displacing unabated coal generation, through improving efficiency of electricity use and shifting generation to lower-emissions alternatives (Figure 7). By 2040, energy portfolios in the 450 Scenario have been diversified towards renewables and nuclear, coal- and gas-fired plants equipped with CCS technology, and aggressive energy efficiency improvements across all sectors to reduce electricity demand.

Figure 7 • Global emissions from electricity generation and heat plants and abatement by fuel ($MtCO_2$)



Source: Analysis builds on data from IEA (2015a), *World Energy Outlook Sepcial Report : Energy and Climate Change*, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf.

The 450 Scenario adds two major policy elements compared to the Bridge Scenario: greater early support for long-term technology development and high carbon prices after 2025 that deploy those technologies. Power generation is a domain where price optimisation plays a key role in investment and operational decisions. As a result, carbon prices lead to a phase-down of unabated coal use and the introduction of variable renewables and CCS. The majority of these additional emissions reductions will take place over the 2025-2040 timeframe as carbon prices increase and low-carbon technologies become more cost effective. If carbon prices were to remain at moderate levels (as in the Bridge Scenario), other policies would need to address this gap.

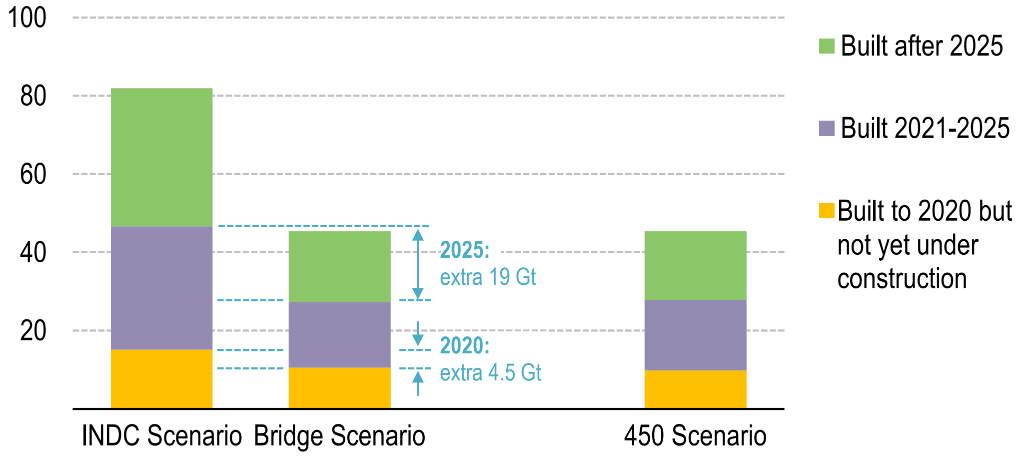
Supporting new low-carbon investment

One of the most striking findings of the *World Energy Outlook Special Report: Energy and Climate Change* (2015) is that the targeted policies of the Bridge Scenario already do a reasonable job in guiding new power investment towards low-carbon options, through the combination of energy efficiency policies curbing demand, and strong support for renewable investment. Cumulative emissions up to 2040 from new power plants are very similar in the Bridge and 450 Scenarios

(Figure 8).[7] From a policy perspective, this suggests that if the high carbon prices of the 450 Scenario are not feasible, new investment in power generation could be kept on track through direct support policies (such as auctions for new capacity, feed-in tariffs or green certificates) – a strategy that is already being followed by many governments.

For renewable and nuclear power generation, price is only one factor in enabling deployment. For instance, developing nuclear power requires securing project mandates at high political levels with substantial public investment, investing in RD&D to support local research and enhance engineering capabilities, anticipating extra security measures and scaling up the supply chain for raw materials. In the 450 Scenario, 245 gigawatts (GW) of additional nuclear capacity are installed relative to the Bridge Scenario, with acceleration particularly strong in non-OECD countries such as China and India. These increases lead to emissions reductions of about 13 gigatonnes of CO_2 – about a tenth of total additional abatement (IEA, 2015a). Deployment of variable renewables on a large scale entails addressing electricity market, transmission and storage issues to enable stable grid operation with variable generation.

Figure 8 • Global committed CO_2 emissions through 2040 from new power plants ($GtCO_2$)



Notes: "Committed emissions" are the cumulative emissions to 2040 from these plants, operating under the conditions of the corresponding scenario. The INDC Scenario is similar to the NPS.

Source: Reprinted from IEA (2015a), *World Energy Outlook Special Report: Energy and Climate Change*, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf.

Driving retirement and carbon capture and storage retrofit of fossil-fuelled generation

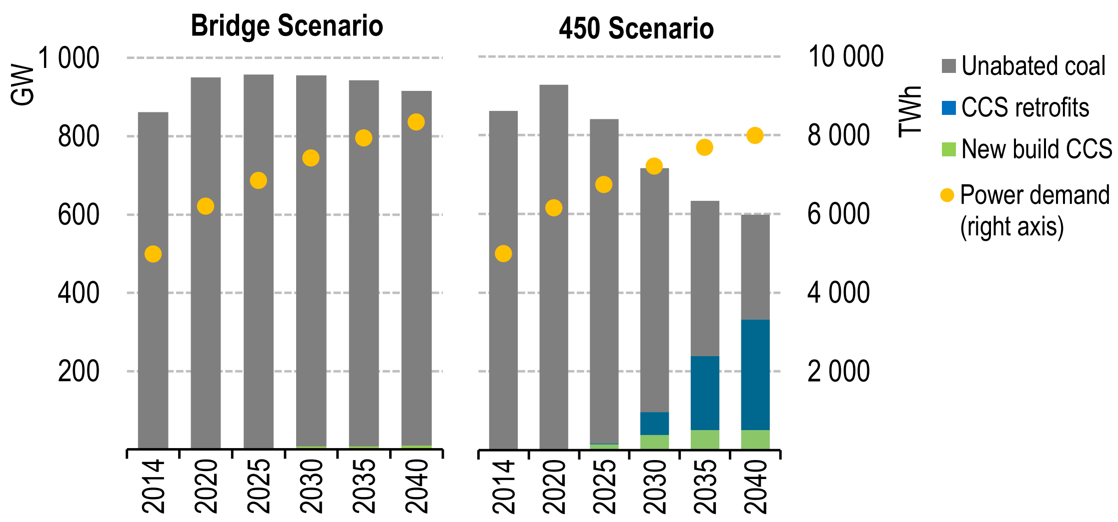
Despite the increasing share of renewables in electricity generation portfolios, fossil fuels remain widely used over 2015-2040. For instance, in the 450 Scenario, about 12% of global electricity is generated from coal and 16% from gas in 2040 (IEA, 2015a).

A major difference between the 450 Scenario and the Bridge Scenario that points to a key result of the high carbon price is the level of unabated fossil-fuelled generation in 2040. China's coal-fired power fleet in the two scenarios provides a striking example of this (Figure 9). Policies in the Bridge Scenario that promote efficiency and renewables, and limit construction and use of inefficient coal, lead to a stalling of growth in coal capacity by 2020, but high carbon prices after 2025 in the 450 Scenario drive more substantial change. In the 450 Scenario coal-fired capacity is

[7] It is important to bear in mind that, considering the need to achieve net-zero emissions from the energy sector by mid-century, the carbon intensity of the power sector fleet in 2040 will be an important determinant in meeting climate targets.

reduced by over one third – plant that would otherwise have operated in 2040. In addition, half of the remaining plants are retrofitted for CCS.

Figure 9 • China's installed coal-fired capacity in the Bridge Scenario (left) and 450 (right)



Source: Reprinted from IEA (2015a), *World Energy Outlook Special Report: Energy and Climate Change*, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf.

Energy, Climate Change and Environment: 2016 Insights (IEA, 2016) explored the range of regulatory and market solutions that could be employed to guide the phase-down of coal-fired generation, many of which are still available even if high carbon prices are not present (Table 2). Characteristics of the power system will determine whether changes to dispatch are most effectively driven by price or mandated through regulations. Options include regulated plant efficiency upgrades, coal-to-biomass co-firing incentives, CCS retrofit mandates or regulatory emissions standards.

Table 2 • Actions to reverse lock-in of existing coal plants, and policies that can drive them

Reversing lock-in action	Policy options		
	Direct regulation of plants	Regulated change in supply/demand balances	Influence markets via price
Retirement of coal plant	• Ownership decision • Regulated lifetime limits • Regulated phase-out	• Fleet-wide GHG emissions performance standard • Regulated increase in renewable capacity • Demand reductions	• Fuel price changes • Carbon pricing • Preferential pricing for renewables
Change dispatch of the existing power generation fleet	• "Clean first" dispatch • Priority dispatch of renewables	• Fleet-wide GHG emissions performance standards	• Carbon pricing • Removal of fossil fuel subsidies
Retrofit of coal plant for CCS	• Regulated lifetime • CCS retrofit mandates	• CCS trading schemes • Fleet-wide GHG emissions performance standard	• Carbon pricing • Preferential pricing for CCS generation • Low cost (or free) capital for construction

Biomass co-firing or conversion	• Ownership decision to convert	• Renewable generation quota • Fleet-wide emissions performance standard	• Carbon pricing • Preferential pricing of renewables

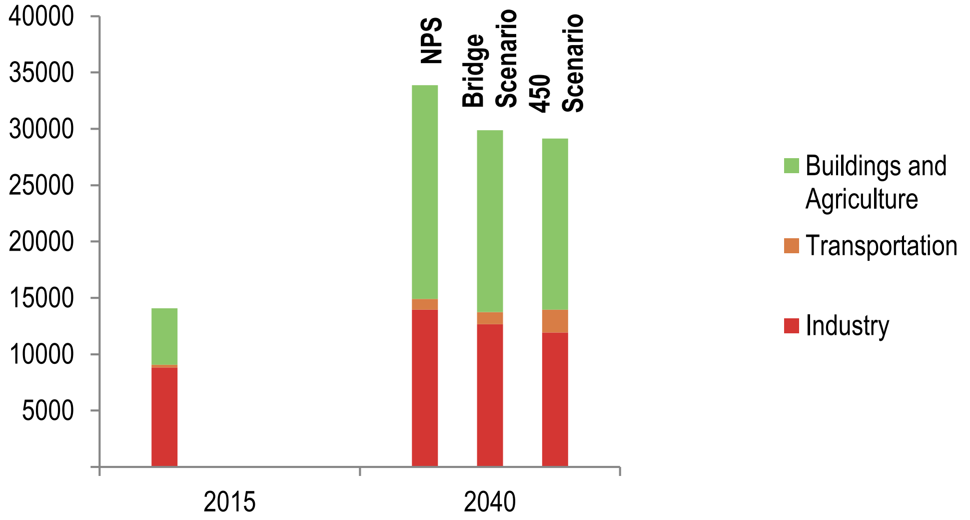
Source: IEA (2016c), *Energy, Climate Change and Environment*, adapted from Chapter 1, "Policies and actions to 'unlock' high-emissions assets: The example of coal-fired power generation", http://dx.doi.org/10.1787/9789264266834-en.

The push for CCS is much stronger in the 450 Scenario compared to the Bridge Scenario due to increasing carbon prices that make it attractive to add CCS to fossil fuel power plants to allow them to compete against other dispatchable low-carbon options. By 2040, about 740 GW of coal- and gas-CCS are deployed worldwide, as it becomes an attractive abatement option (IEA, 2015a). Countries which rely heavily on coal benefit more from CCS. Among these are China, India and the United States. This push is not linearly phased in time, with deployment accelerating after 2030.

Enhancing efficiency of electricity use

Electricity consumption falls by about 10% in 2040, between the NPS and Bridge Scenario, mostly driven by reduced demand for electricity in buildings. This sector accounts for more than 30% of total final energy consumption (Figure 10).

Figure 10 • Global Final Consumption of Electricity (TWh)



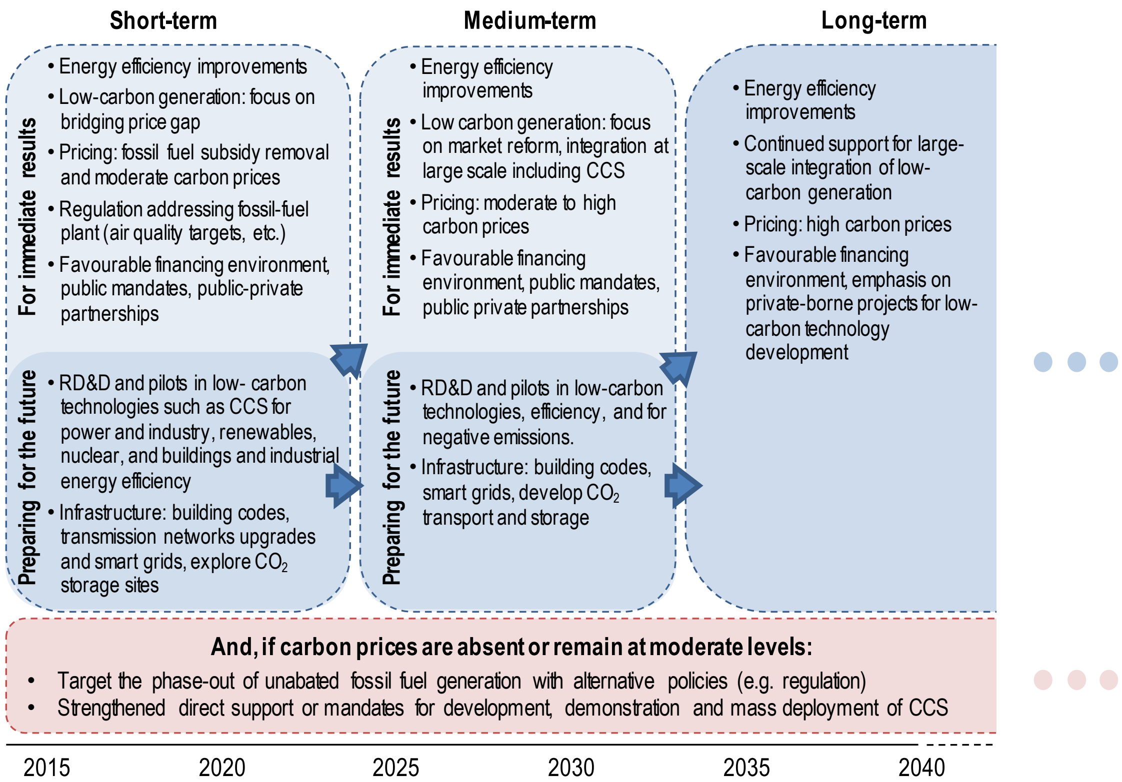
Source: Analysis builds on data from IEA (2015a), *World Energy Outlook Special Report: Energy and Climate Change*, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf.

In the Bridge Scenario, strong policy efforts are made to reduce electricity consumption. These energy efficiency gains result from policies such as higher minimum energy performance standards (MEPS) to phase out least-efficient categories of appliances (refrigeration and cleaning appliances in particular), as well as televisions and computers, and incandescent and halogen light bulbs. Higher standards are also applied to new cooling and heating equipment, as well as insulation. Additionally, the use of heat recovery is expanded. The relatively smaller incremental emissions savings in moving to the 450 Scenario suggest that high carbon prices (passed through into electricity prices) are not a strong driver of change in this sector.

Summary: Policy packages for the power sector

The IEA low-carbon scenarios approach power sector transformation with an integrated package of polices across energy efficiency support for investment in low-carbon generation, carbon pricing, and RDD&D of technologies. In the 450 Scenario, high carbon prices drive the bulk of emissions reductions after 2025, notably by making the retirement of unabated coal-fired generation and retrofit with CCS cost-effective. If carbon prices remain at more modest levels, alternative policies may be needed to target the same outcomes, although moderate carbon pricing still plays an important role in mediating price-based decision making in the sector, such as electricity sector dispatch. The package of policies will need to evolve over time through the different phases of the clean energy transition.

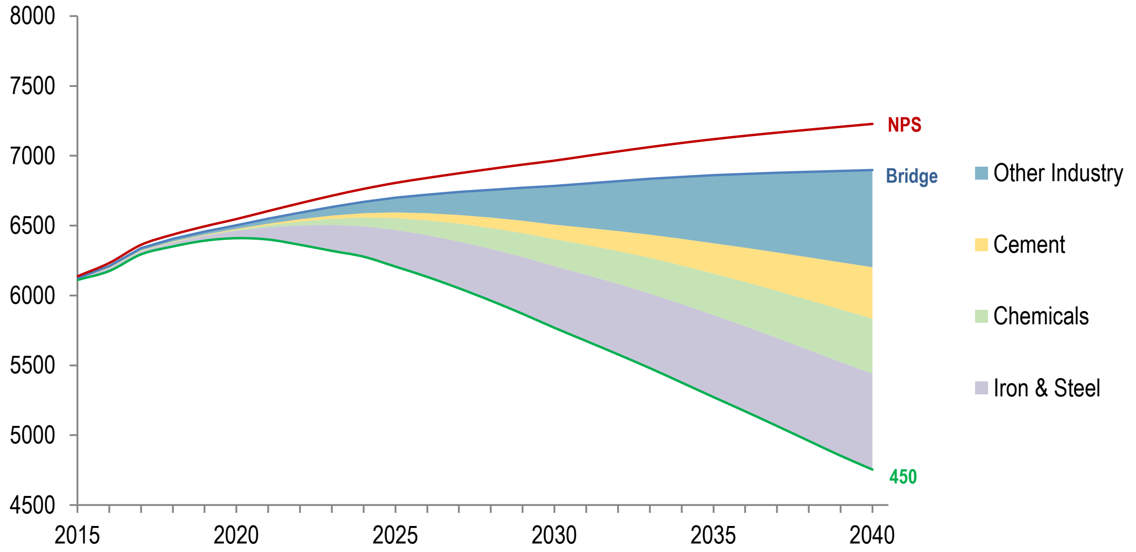
Figure 11 • Policy drivers of the "real-world" energy transition in the power sector



Policy packages for industry sector transition

In 2015, energy-related industry emissions aggregated to about one-fifth of global emissions, with emissions from coal constituting about 60% of these. In this sector, the targeted policies of the Bridge Scenario have a much smaller impact on emissions, with the majority of abatement opportunities only being realised with the stronger policies of the 450 Scenario. The reductions are spread across multiple industrial sub-sectors, with iron and steel, chemicals and cement providing the majority of energy-related savings (Figure 12).

Figure 12 • Global energy-related emissions in industry and CO_2 abatement by sub-sector ($MtCO_2$)



Note: Processed CO_2 emissions from industry are not included in energy-related industrial emissions.
Source: Analysis builds on data from IEA (2015a), *World Energy Outlook Special Report: Energy and Climate Change*, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf.

As in the power sector, the majority of energy-related emissions reductions by fuel between the Bridge and 450 Scenarios result from reductions in coal emissions. Coal is responsible for 75% of cumulative emissions savings, with gas and oil responsible only for 15% and 10% respectively. Though not shown here, process-related CO_2 emissions from industry are a further important source of emissions reductions, particularly from clinker manufacture, methanol and ammonia production. Clinker (used to produce cement) is responsible for the highest aggregate CO_2 emissions from industrial processes, producing about 35% of industrial processes emissions in 2040. It also holds the greatest abatement potential, yielding the largest emissions reductions in the 450 Scenario relative to the Bridge Scenario.

The fact that 90% of reductions in the 450 Scenario are achieved only after 2025 when carbon prices become high, suggests that there is no policy "quick fix" for short-term mitigation, and that demonstration and deployment of alternative technologies at scale will require some time. Short-term policy packages for this sector therefore need a substantial focus on preparing for long-term reductions, including a research and demonstration into innovative low-carbon production methods. The policy support focus should be on breakthrough technologies for low-emission processes, improving energy use, recovered excess heat as well as on material efficiency through, for instance, by-products and waste management. Electrification also offers long-term potential in industry given recent R&D developments. For instance, it can be used to power a broad variety of tools and processes (EPRI, 2016). Biomass could be more widely used in industry in the future as well, in chemicals (Netherlands Enterprise Agency, 2015) and cement production for combustion purposes.

Energy efficiency improvements

Improving the energy efficiency of industrial processes contributes to achieving climate goals by decreasing the amount of fuel consumed per unit of output (greater efficiency in production), and/or reducing the emissions per unit of fuel consumed (lower emissions intensity).

In the Bridge Scenario, there is a specific focus on energy efficiency improvements in industrial motors that are responsible for around one half of global electricity consumption in industry, while the 450 Scenario broadens its measures to steam systems and process heat. Adoption of energy efficiency improvements at scale is largely price-driven, with greater uptake in the 450 Scenario where carbon price makes greater efficiency investment cost-effective. Coal and gas demand mostly declines after 2025 in the 450 Scenario, when carbon prices are high.

If carbon prices were to remain modest beyond 2025, then other policies to drive energy savings would need to be strengthened accordingly, including for example through mandatory sectoral efficiency targets or incentive schemes to improve energy performance and enhance the efficiency of production processes.

Low-carbon industrial technology innovation

As in the power sector, industrial technology RDD&D plays a major role in reducing emissions in industry. Although the fuel mix in industrial consumption remains more or less the same between the two scenarios, the emissions intensity of fuels falls significantly in all industrial sub-sectors in the 450 Scenario relative to the Bridge Scenario largely due to the deployment of CCS. For instance, for the same amount of iron and steel and cement produced, emissions are about 40% lower in the 450 Scenario. The cement and iron and steel sub-sectors benefit most from breakthrough technologies, such as CCS, because of limited alternatives to their carbon-intensive industrial processes.

In the 450 Scenario for instance, about half of global cement and iron and steel production capacity is equipped with CCS in 2040. In the chemicals sub-sector, savings are achieved from ammonia and methanol production, which offer a short-term opportunity for CCS development given the purity of CO_2 in their flue process gases, making the capture relatively inexpensive. Most CCS capacity is added in non-OECD countries such as China, India, Russia and the Middle East. Among OECD countries, the United States and the European Union deploy the most CCS. This is due to the concentration of industrial production capacity and expected strong growth in these areas.

Box 2• Key actions to accelerate the development of CCS technology in the power sector

The following actions, presented in IEA's Technology Roadmap: Carbon Capture and Storage (2013), constitute a pathway to accelerate the deployment of CCS. Overall, actions fall within four broad themes: funding (incentives for capital deployment, operations and R&D), costs and risks (borne by both the public and private sector in the short term, only by private stakeholders in the long term), subsidies/penalties (financial incentives and increasing carbon prices) and technology support (IEA, 2017b; IEA 2016e). These actions aim to:

- prove capture systems at pilot scale where CO_2 capture has not yet been demonstrated
- increase efforts to improve understanding among the public and stakeholders of CCS technology
- introduce financial support mechanisms for demonstration and early deployment to attract private financing
- implement policies that encourage CO_2 storage exploration, characterisation and development
- develop national laws and regulations as well as provisions for multilateral finance that effectively require new-build, base-load, fossil fuel power generation capacity to be CCS-ready
- reduce the cost of electricity from power plants equipped with capture through continued technology development and use of highest possible efficiency power generation cycles

- encourage efficient development of multi-user CO_2 transport and storage infrastructure accommodating various clusters of sources (including existing and future power stations)

As a sector where operational and investment decision making is highly cost sensitive, the high carbon price of the 450 Scenario is a significant force in the take-up of CCS. Carbon pricing increases end-use fossil fuel energy prices in industry. The resulting large increase in the cost of direct coal use in the 450 Scenario provides a strong incentive for the adoption of innovative low carbon technologies.[8] In the absence of high carbon prices, however, policy support (such as financial support mechanisms or tax credits) would be required for the cost-competitiveness of these technologies. The challenge for CCS technology is not only to reach cost levels competitive with other low-carbon technologies, but is also to deliver a number of additional actions to unlock the uptake of CCS at scale (Box 2).

Box 3 • Reducing methane emissions from oil and gas operations – the role of energy pricing

Methane is a highly potent, albeit short-lived greenhouse (GHG) gas. 60% of annual methane emissions stem from anthropogenic sources, with the energy sector (extraction of oil, natural gas and coal, biofuels and biomass burning) and agriculture being the largest emitters, accounting for 26% and 24% of emissions respectively (Saunois et al. 2016). The short-lived nature of methane complicates evaluation of its attribution to long-term climate change, but makes reducing methane releases from upstream oil and gas operations an important element in efforts to peak global GHG emissions in the 2020 horizon (IEA, 2015a).

Methane emissions from oil and gas operations were estimated at 76 Mt in 2016 and are projected to rise to over 105 Mt by 2040 due to the growth demand for oil and gas in the NPS (IEA, 2017a). Abatement technologies that prevent vented and fugitive emissions are however widely available. Captured methane emissions can often be monetised, resulting in lowered or even negative total costs of emissions reductions. The main technical challenge is detection and measurement of emissions in a comprehensive and cost-effective manner.

Estimating marginal abatement costs for oil- and gas-related emissions by country and emission type shows that a total of 75% reduction from current methane emission levels seems feasible if all available technologies were to be deployed (IEA, 2017a; IEA, 2015a). Importantly, latest IEA analysis shows that some 50% of methane emissions could equally be avoided just by using technologies and approaches that would pay for themselves through the captured methane that can be sold (based on 2015 gas prices) (IEA, 2017a).

Furthermore, marginal abatement costs show high sensitivity to prevailing natural gas prices. At lower (2016) gas prices, the level of possible emissions reductions globally with measures that have positive net present values would drop from 50% to 40%. Conversely, given the increase in natural gas prices around the world estimated in NPS by 2040, the proportion of total emissions in this category increases to 60% (IEA, 2017a). Changes in energy prices therefore play a key role in the cost-effectiveness of methane emissions reductions, implying that carbon pricing could play an important role in making more emission reduction opportunities economically attractive. However, this is not to say that pricing alone is the best policy to unlock this potential: the jurisdictions with the most advanced policy frameworks to address

[8] The impact on electricity prices is relatively smaller given the availability of cost-effective alternative power decarbonisation options.

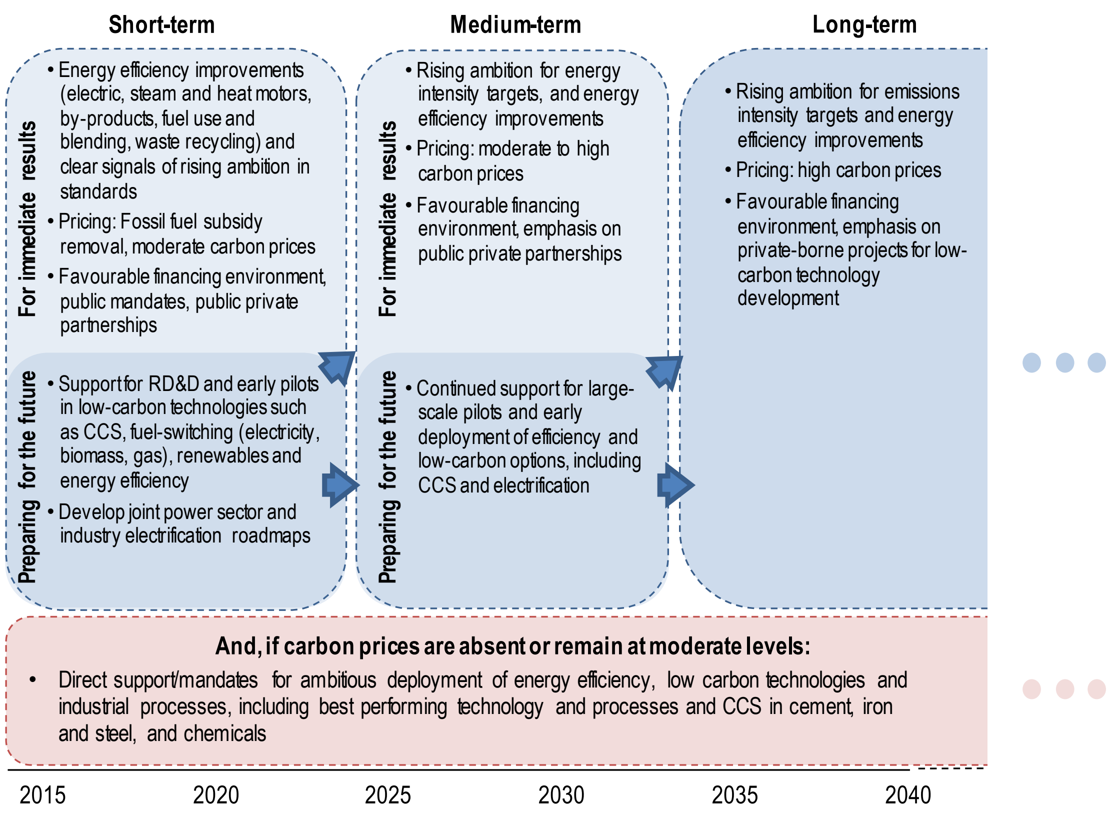
methane emissions do so through targeted regulations, such as requiring uptake of specific technologies and implementation of specific practices and standards, in addition to reporting requirements.

Note : Box 3 provides details on methane emissions reductions from oil and gas sector only. Other parts of this section discuss CO_2 emissions reductions

Summary: Policy packages for the industry sector

Policies for the industrial sector are driven by the potential for improvement in energy efficiency over the short term and the availability of higher-cost deeper emissions savings in the long term. In the 450 Scenario, high carbon prices deploy these low-carbon options in later time periods. However, if prices remain modest for longer, alternative policies, such as direct support for technology innovation, large-scale CCS deployment or strict efficiency mandates, may be needed to steer investment.

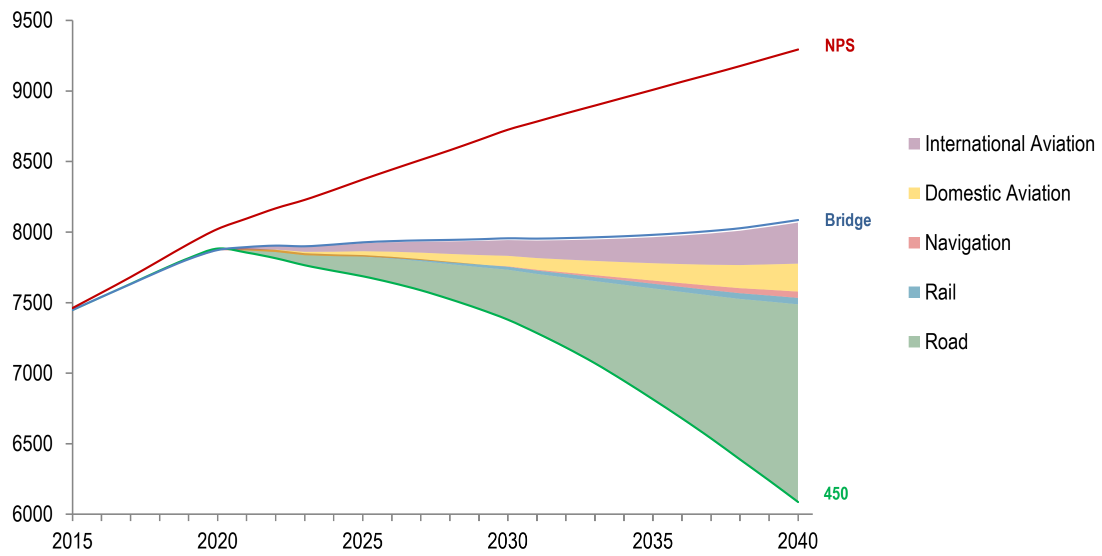
Figure 13 • Policy drivers of the "real-world" energy transition in industry



Policy packages for transportation sector transition

The transport sector is the second largest emitter of GHGs after power generation, reaching about 25% of global energy-related combustion CO_2 emissions in 2015. Addressing emissions from transportation is important both to decrease global emissions and to mitigate local pollution issues. Road transport (passenger and freight) constitutes the bulk of transportation emissions, about 75% in 2015, and is also the primary cause of emissions growth due to a growing demand for personal mobility and goods transport. Road transportation contributes the largest share of abatement in transportation between the Bridge Scenario and NPS, followed by aviation (Figure 14).

Figure 14 • Global energy-related emissions in transportation and CO_2 abatement by sub-sector ($MtCO_2$)



Source: Analysis builds on data from IEA (2015a), *World Energy Outlook Special Report: Energy and Climate Change*, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf.

In 2040, 75% of transportation emissions remain road-based. Transportation still holds great abatement potential beyond 2040, suggesting that policy packages should include long-term perspectives with increasing ambition beyond 2040.

Fuel-economy standards are the main driver of short-to-medium-term emission reductions in the Bridge Scenario, with additional stringency compared to the NPS. Fuel consumption for new light duty vehicles is capped at about 4L/100km by 2030 (equivalent to a reduction of about 50% relative to 2005). For new freight trucks, standards achieve a 30% reduction in average fuel consumption per truck in 2030 compared to 2015. Thanks to more ambitious policies, the 450 Scenario taps into a greater mitigation potential, with EVs and biofuels development accelerating between the Bridge Scenario and the 450 Scenario.

Pricing in the transport sector can play a synergistic supporting role by moderating demand, as it can compensate for rebound effects. Due to falling demand in fossil fuels (given tighter fuel economy standards and greater diversity in the fleet with EVs and biofuels) in the 450 Scenario, lower global demand for transport fuels results in lower global oil prices, which would flow through into a rebound in transport demand. To avoid this, end-user prices for transport fuels are adjusted in the 450 Scenario (effectively a top-up fuel tax) so that prices, and hence demand behaviour, remain unchanged. The magnitude of price needed to avoid this rebound effect is substantial: converted to an equivalent carbon price, the difference between the Bridge and 450 Scenarios is around USD 50/t in 2030, rising to USD 130/t in 2040, similar in magnitude to the explicit carbon prices introduced in the power and industrial sectors[9].

[9] As road vehicles electrify, declining fuel tax revenues will need to be replaced by vehicle-kilometre based pricing schemes. In the mid-to-long term, road pricing can provide a revenue stream for the maintenance and strategic build-out of road and other transport infrastructure, and further counteract potential rebound from efficiency-driven reductions in the costs of goods and personal transport.

EVs also contribute to the emissions reductions in 450 relative to Bridge. In the short term, country targets drive deployment, primarily in China, India, the United States and the European Union. Challenges include production costs, battery energy density and recharging infrastructure costs, as well as education of the public on performance and safety. Large-scale deployment only occurs in the late 2020s. The long-term potential of EVs resides in the parallel transition to a low-carbon power sector and lower emissions in electricity generation. In countries where power generation has not been sufficiently decarbonised, EVs emission intensity, although lower than the one of an internal combustion engine vehicle, remains high. This supports the rationale for designing holistic policy packages that address sectors complementarily. Ambitious EV targets are more effective if simultaneous policies are undertaken in the power sector.

Because biofuels and EVs are not yet fully mature technologies, support is required in the short term (for example, in roll-out of charging infrastructure) before wide-scale deployment can take place in the 2020s.

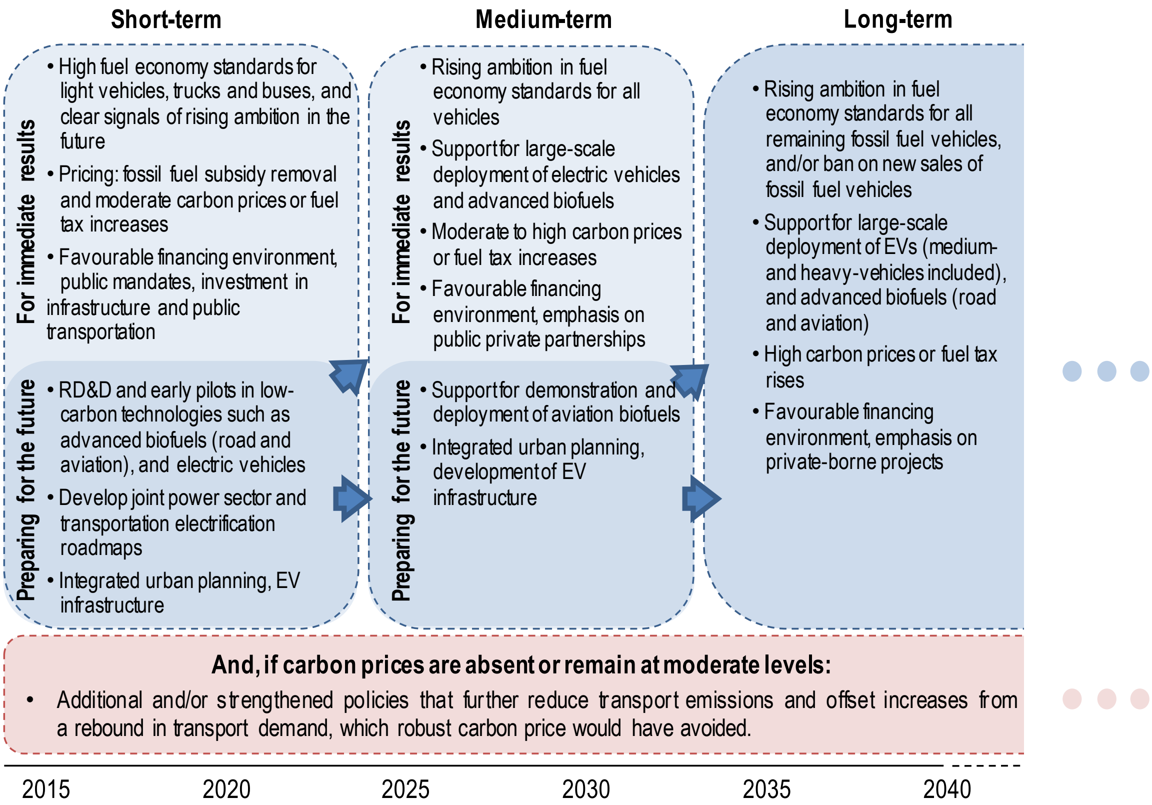
Biofuels are a major technology shift between the 450 Scenario and the Bridge Scenario (the quantity of biofuels nearly doubles). The main challenges for biofuels include the reduction of production costs. Advanced biofuels are available at scale only in 2020, suggesting that strong policy support in RD&D and early deployment are required in the short term. Because moderate carbon prices in the short term cannot trigger broad deployment, national targets for biofuels are the key driver for deployment of the technology. The compatibility of existing refuelling infrastructure with biofuels deployment is also one of the key elements aiding their scale-up. Policy packages can support biofuels more easily in markets where the raw material required for biofuel production is available locally. For instance, Brazil benefits from abundant resources that are highlighted by the 450 Scenario, leading road passenger transportation to a near-complete replacement of fossil fuels by bioethanol, despite a growing demand for mobility.

In addition to technology shifts between 450 and Bridge, municipal travel demand management (TDM) measures to "avoid" unnecessary travel and "shift" it to less emissions-intensive modes will also be needed to reduce transport sector emissions. The portfolio of available measures includes *fiscal policies* (such as congestion charging and parking pricing); *investments* in public transit (including both infrastructure funding and fare subsidies) and in non-motorised transport; and *urban form policies* conducive to reducing the emissions footprint of transport, such as densification and mixed-use development. Such measures play an important role in the transport policy package as they not only augment the effectiveness of pricing that captures the societal and environmental externalities associated with motor vehicle travel, but also provide more affordable mobility alternatives than private car ownership (IEA, 2016e).

Summary: Policy packages for the transportation sector

Large shifts in transport systems will not be triggered by moderate carbon pricing alone in the short term. Further governmental action could include vehicle performance standards, low-carbon fuel mandates, RD&D support, investments in public transportation and financial incentives. Additionally, financial support is needed to develop infrastructure in cities (charging stations, smart grids that can support large fleets, etc.) and on highways.

Figure 15 • Policy drivers of the "real-world" energy transition in transportation



Conclusion: Lessons learned from IEA scenarios on the role of carbon pricing

Policy packaging plays an important role within the IEA's low-carbon scenarios: a high carbon price alone does not address all the aspects of energy transition and comprehensive policy packages are needed which vary by energy sub-sector and over time. The steep cuts in emissions needed after 2030 point to the importance of both short-term policy actions that deliver immediate results and those that support long-term mitigation ambitions, such as RDD&D investment in emerging technologies. The role of carbon pricing across sub-sectors differs based on their sensitivity to price. While carbon pricing can incentivise a large share of opportunities in power generation and industry, it plays only a supporting role in the transport and buildings sectors. Progressively increasing carbon prices in the power sector drives a shift to low-carbon technology dispatch, uptake of low-carbon technologies, such as variable renewables and CCS, and a phase out of unabated coal and gas-fired generation. In the industrial sector, they drive a shift to low-carbon production processes and the development of innovative low-carbon technologies like CCS for processes which currently have limited alternative technology potential. Carbon pricing in the transport sector keeps the demand for carbon intensive transport in check, but does not itself unlock more substantial technology shifts, such as electrification, advanced biofuels development and other large-scale investments for transport infrastructure.

In the absence of high carbon prices in the medium-to-long term, "real-world" policy packages would need to address some of these mitigation areas with alternate policies. In the power sector, additional policies may be needed to steer the retirement of unabated coal-fired generation. In both power and industry, the deployment of technologies with deeper long-term emissions reductions potential, such as support for variable renewables integration and CCS, would need separate support. In the transport sector, even further strengthening of other policies (e.g. fuel standards, subsidies) and deploying of charging infrastructure would be needed in the case that carbon prices (or additional fuel taxes) are not introduced to mediate carbon intensive transport demand.

Case study: Low-carbon energy transition policy packages in Canada

This section presents a case study of Canada examining the challenges and opportunities in designing policy packages for sustainable energy transition. By illustrating key issues encountered in policy making in one country's "real-world" national context, lessons can be extracted for other countries facing similar circumstances in seeking to deliver efficient, effective and well co-ordinated policies for sustainable energy transitions. These circumstances may include shared national and sub-national jurisdiction over energy transition policy, a strong contribution of energy and fossil fuel sectors to economy and employment, and resource and political diversity across sub-national regions. A range of policies and measures at the federal and sub-national levels have been implemented or announced to drive the low-carbon energy transition in Canada. With reference to the framing discussion of section 1, successful policy packages should cover all three "domains" of policy (overcoming barriers, price-based optimisation and strategic actions for the future), will be shaped by national constraints on policymaking, and should be aligned with wider national objectives. From this perspective the case study includes several interesting elements:

- mixed governance of energy and climate policy making between provincial and federal levels, that acts as a constraint but also creates opportunities for policy design options
- addressing the second domain of energy transition policy, the benchmark and backstop nature of Canada's federal carbon pricing approach, which is set to result in hybrid implementation of carbon pricing across multiple provincial systems and using multiple instruments. The design of this policy is shaped by factors including mixed provincial and federal governance and concerns about industrial competitiveness.
- covering the first and third domains, a wide set of complementary energy policies, such as sectoral and fuel regulations and support for clean energy technology innovation, aimed at delivering both short-term emissions reductions and preparing for longer-term deeper transformation

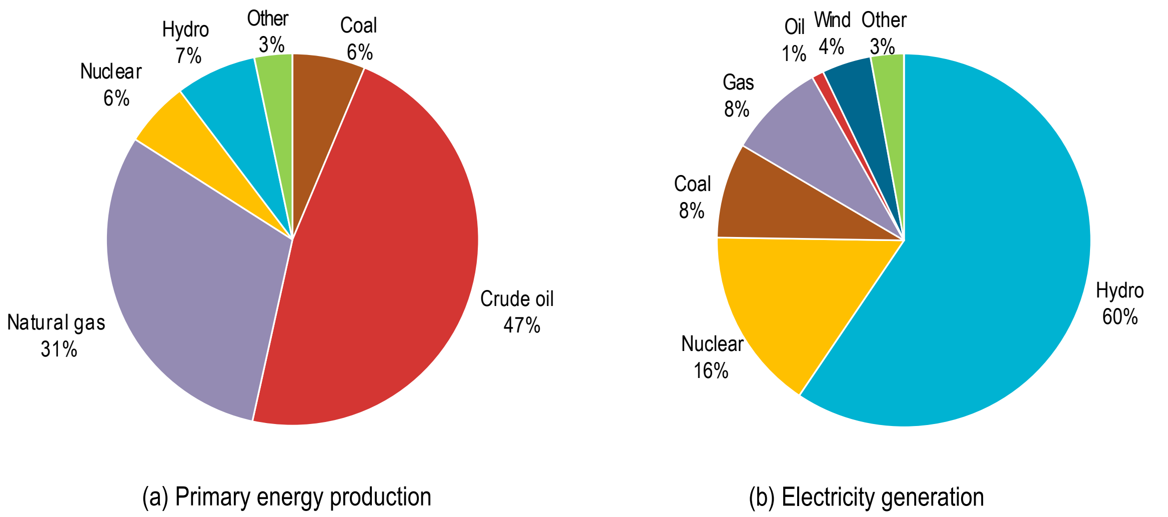
This section explores two issues in the Canadian context: enhancing co-ordination amongst national and sub-national policies, and complementing carbon prices with other low carbon policies and understanding policy interactions. The section concludes with key takeaways for countries facing similar issues.

Canada's energy and climate policy landscape

Rich in energy resources, Canada is the largest energy producer per capita amongst IEA member countries. The energy sector plays an important role in Canada's economy, contributing about 10% of gross domestic product, employing approximately 270 000 people[10] and was responsible for about 18% of Canada's exports[11] in 2016 (NRCan, 2017a). The energy sector contributes about 80% of Canada's anthropogenic GHG emissions (NRCan, 2017b). Canada's primary energy mix relies primarily on oil (47%) and gas (31%), with renewable energy including hydro making up about 10% (Figure 16a). Canada's electricity mix boasts a high share of renewable sources: over 80% of electricity generated comes from low-carbon energy sources, primarily hydro (59%) and nuclear (16%), with wind, solar, tidal and other sources making up the remainder (Figure 16b).

[10] direct employment in the oil and gas sector
[11] merchandise exports

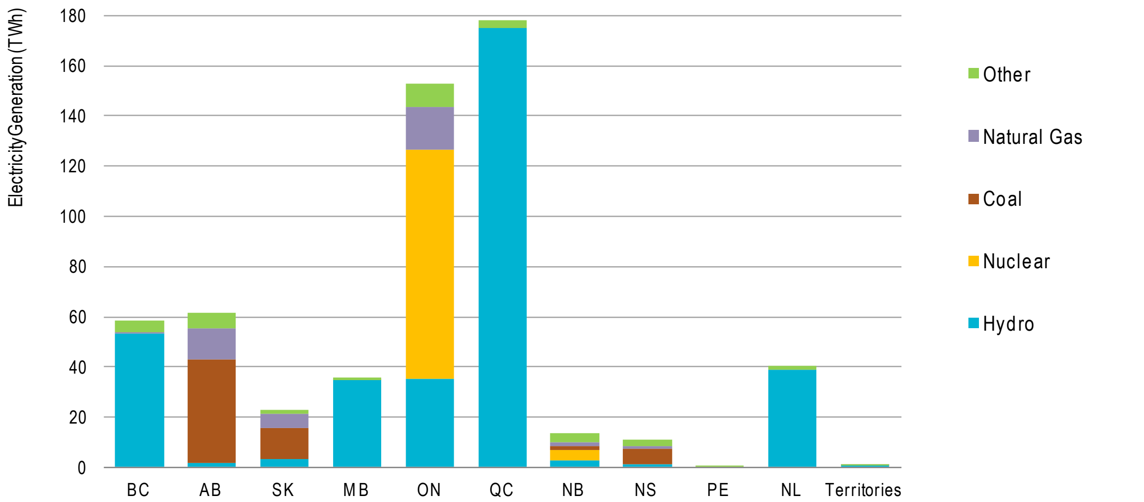
Figure 16 • Primary energy production (a) and electricity production (b) by source in Canada, 2016



Note: "Other" includes solar, tidal, biofuels and waste. For the chart showing primary energy production, "other" also includes wind. Crude oil includes natural gas liquids and feedstocks. 2016 data are provisional.

Sources: IEA (2017d), *Electricity Information*, and IEA (2017c), *World Energy Balances, https://www.iea.org/publications/freepublications/publication/WorldEnergyBalances2017Overview.pdf.*

Figure 17 • Sources of provincial electricity generation in Canada, TWh in 2015



Notes : "Other" denotes electricity generation by wind, tidal and solar, other fuels, steam from waste heat and other generation.

BC – British Columbia; AB – Alberta; SK – Saskatchewan; MB – Manitoba; ON – Ontario; QC – Québec; NB – New Brunswick; NS – Nova Scotia; PE – Prince Edward Island; NL – Newfoundland; "Territories" aggregates electricity generation across the three territories of Yukon, Nunavut, and the Northwest Territories.

Source: Environment and Climate Change Canada (2017a), *National Inventory Report 1990:2015*, http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php.

Energy resources are unevenly distributed across the country and most energy policy is determined at the sub-national level, resulting in diverse energy systems across provinces and territories. In the electricity sector for instance, certain provinces rely primarily on hydro resources (British Columbia, Quebec, Manitoba and Newfoundland and Labrador), while coal, and increasingly natural gas, play a major role in Alberta, Nova Scotia, and Saskatchewan. Nuclear energy makes up over 50% of the generation mix in Ontario, while the northern territories rely on hydro for grid-connected communities and diesel generation for off-grid areas (Figure 17).

This reliance on different energy resources, along with differences in population size and economic structure, produce a varied picture of GHG emissions at the sub-national level.

Economy-wide, CO_2 emissions declined 2% since 2005 while carbon intensity (CO_2/GDP) decreased 16%, due in part to fuel switching to cleaner sources of electricity (notably from coal to natural gas), a shift away from energy-intensive industry, and improved industrial efficiency.

Canada's low-carbon policy mix

The *Pan Canadian Framework on Clean Growth and Climate Change* (hereafter the *Pan-Canadian Framework*) was released in December 2016 and represents a suite of low-carbon and energy policies at both federal and sub-national levels. A central pillar is the commitment to pricing carbon nationally applied as a backstop for all provinces and territories that do not meet benchmark carbon price requirements by 2018. Other key federal policies[12] within the *Pan-Canadian* Framework include vehicle emissions standards for light- and heavy-duty vehicles and fuels regulations, as well as emissions standards for natural gas and coal-fired power plants, which effectively ban operation of any coal plant without CCS technologies by 2030.[13] Technology support and innovation policies also play an important role in Canada's policy mix, including support at both early-stage technology development as well as commercialisation and technology adoption. As such, Canada's low-carbon policy package includes elements that address each of the three domains of policy packages for energy transition, as described in Section 1. Examples of federal policies in each domain include:

- first domain: energy efficiency appliance standards and stricter energy building codes
- second domain: the backstop federal carbon price and complementary sectoral regulations
- third domain: technology support and innovation policies

While GHG emissions reduction has been a primary driver of these policies, it has not been the only one. Canada's low-carbon policy package aims to fulfil a wider set of clean growth and energy transition objectives, including job creation, economic diversity and competitiveness and clean environment (Government of Canada, 2016).

The *Pan-Canadian Framework* and benchmark carbon pricing policy represent a shift towards a more active and directive federal role in low-carbon policy making in Canada compared to the historical facilitative and convening approach (Snodden and VanNijnatten, 2016), as outlined in IEA's 2015 review of Canada's energy policies (2015b). It also reflects a more collaborative approach of Canada's sub-national jurisdictions to address climate change.[14] Over the previous decade, the provinces have been at the forefront in advancing low-carbon policies, enabled by the relatively decentralised nature of Canadian federalism including on energy and climate change matters. This active role, in combination with the unique energy resource endowments, economic structure, and the political priorities of each region, has resulted in a complex patchwork of energy and climate change policies across the country (Table 3). While Canada's policy mix covers all sectors including forestry, agriculture and waste, this case study focuses on energy-related emissions only.

[12] The Annex contains details of individual policies.

[13] Nova Scotia and the Government of Canada have agreed in principle to negotiate an equivalency agreement to allow coal-fired power plants in Nova Scotia to continue operating past 2030, if equivalent emissions reductions are achieved elsewhere in the electricity sector.

[14] At the time of writing, Saskatchewan and Manitoba had not signed the *Pan-Canadian Framework*.

While the *Pan-Canadian Framework* and proposed carbon pricing approach result from reinvigorated political will at the federal level to advance the low-carbon transition agenda, implementation of these policies also benefited from a favourable "window of opportunity" for policy change. These enabling conditions included the election of a provincial government supportive of climate policy in Alberta – Canada's largest fossil fuel producer and historically vocal opponent of stringent climate policy – the existence of carbon pricing already in several jurisdictions and global momentum around the low-carbon energy transition following the negotiation of the Paris Agreement.

At the international level, Canada has ratified the Paris Agreement and has committed to reducing its GHG emissions by 30% below 2005 levels by 2030 as outlined in its Nationally Determined Contribution (NDC). Canada has also developed a long-term, low-carbon development strategy and was one of the first countries to submit this mid-century strategy to the United Nations Framework Convention on Climate Change (UNFCCC).

Table 3 • Key policies in Canada to drive low-carbon energy transition

<table>
<tr><th>ELECTRICITY</th><th>INDUSTRY</th><th>BUILDINGS</th><th>TRANSPORT</th></tr>
<tr><td colspan="4">Federal</td></tr>
<tr><td colspan="2">Output-based tradeable performance standard*</td><td colspan="2">Backstop carbon price*</td></tr>
<tr><td colspan="4">Clean fuel standard*</td></tr>
<tr><td>Accelerated coal phase-out*</td><td>Hydrofluorocarbon and methane regulations*</td><td></td><td></td></tr>
<tr><td>National model building codes</td><td></td><td>National model building codes</td><td></td></tr>
<tr><td>Appliance efficiency standards</td><td></td><td>Appliance efficiency standards</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Vehicle emission regulations</td></tr>
<tr><td></td><td></td><td></td><td>Renewable fuels regulations</td></tr>
<tr><td colspan="4">Clean energy technology investment and support (see Table 4)</td></tr>
<tr><td colspan="4">Low Carbon Economy Fund</td></tr>
<tr><td colspan="4">Provincial</td></tr>
<tr><td colspan="4">BC carbon tax</td></tr>
<tr><td colspan="2">BC emissions performance standards for industry</td><td></td><td>BC renewable and low-carbon fuel requirements</td></tr>
<tr><td></td><td></td><td></td><td>BC clean energy vehicle support</td></tr>
<tr><td></td><td>AB oil sands emissions cap*</td><td colspan="2">AB carbon levy</td></tr>
<tr><td colspan="2">AB intensity-based ETS (SGER) to be replaced with output-based system in 2018</td><td></td><td></td></tr>
<tr><td>AB renewable energy tenders</td><td></td><td></td><td></td></tr>
<tr><td>AB coal phase-out</td><td></td><td></td><td></td></tr>
<tr><td>SK Boundary Dam CCS project support</td><td></td><td></td><td></td></tr>
<tr><td>ON coal phase-out</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">ON cap-and-trade</td></tr>
<tr><td></td><td></td><td></td><td>ON EV subsidies</td></tr>
<tr><td colspan="4">QC cap-and-trade</td></tr>
<tr><td></td><td></td><td></td><td>QC zero-emission vehicles standard</td></tr>
<tr><td>NS electricity emissions cap</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">NS cap and trade*</td></tr>
</table>

Colour indicates policy type:

Carbon price	Flexible performance standard	Regulation	Financial or other support

Notes: National model building codes are themselves not mandatory, but are used as a model for mandatory building codes at the sub-national level. BC – British Columbia; AB – Alberta ; SK – Saskatchewan; ON – Ontario ; QC – Quebec; NS – Nova Scotia. This is not an exhaustive list of low-carbon policies in Canada.

* denotes policies that have been announced or are in development but not yet implemented.

Federal backstop carbon price

The federal carbon pricing policy is a keystone of Canada's low-carbon policy package. It was announced in October 2016, a month before the release of the Pan-Canadian Framework. A technical discussion paper on the carbon price released in May 2017 outlines the following key elements of the proposed policy (ECCC, 2017b):

- A federal carbon levy and output-based pricing system would be applied to those jurisdictions that do not meet the national carbon pricing benchmark, at a fixed price path of CAD 10 in 2018, rising by CAD 10 each year reaching CAD 50 by 2022.[15]
- Jurisdictions can implement their own carbon pricing mechanisms either in the form of a cap-and-trade system or an explicit price-based system such as a carbon tax.[16] Those applying a price-based system would need to meet the specified 2018-2022 price path. Those applying a cap-and-trade system would need an emissions limit equating to a 30% reduction below 2005 by 2030, Canada's NDC target under the Paris Agreement. The system must also include a declining annual emissions cap to at least 2022, which corresponds to projected reductions achieved by the federally-determined carbon price path (determined through modelling).
- Benchmark coverage would entail the same sources as covered by British Columbia's carbon tax, which includes all emissions from fossil fuel combustion including in buildings and transportation.
- To address competitiveness concerns, large final emitters (in industry and electricity) emitting 50 kilotonnes (kt) CO_2-equivalent or more annually[17] would be exempt from the backstop carbon levy, and would be subject to a tradeable output-based performance standard. Emissions performance standards would be determined for each sector and based on best-in-class performance. Again, this standard would only apply where provincial systems do not meet the benchmark carbon price.
- In early 2022, a review of the carbon price approach would assess effectiveness and stringency across jurisdictions. An interim report would also assess approaches addressing competitiveness impacts of emissions-intensive, trade-exposed sectors.

Shared jurisdiction over low-carbon and energy policy

Canada's federalist system results in shared jurisdictional responsibilities on low-carbon and energy policy between the federal and sub-national (10 provincial and 3 territorial) governments. Formally, provinces own their natural resources, including energy, and hold the jurisdictional power to manage their development including regulating pollution and GHGs. The federal government also has jurisdiction over pollution management as well as interprovincial and offshore natural resources and infrastructure. As a result, both levels of government hold authority to develop policies for low-carbon energy transition and in practice, have shared responsibilities in this domain.

[15] If prices continue to increase at the same rate after 2022, they would be broadly consistent with those in IEA's 450 Scenario (consistent limiting warming to 2°C from preindustrial levels) where carbon prices in all advanced economies reach USD 63 by 2025 and USD 140 by 2040.

[16] Jurisdictions could also implement a hybrid approach composed of a carbon levy and output-based pricing system such as in Alberta.

[17] Smaller emitters would have the option of opting in.

Costs and benefits of sub-nationally driven policy

IEA's 2015 in-depth review of Canada's energy policies found that active development of energy and low-carbon policies at the sub-national level have allowed provinces and territories to tailor policies to regional circumstances. These are varied as to their energy and resource endowment, political priorities and economic circumstances. For example, Quebec, whose electricity generation mix has very high shares of clean electricity in the form of hydropower, has prioritised electrification of end-uses in transport and buildings. Alberta, the largest oil and gas producer in Canada, has focused on upstream producers through an oil sands emissions cap and ETS for industry and electricity, which addresses concerns of competitiveness and electricity price rises.

Over the past decade, sub-national action has also helped low-carbon policy to advance in the absence of federal drivers and to side-step contentious issues around national burden-sharing and redistribution of carbon price revenues (Ecofiscal Commission, 2015). It has also created a diverse set of policy experiments across the country, generating lessons to inform policy development including the Pan-Canadian Framework. However, this bottom-up patchwork also creates risks of increased costs due to policy duplication,[18] lack of policy coherence and certainty at the national level, and regional policy "gaps" including on carbon pricing, with some jurisdictions facing no explicit carbon price.

Canada's federal government can act to address some of these challenges by encouraging policy co-ordination (through discussion fora such as the Canadian Council of Ministers of the Environment and institutions co-ordinating support for clean technology and innovation), encouraging linkages between policies such as emissions trading schemes, or implementing mandatory national standards or regulations (such as appliance energy efficiency standards, or the proposed benchmark carbon price). National co-ordination promises several beneficial outcomes:[19]

- It can lower the costs of reducing emissions by minimising policy duplication and harmonising the costs per tonne of reducing emissions. This point is developed in the next paragraph.[20]
- It can enhance policy coherence on a national scale, improving consistency of policy signals for businesses with operations in different jurisdictions, or for foreign trading partners who deal with multiple jurisdictions.
- A more consistent national level of policy ambition can minimise inter-jurisdictional emissions "leakage," where emitters in one jurisdiction move operations to another with less stringent regulations.
- Federal action can enhance overall ambition and help fill regional policy "gaps" by driving jurisdictions with less stringent policies to meet a minimum benchmark.

Analysis shows that linking sub-national policies can improve policy efficiency and reduce the costs of reaching Canada's 2030 NDC target by expanding access to lower-cost emissions reduction opportunities. Sawyer and Bataille (2017) find that linking emissions trading across

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[18] A distinction is made between policy overlap and policy duplication. "Overlap" refers to policies covering the same emissions sources (such as a vehicle emissions performance standard and renewable fuels standard both covering transport emissions). Overlap is not necessarily undesirable if each overlapping policy has been designed to meet its own objective(s) or has been established to provide additional policy certainty. "Duplication" refers to overlapping policies that share the same set of objectives and functions.

[19] While not elaborated in this paper, another benefit to federal or inter-regional co-ordination would be to promote inter-provincial energy trade including electricity interconnections, to support low-carbon and energy security goals.

[20] Can harmonise marginal, average, or even implicit carbon costs.

large final emitters (in industry and electricity sectors) results in a GDP decline by 2030 of only 0.04% from the business-as-usual level, compared to 0.52% GDP loss where sub-national policies are scaled up individually without linking. This translates to a benefit of approximately CAD 23.5 billion21 in 2030. Linking the industry and electricity sectors also limits the carbon price to CAD 100/tonne to meet Canada's 2030 NDC, compared to CAD 150/tonne in an unlinked scenario.

In the "real world" context, there may be practical challenges to creating a fully-linked system across all jurisdictions, as large final emitters are currently covered by different schemes in each jurisdiction, including the carbon tax in British Columbia, an emissions trading scheme in Alberta, cap-and-trade in Ontario and Quebec,[22] and an electricity sector emissions cap in Nova Scotia. While the federal backstop of a tradeable output-based performance standard for large final emitters could facilitate national linking, the largest provinces have established their own pricing systems and several others have indicated their intention to implement their own provincial systems. Political challenges to inter-jurisdictional linkage would also need to be addressed.

One concern raised with the province-led "patchwork" is on long-term policy durability: if inter-provincial competitiveness concerns are not adequately addressed by individual provinces and territories, future advances in policy stringency that could exacerbate such concerns may be more challenging. For example, jurisdictions applying different carbon pricing instruments could have different explicit carbon prices, as the federal benchmark differs between price-based and quantity-based pricing systems. Furthermore, recycling of ETS revenue into complementary policies can suppress the allowance price in cap-and-trade systems.

However, opportunities for alignment exist as provinces develop and strengthen their own carbon pricing systems for designing programmes with "link-ready" sectors.[23] Shared offset markets amongst provinces for sectors outside those covered by the carbon price (such as agriculture and waste) could also be considered. For example, Ontario has signaled its intention to accept offsets from outside the province that use Ontario-approved protocols. Alternatively, clusters of jurisdictions could link their carbon pricing schemes, creating separate carbon "clubs" such as the Western Climate Initiative (WCI).[24]

Layering policy onto an existing patchwork

Canada's provinces, being first-movers on low-carbon policy, have largely defined the national policy landscape. Federal action has thus had to consider this established policy mix, creating certain opportunities but also constraints for federal policy implementation. For instance, the existence of carbon pricing systems in multiple jurisdictions across Canada paved the way for the broad political and public acceptance of a federal carbon pricing policy. Meanwhile, the federal policy was unlikely to have mandated carbon price levels[25] lower than those already in place, and requiring the application of a particular instrument such as carbon tax or cap-and-trade would have required time-consuming and politically challenging reversal of established pricing systems.

[21] Real 2016 dollars.

[22] In 2018, Ontario's cap-and-trade system will be linked to the already-linked Quebec and California systems.

[23] This can be achieved by harmonising programme design elements, such as monitoring, reporting and verification (MRV) methodology and the use of offsets. Alignment of MRV requirements specifically could also decrease regulatory burdens for emitters operating in multiple jurisdictions, as well as facilitating potential programme linkage.

[24] WCI is an agreement between California and four Canadian provinces – British Columbia, Manitoba, Ontario and Quebec – to develop a regional cap-and-trade system with a shared GHG reduction goal. Currently, California and Quebec are operating a linked cap-and-trade system under the WCI, with Ontario set to join in 2018.

25 Carbon price levels refer to marginal prices unless otherwise specified.

Various elements of the federal carbon pricing policy help address challenges of layering new policies onto existing ones, including concerns of policy duplication as well as of federal "interference" in provincial affairs:

- The "backstop" approach to the carbon price is designed to avoid the same emissions sources being covered by federal and provincial measures, and only applies in jurisdictions that do not meet a minimum standard for stringency or coverage.[26] This ensures that the federal government does not create a duplicative policy signal where provinces already have coverage.
- Revenues of a federally-imposed carbon levy will be fully returned to each jurisdiction, which is free to use the proceeds as it sees fit. This avoids political concerns of national wealth redistribution.
- Provinces and territories have flexibility in choosing their carbon-pricing instrument, whether it be cap-and-trade or an explicit price-based system. Furthermore, the federal policy does not prescribe elements of carbon pricing design including use of revenue and for cap-and-trade, the allocation method of allowances or linking to other systems.
- The benchmark carbon price does not impact sub-national GHG reduction targets and energy transition goals themselves, and thus implicitly, each jurisdiction's contribution to the national target.

In practice, only one territory in Canada (Yukon) has publicly stated its intention to have the federal government implement its backstop carbon pricing system. Therefore, in 2018 the vast majority of jurisdictions in Canada may have provincially-designed and implemented carbon price policies in place, but which are set to meet federally-determined minimum standards.

Complementing carbon prices with other policies

Carbon pricing is a key element of Canada's low-carbon policy package, but it remains one policy among many within the wider mix. The benefits of carbon pricing are numerous: it is the most cost-efficient means of achieving emissions reductions; it allows flexibility in responding to increased fossil fuel prices; it creates revenues that can be used for a range of purposes; and at high enough levels, it is effective in driving many required changes to meet low-carbon goals. However, carbon pricing alone is inadequate in "real-world" contexts:

- Where broader energy transition objectives beyond emissions reduction exist, requiring a more diverse package of policies.
- Where market barriers prevent the proper functioning of the carbon price, which even at high levels will not drive certain changes such as energy efficiency investment (Canada Working Group on Specific Mitigation Opportunities, 2016; Bataille et al., 2015; Hood, 2013).
- To drive development and deployment of technologies that are more costly in the short-term, but have the potential to reduce long-term costs.
- Where carbon pricing levels in the "real world" remain at low-to-moderate levels, with a lack of visibility and/or investor confidence in high future carbon price paths.

[26] The negotiation of provincial "equivalent outcomes" is complex. There is no agreed-upon definition of "equivalency", which is negotiated bilaterally with the federal government on a province-by-province basis.

Canada's low-carbon policy package illustrates how these challenges have been approached by Canadian policy makers, through the implementation of policies that complement and/or strengthen a carbon price.

Benefits of policy packages beyond carbon pricing alone

A sustainable energy transition involves decarbonisation of the energy sector, alongside the pursuit of a broader set of objectives related to energy security, energy efficiency and cost reduction, air pollution, and economic growth and development (see Section 1 above). Priorities in Canada's low-carbon transition include job creation and enhanced economic competitiveness including for low-carbon sectors, just transition for affected workers and sectors, and improved air quality (ECCC, 2016). The *Pan-Canadian Framework* also lays out objectives specific to particular regions and populations, such as northern, remote and indigenous communities for which energy security, economic development and a clean environment are particularly high policy priorities.

Therefore, while emissions reduction to meet Canada's NDC target is a primary driver of Canada's low-carbon policy package, it is not the only one. For example, air quality improvement and public health benefits were key motivators for the development of federal and provincial coal phase-out regulations in Ontario and Alberta, vehicle emissions regulations and measures to reduce reliance on diesel in remote communities. Economic competitiveness and the growth of clean technology sectors drove proposed measures in the *Pan-Canadian Framework* to promote skills development and immigration of workers in high-growth clean technology sectors, as well as exports of clean technology products.

Analysis by IEA and Canadian researchers supports the need for targeted policies beyond carbon pricing to drive specific objectives within energy transition, such as electricity sector decarbonisation and enhanced energy efficiency (Box 3).

Box 4 • Achieving pathways to energy transition requires an array of policy responses

IEA's *Energy Technology Perspectives 2017* (ETP) highlights the need for multiple policies to drive decarbonisation pathways to meet international climate change goals (IEA, 2017e). ETP analysis identifies several key areas of global policy action: early action on energy efficiency, electrification of end uses, decarbonisation of electricity supply, increased deployment of biofuels and CCS, and increased technology investment. These are consistent with the outcomes of a study by Sustainable Canada Dialogues, which identified key elements of energy transition in Canada: energy efficiency and conservation, low-carbon electrification, and deployment of low-carbon alternatives (Potvin et al., 2017). Successfully achieving each element requires significantly ramped up policy action on carbon pricing, but also targeted policies such as for decarbonising electricity (e.g. Canada's accelerated coal phase-out), energy efficiency (e.g. Canada's energy efficiency appliance and national model building code), and deployment of biofuels (e.g. Canada's *Renewable Fuels Regulation* and proposed Clean Fuel Standard).

Acting where carbon pricing functions less effectively

Certain market barriers including lack of information, misaligned incentives amongst agents, bounded rationality[27] and low responsiveness to price changes can prevent the effective functioning of a carbon price in influencing household and business decisions, particularly for energy efficiency investment (Ryan et al, 2011; Hood, 2013). In this domain, targeted policy interventions can move consumers closer to cost-effective decision making, as described in Section 2, and reinforced in the Section 3 analysis on enhancing electricity efficiency.

IEA's New Policies Scenario[28] provides one example where the lack of targeted policy support in Canada for renewable heat use in buildings results in only modest growth of this energy source despite significant cost-effective potential (IEA, 2016a). Although cost competitiveness can be addressed with carbon pricing, other barriers such as high upfront costs, split incentives, or consumer inertia can result in sub-optimal investment in renewable heat, requiring additional policy support.

Bataille et al. (2015) find that for achieving deep decarbonisation of Canada's economy, flexible regulations are key to driving energy efficiency improvements and other technology and behavioural changes in sectors where price signals are less effective, notably in the buildings and transportation sectors. They find a strong role for building and appliance efficiency standards in buildings, and for federal vehicle emissions regulations and renewable fuel regulations in the transport sector where consumers respond to a limited extent to short-term fuel price changes.

Lastly, a level of uncertainty in emissions measurement can make carbon pricing difficult to implement on certain energy sources, such as fugitive methane emissions from upstream oil and gas (Box 3). Specific policies can target these more effectively. For instance, Canada has proposed sector-specific methane regulations to come into force by 2023[29] to help reach the target of 40-45% methane emission reductions below 2012 by 2025 from the oil and gas sector.

Accelerating technology innovation and driving long-term transition

As discussed in Section 2, an important element of the policy package for energy transition is to develop near-zero or negative-emissions technologies that will be needed for deeper changes in the long term, such as CCS technologies including bioenergy CCS, and energy storage technologies. In Canada, supportive infrastructure that can enable the uptake of these technologies may also require targeted policy support and potentially government investment, such as for smart and flexible electricity grids, or EV charging infrastructure, as well as market reforms to facilitate high shares of variable renewable energy. While these actions may not result in meaningful emissions reductions in the short term, they can set up the required technology and market frameworks to facilitate the path towards deeper energy transition.

Canada's policy package includes an array of measures supporting clean technology innovation through the various stages of research, demonstration, development and deployment, focusing on natural resources including the oil and gas sectors. These policies are important for laying the groundwork and reducing the costs of deeper transition in the long term (Table 4).

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[27] Refers to decision making with less-than-full rationality, due to limited information, cognitive capacity and time.

[28] IEA's New Policies Scenario includes announced and implemented policies and represents the central scenario. In comparison, IEA's 450 Scenario includes policies and measures to limit temperature rise to 2 degrees Celsius above preindustrial levels.

[29] A portion of the proposed regulations would come into force in 2020.

Table 4 • Examples of Canadian government support at various stages of clean technology innovation

Stage of innovation	Policy or programme
Research, development, deployment	Energy Innovation Program (co-funded grants; CAD 25 million); Sustainable Development Technology Canada SD Tech Fund (co-funded grants; CAD 400 million over five years); CanmetENERGY research laboratory (clean energy research institution)
Commercialisation	Clean technology financing (equity financing and working capital; CAD 1.4 billion); Strategic Innovation Fund (grants and loans including CAD 100 million for clean technologies)
Adoption	Green infrastructure investment (promoting deployment of smart grids, renewable energy technologies, electric charging infrastructure, amongst others; CAD 820 million)
All	Innovation Canada (new institution includes the Clean Growth Hub to streamline and co-ordinate clean technology support across the country)

Note: Dollar commitments from 2017 federal budget for 2017-2018 fiscal year, except where otherwise stated.

Source: Government of Canada (2017), *Budget 2017 Measures to Support Clean Technology*, https://www.canada.ca/en/innovation-science-economic-development/news/2017/04/budget_2017_measurestosupportcleantechnology.html.

Analysis from the Deep Decarbonisation Pathways Project[30] underscores the need for accelerated commercialisation of innovative technology particularly in Canada's heavy industrial sector, including upstream oil and gas (Bataille et al., 2015). In the electricity sector, the Canadian government has supported the Boundary Dam CCS project, the world's first commercial-scale, coal-fired CCS project. The federal government provided CAD 240 million in direct project support[31] estimated to equal an approximate carbon price of CAD 60-80/tonne CO_2 reduced (Jaccard et al., 2016). While this cost per tonne is higher than current carbon price levels, early support for demonstration projects is essential for future cost reductions that reduce the overall long-term cost of clean energy transition (IEA, 2015d).

By expanding technology options and lowering technology costs, technology support policies could also serve to improve public and political acceptability of carbon pricing in the long term.

Strengthening and backstopping the actions of a medium-term, moderate carbon price

Even if a carbon price alone could drive the many changes required for energy transition in an ideal world, "real-world" carbon prices in general are not currently set at sufficiently high levels, or with sufficient clarity over long enough time frames to achieve these changes. Canada's backstop carbon price is set to reach CAD 50/tonne by 2022, while analysis suggests that relying primarily on a rising carbon price to meet Canada's NDC target requires a price on the order of CAD 200/tonne[32] by 2030 (Jaccard et al., 2016). With the lifetime of many energy sector investments spanning decades, today's investment decisions will be influenced by expectations for long-term carbon pricing.

Complementary policies can be employed to drive certain actions that the carbon price cannot achieve at moderate levels. For example, low-to-moderate carbon prices can drive coal- to gas-fuel switching in power plants but may not create adequate incentives to retire coal-fired power plants before the end of their economic lifetime (see Section 2). Canada's regulatory approach to

[30] The Deep Decarbonisation Pathways Project is a global collaborative of national research teams exploring ambitious long-term decarbonisation pathways in different countries, consistent with meeting an emissions target of 1.7 tonnes per capita by 2050.

[31] The provincial electric utility, SaskPower, invested the remainder of the CAD 1.24 billion project costs.

[32] 2015 dollars

accelerated coal phase-out by 2030 achieves what would otherwise have required a much higher carbon price. IEA analysis also shows that rising carbon prices help increase the attractiveness of bioenergy in relation to natural gas in Canada, where gas prices remain relatively low. However, carbon pricing will not enable the more expensive forms of bioenergy to compete in all applications necessary for low-carbon transition (IEA, 2016a). As shown in Section 2, rising carbon prices are the main driver for improving the cost-effectiveness and driving commercial roll-out of CCS in the electricity sector: in the absence of these rising prices targeted policy support would be required.

Lastly, where the future of Canada's carbon price beyond 2022 is uncertain, regulatory measures – which tend to be implemented with longer time frames – can strengthen certainty of the policy environment in the medium-to-long term. For instance, Canada's federal vehicle emission regulations cover light-duty vehicles for models years to 2025 and heavy-duty vehicles to 2027. The announced accelerated coal phase-out and Clean Fuels Standard both have time frames to 2030. This policy predictability is important for investment decisions, particularly for long-lived energy infrastructure. However, if Canada is able to raise carbon price levels or provide certainty of a carbon price path beyond 2022, this may diminish the role of some complementary policies.

Policy interactions across sectors and jurisdictions

While well-designed policy packages can produce benefits beyond what the carbon price alone can achieve, packages of policies can add to the costs of meeting low-carbon goals if overlapping policies interact to undermine one another's intended outcomes. In particular, complementary policies, if not well integrated, can undermine the economic efficiency of carbon pricing. In the real-world context, policy overlap – where policies cover the same emissions sources – is unavoidable, and not necessarily undesirable where multiple policies help serve multiple functions.

Previous IEA work (Hood, 2013) shows that complementary energy and climate policies that cover the same emission sources as a carbon price can serve to either complement or undermine the pricing policy, depending on factors which include the carbon pricing policy instrument (e.g. carbon tax or cap-and-trade) and the objectives of the respective policies. The challenge for policy makers is to map the policy landscape to identify these interactions, determine whether the benefits of additional policies merit the added costs and complexity, and if so, manage interactions by adjusting policy design.

Policies can be mutually supportive

The policies in Canada's policy package serve a variety of complementary functions. In the transport sector (see the section below: Focus: Two examples of sectoral policy packages in Canada), a variety of policies and measures serve multiple complementary functions in driving the low-carbon transition in transportation, such as shifting to clean modes of transport, improving vehicle efficiency and reducing overall transportation demand.

From the perspective of emissions reductions, synergistic interactions amongst policies can result in more emissions reductions all together than the sum of each individually. Modelled end-use electrification policies (in buildings and transport), electricity supply regulations (coal phase-out and renewable portfolio standards) and an economy-wide carbon price were found to reduce more emissions by 2030 as a policy package, because a cleaner electricity supply allows end-use electrification policies to make a greater emissions reduction impact (Navius Research, 2016).

Policies can undermine one another

Quantity-based carbon pricing systems, such as cap-and-trade schemes, for example those in Ontario and Quebec, are susceptible to interactions with energy efficiency and clean energy policies. If the cap has not been set by taking these policies into account, the additional emissions reductions from these policies result in lower reductions being required elsewhere in covered sectors (Hood, 2013; Rivers, 2012).[33] This can affect both the effectiveness and cost efficiency of the interacting policies.[34] In this case, attention to initial cap-setting is critical, as is building in flexibility to adjust permit supply over time (for example the Allowance Price Containment Reserve operating under the Quebec cap-and-trade).

For intensity-based emissions trading schemes, like the one proposed for large final emitters under the Pan-Canadian Framework and operating in Alberta, only policies that impact emissions generated per unit of production (e.g. CO_2/MWh-generated) will directly impact tradeable unit prices. An example is policies that promote fuel switching such as renewable energy policies or coal phase-out. This contrasts to policies that reduce total output (e.g. MWh electricity produced), such as energy efficiency policies that reduce electricity demand for the electricity generation sector,[35] or structural change policies that reduce industrial output, which will not have a strong impact on the obligation to meet a given emissions intensity (see Hood, 2013 for further detail). Table 5 provides examples of policy interactions in Canada between these various types of policies.

Policy overlap also runs the risk of "muddying" policy signals, especially if policies have conflicting functions or objectives. One example is the existence of fossil fuel subsidies, which promote the consumption and production of fossil fuels relative to cleaner energy sources, alongside carbon prices which advantage low-carbon energy. Canadian fossil fuel support for both production and consumption totaled CAD 3.5 billion in 2014, though this amount has been halved since 2008 (OECD, 2017). Canada has committed to phase out inefficient fossil fuel subsidies by 2025.

[33] Burtraw et al. (2017) refer to this phenomenon as the "waterbed effect" and propose the development of an "Emissions Containment Reserve (ECR)" to absorb a certain quantity of allowances if prices drop below pre-determined thresholds. The Regional Greenhouse Gas Initiative (RGGI) cap-and-trade system in the Northeastern and Midwestern United States is set to include an ECR following its latest programme review.

[34] A lowering of cap-and-trade stringency leading to reduction in allowance prices could also be perceived positively by market players in the system. However according to recent ETS experience where allowance prices have been suppressed (e.g. European Union Emissions Trading System, RGGI, California), this has been characterised as problematic, resulting in various interventions to raise prices/lower allowance quantities.

[35] Alberta has indicated the inclusion of the electricity sector in its output-based emissions trading scheme.

Table 5 • Examples of interactions amongst low-carbon and energy policies in Canada

Interaction type	Policies	Potential interactions
Carbon tax with regulations	carbon tax (British Columbia: BC, and Quebec: QC) *with* federal vehicle emissions standards	• Rivers (2012) finds that vehicle purchasing decisions influenced by carbon taxes in BC and QC relax the federal vehicle emissions regulations in other provinces without carbon taxes, allowing manufacturers to produce less efficient vehicles in non-taxed jurisdictions. The study finds carbon tax effectiveness is cut in half in passenger transport. • Vehicle emissions standards act to reduce fuel demand, including in the short term when consumers are less price-responsive. • Vehicle emissions standards can help meet other objectives such as air quality improvement and strengthening longer-term policy certainty.
Output-based ETS with regulations	output-based ETS (forthcoming in 2018 in Alberta) *with* Alberta coal phase-out	• Both policies cover electricity sector emissions • Phase-out of coal by 2030 will reduce overall emissions/kwh electricity generated and displace emissions targeted under the intensity-based ETS, This could make the intensity targets easier to achieve, if the targets are not set to account for the impact of the coal phase-out. • Coal phase-out policy drives early plant retirement in the absence of high carbon prices and fulfils other objectives including air pollution reduction
Between regulations	proposed clean fuel standard (CFS) (federal) *with* existing renewable fuel regulations (RFR) (federal) *with* provincial low-carbon and renewable fuel regulations (BC, Ontario)	• RFR can drive more expensive emissions reductions by requiring the use of specific fuels, to contribute to a clean fuel standard (Scott, 2017) • Provincial RFRs also interact with the federal RFR relaxing obligations in provinces without RFRs. This is also the case for BC's low-carbon fuel standard and the proposed federal standard. • RFR and CFS can help drive the market for biofuels and establishment of associated biofuels infrastructure

Note: The forthcoming output-based pricing system in Alberta will operate like an intensity-based ETS, with emissions allowances allocated freely to emitters up to an output-based performance benchmark (e.g. CO_2 emissions/kWh electricity generated). Emitters out-performing the benchmark can sell their performance credits to firms performing below the benchmark.

Focus: Two examples of sectoral policy packages in Canada

Canada's transport sector

A suite of policies exist in Canada's transportation sector to achieve emissions reductions, as well as other related objectives such as reducing air pollution, modal shift (away from personal motorised vehicles to active and public transportation), reduction in vehicle distance travelled and more liveable communities (Table 6).

Table 6 • Policies in Canada's transportation sector serve different functions

Policy	Primary objective(s)
Vehicle emissions standards	Improve vehicle fuel efficiency
Clean Fuel Standard (CFS; proposed)	Drive switch to cleaner fuels across all sectors, including supporting infrastructure
Renewable Fuels Regulation (RFR)	Drive switch to biofuels (biodiesel and ethanol) in transportation Support of biofuels markets and supportive infrastructure
Zero-emissions vehicle (ZEV) support, including vehicle purchase subsidies	Increase deployment of zero-emissions road vehicles Support ZEV infrastructure
Fuel excise and sales taxes	Generate revenue for public budgets including public transit Reduce air pollution and congestion
Support for transit and active transportation	Shift from vehicles to lower-emitting modes of transport Promote more liveable communities
Urban planning and design	Reduce vehicle distance travelled through compact or mixed urban use Drive modal shift or switch to cleaner fuels (e.g. bike lanes, EV charging stations)
Carbon price	Lower demand for vehicle distance travelled (especially in the long term) Drive shift to cleaner fuels Shift to more efficient vehicles

Federal vehicle performance standards for both light- and heavy-duty vehicles, harmonised with those of the United States, require vehicle manufacturers to meet progressively more stringent emissions standards (emissions per kilometre travelled) on average across their fleet. The proposed federal Clean Fuel Standard (CFS) requires a percentage reduction in the life-cycle carbon intensity of fuels sold in a given year and is expected to cover fuels in all sectors including buildings and industry, as well as transport (ECCC, 2017c).

Potential benefits of the CFS may be to drive targeted advancement of the low-carbon fuel sector including supporting infrastructure. Jaccard et al. (2016) find that a low-carbon fuel standard in the Canadian transportation sector results in a higher uptake of ethanol in personal vehicles (25% of all vehicles) in 2030 compared to a scenario where only a carbon price meets the same reduction target, where it fuels only 5%. Hence, they find that the regulation may help drive the building of supportive low-carbon infrastructure, which the carbon price was not sufficiently high to achieve.

The federal renewable fuel regulations (RFR) require a minimum renewable content in fuels (5% in gasoline and 2% in distillate and fuel oil) supplied in Canada. Whereas the RFR mandates a minimum quantity of a particular fuel, the more flexible CFS could allow for measures such as alternative fuels including electricity and natural gas to meet the target. The CFS also covers more fuels. However, the RFR could serve to support the renewable fuels (biofuel and ethanol) sectors specifically, including farmers (ECCC, 2017d).

To support ZEV technologies specifically, Canada has announced it will develop a ZEV strategy by 2018, which targets increased deployment of ZEVs including battery electric, hybrid electric, and hydrogen fuel cell vehicles. Certain provinces (BC, ON, Quebec) also offer vehicle purchase incentives and support for charging infrastructure.

Policies such as consumption taxes on fuels including excise and sales taxes, help raise revenue for road infrastructure and public transit while also serving to increase gasoline prices to reduce consumption (and therefore GHG emissions). Other policies target modal shift and demand reduction, such as land-use policies promoting compact and mixed urban form, public transportation support and support of active transportation infrastructure (such as bicycle lanes). Notably, the CFS and RFR primarily drive cleaner fuel supply, without creating significant incentives to reduce fuel use or use alternative modes of transport. This reinforces the role for measures such as vehicle emissions standards, support for ZEVs and public transport, and land-use planning.

In Canada's transport sector policy package, the various elements fulfil different roles and objectives. However, attention must be paid to where policies in the package overlap and interact. The proposed CFS, for example, would cover the same emissions sources as provincial-level carbon prices, federal and provincial renewable fuel standards for transportation, provincial clean fuel standards[36]and fuel-switching policies in buildings and industry sectors.[37] The existence of more prescriptive region- and fuel-specific measures may increase the costs of complying with the more flexible "baseline and credit" system of the CFS. For example, provincial RFR[38] policies would mandate the uptake of particular fuels in particular provinces even if it would be cheaper to meet the CFS using other measures, such as increasing the use of electricity for transport, or in jurisdictions without RFRs.

The proposed CFS could also raise the costs of complying with other policies, by interacting with provincial carbon pricing systems. The proposed backstop carbon pricing policy includes the transport, building and industrial sectors. As mentioned above, the CFS, which acts like a tradeable performance standard, would interact with a carbon price depending on whether the price is a carbon tax/levy, cap-and-trade or an output-based ETS. For industrial emitters under the output-based system, the CFS would place a specific obligation on fuel suppliers to reduce the emissions intensity of fuels – which may be costlier reductions compared to other measures to reduce industrial emissions intensity, such as improving the energy efficiency of industrial processes. The proposed CFS can interact with provincial cap-and-trade systems with absolute caps (Ontario and Quebec) by displacing emissions under those systems.[39]

Understanding these interactions allows policymakers to determine whether added costs justify the value of additional policies. This can also allow policymakers to initially calibrate policies and over time, adjust them as needed, such as by modifying allowance quantities in cap-and-trade systems to account for emissions reduced by other policies.

Alberta's electricity sector

Electricity production in Canada is managed by provincial and territorial governments, although federal policies such as the proposed accelerated coal phase-out and proposed benchmark carbon price will have impacts on sub-national electricity systems. Alberta provides an interesting case, with the election of a new provincial government in 2015 resulting in a shift in provincial low-carbon policy. Alberta's electricity sector now faces a regulated coal phase-out, a renewable electricity procurement programme, and an ETS with allowances allocated based on (facility-specific) historical baselines, which is transitioning in 2018 to output-based allocation for compliance. A cap on electricity prices and the forthcoming capacity market will also promote electricity affordability, reliability and smooth transition to low-carbon sources. The elements of

[36] British Columbia has a clean fuel standard in place (called the Low Carbon Fuel Standard) and Ontario has proposed one.

[37] This assumes these policies remain in place as implemented or announced.

[38] Mandates for minimum renewable content in fuels have been implemented in British Columbia, Alberta, Saskatchewan, Manitoba and Ontario.

[39] A study of the California system showed that when a state cap-and-trade programme includes the transportation sector, the state low-carbon fuel standard will result in partially, fully or more than fully offsetting emissions reductions driven by the cap-and-trade system (Schatzki and Stavins, 2012).

this policy package include various policy drivers as outlined in Section 2 above, and each serves to meet different objectives in driving energy transition of the electricity sector (Table 7).

Table 7 • Different objectives of electricity sector policies in Alberta

Electricity sector policy	Primary objective/s
Coal phase-out	Improve air quality and public health, low carbon transition
Coal phase-out transition payments	Provide economic and social assistance to affected workers, communities, and companies
Renewable Electricity Program	Complement to coal phase-out to ensure stable transition Drive economic development and job creation in renewable energy sectors
Specified Gas Emitters Regulation (facility-specific allocation of allowances based on historical baselines ; phased out by 2018)	Incentivise low carbon shift while preserving economic competitiveness Generate revenue for low carbon investment, such as in CCS
Output-based allocation system (forthcoming in 2018)	Enhance incentives for low carbon transition (from SGER) while minimising electricity rate increases for consumers and protecting competitiveness
Development of capacity market	Support electricity reliability and affordability Encourage stable transition towards renewable sources
Electricity price cap	Ensure electricity affordability Create price predictability for consumers and investors
Demand-side energy efficiency rebates	Encourage demand reduction/energy conservation

For example, the provincial accelerated coal phase-out by 2030 – implemented to achieve both public health and decarbonisation benefits – is complemented by the renewable electricity bidding programme to procure 5 000 MW[40] of additional renewable energy capacity by 2030. The phase-in of renewable energy alongside the phase-out of coal is intended to ensure a stable transition to low-carbon sources, in addition to meeting air quality and economic growth objectives.

The current intensity-based emissions trading scheme, the Specified Gas Emitters Regulation (SGER), covers the industry and electricity sectors and allocates emissions allowances based on historical baselines at the facility level. Its revenue has been used to invest in energy efficiency improvements, CCS technology development and other emissions reductions activities, which highlights the potential for revenue to further advance energy transition objectives. In 2018, the SGER will transition to one that prices emissions based on "best in class" output benchmarks, such as emissions per kilowatt hour generated by the most efficient gas-fired power plants for all power generation. This output-based allocation system is intended to enhance the incentive at the sector level to meet and exceed performance benchmarks – as facilities performing better than the benchmark will receive credits that can be sold or banked – without creating the incentive to raise electricity prices.

The goal of energy transition is central in Alberta's electricity sector, which has one of the most fossil fuel-dependent generation mixes in Canada (Box 5). Transition refers to the economic and social transition away from fossil fuels, including for affected workers, as well as the mode of transition, to facilitate a steady and incremental shift.

[40] Alberta's current electricity generation capacity is 16 300 MW, half of which is from coal-fired power plants.

Box 5 • Facilitating the fossil fuel transition in Canada

The oil and gas sector emitted 192 Mt CO_2e in 2014, accounting for the highest sectoral share (26%) of GHG emissions in Canada (ECCC, 2017e). Oil and gas production is concentrated in the Western provinces: Alberta (81%) and Saskatchewan (11%) together account for 92% of oil production; Alberta (68%) and BC (28%) account for 96% of natural gas production (CAPP, 2017). While the region's relative economic dependence on oil and gas has declined over the past 30 years (e.g. in Alberta, from 36% of GDP in 1985 to 19% in 2015), it remains an important employer and contributor to provincial royalty revenues (Alberta Energy, 2016; Statistics Canada, 2017).

With proven reserves of 165 billion barrels as of 2016, Alberta's oil sands are the third largest oil reserves in the world (Alberta Energy, 2017b). However, international climate policy could drive a reduction in global demand (and prices) for petroleum products, leaving higher cost and carbon-intensive sources of oil, including the Alberta oil sands, at a disadvantage. Under the IEA 450 Scenario, global oil demand in 2040 falls to 73 mb/d, compared to 104 mb/d under the New Policies Scenario. Canada oil sands production grows to just 2.8 mb/d by 2040 under the 450 Scenario* compared to 3.8 mb/d under the New Policies Scenario (IEA, 2016a).

Modelling efforts over the past five years have advanced the discussion on climate policy, oil sands and economic growth. As the range of results from Chan et al. (2012) and Peters (2012) demonstrates, impacts of low-carbon policy on oil sands production are highly sensitive to model assumptions, including the elasticity of supply for oil production, future oil prices, adoption of low- carbon technologies such as CCS and climate policy design. More recently, Bataille et al. (2015) simulated a range of oil price scenarios with deep decarbonisation policies, and found strong regional effects (e.g. low oil prices negatively affecting Alberta but benefiting Ontario and Quebec), though overall national GDP is relatively unaffected.

The latest studies explore hybrid policy approaches, with findings relevant to facilitating a fossil fuel transition. Sawyer and Bataille (2016b) find that economic impacts of carbon pricing can be minimised by accompanying a national carbon tax with an output-based performance standard for large emitters compared with a carbon tax alone, with the greatest economic benefits realised in Alberta and Saskatchewan. Jaccard et al. (2016) find that flexible regulations in key sectors (transport, industry, power, etc.), in conjunction with a modest carbon price rising to CAD 40/t in 2030 could meet Canada's Paris NDC. This policy package includes less stringent performance standards for trade-exposed industries such as oil sands, resulting in a lower implicit carbon price trajectory for those industries, reaching about CAD 100 by 2030 (compared to almost CAD 200 for unprotected industries). The legislated oil sands emissions cap in Alberta (100 Mt) plays a key role in limiting large increases in emissions in the sector, particularly under a high oil price scenario that encourages higher oil sands production that would delay the transition.

These studies signal the potential value of well-crafted policy packages that adjust regulations to protect emissions-intensive, trade-exposed industries to facilitate a fossil fuel transition. Alberta's transitional payments related to its accelerated coal phase-out, as well as its proposed output-based allocation system, follow this approach. Outside the fossil fuel industry, the government of British Columbia has offered transitional incentive payments to the cement industry (2015-2018) to encourage the adoption of cleaner fuels. With international and domestic climate policy having potentially substantial regional economic impacts in Canada, federal and provincial policy makers need to ensure co-ordinated climate and energy policy design and implementation to ensure a just transition.

Alberta has appointed an Advisory Panel on Coal Communities to facilitate the transition for affected workers and communities, including by establishing a fund to support economic development projects in specified impacted communities. For affected companies, Alberta's accelerated coal phase-out programme will provide transition payments to six coal-generating units.[41] These transition payments - funded by revenues from the output-based allocation system on large final emitters - are intended to provide compensation to generators for stranded assets and incentivise the switch to natural gas.

Where the goals of decarbonisation, energy transition, reliability and affordability intersect in the electricity sector, various policies have been designed to meet them. As with any policy package, monitoring and evaluation over time will be important to maintain alignment with policy objectives. For instance, transitional assistance to coal-affected workers and free emissions permit allocation to large industrial emitters can ease the burden of transition on certain groups and sectors in the short term, though if kept in place longer than needed, can lead to disproportionate support of certain groups and high policy costs. Monitoring and evaluation of the policy package can also identify competing objectives and policies. For instance, an electricity price ceiling – on the one hand – prevents electricity prices rising above a given level, maintaining affordability. On the other hand, this policy may mute the carbon price signal, which could drive behavioural change by end-users to conserve electricity.

Incorporating flexibility into policy packages

Compliance flexibility can enhance cost-effectiveness

A key strength of carbon pricing is the flexibility it offers in delivering emissions reductions. This is the primary reason for its cost-effectiveness in that it allows economic forces to find the lowest cost means of reducing emissions. Where policy packages include carbon prices along with other policies (or no carbon price at all), undue costs can be placed on the economy if non-pricing policies are overly prescriptive (i.e. too specific in defining what changes take place, by whom and by when) if cheaper means exist to meet the various policy goals.

Incorporating compliance flexibility into the design of policies within a package can reduce the costs of meeting policy goals. Compliance flexibility can exist across actions, agents in the economy and time (Ecofiscal Commission, 2017). Jaccard et al. (2016) find that a package of policies including a moderate carbon price[42] and flexible regulations in electricity, transport and industry could approach – though not quite match – the cost effectiveness of relying primarily on a carbon price to meet Canada's 2030 NDC target. Sawyer and Bataille (2017) model a policy package that includes the federal benchmark carbon price and ramps up existing low-carbon regulations, many of which incorporate compliance flexibility including federal vehicle emissions

[41] The federal government implemented regulations to phase out coal-fired power generation in 2012, which were set to retire 12 out of Alberta's 18 coal plants. In 2015, the Alberta government committed to an accelerated coal phase-out by 2030, affecting the remaining six coal plants. One year later, the federal government also announced its intention to accelerate its national phase-out of traditional coal plants by 2030, affecting four additional facilities across Canada. Policy details and possible equivalency agreements are currently under development between federal and provincial governments.

[42] The modelled carbon prices – CAD 25/tonne CO_2e in 2021 rising to CAD 40/tonne by 2030 – are even lower than the proposed federal benchmark price levels as the study was conducted before the federal policy announcement. Therefore, a policy package containing higher carbon prices – as currently proposed in Canada – may be even more cost-effective than the study's scenario.

regulations and building energy efficiency standards.[43] They find this policy package results in a 38% GDP growth by 2030 from today, compared with a 39% growth in a business-as-usual scenario.[44]

However, compliance flexibility – and therefore cost-effectiveness – must be balanced where other goals are being pursued. For instance, renewable portfolio standards, targeting a specific percentage of renewable energy in the electricity generation mix are in place in numerous provinces. While they are not as flexible as carbon prices because they prescribe the uptake of certain technologies in certain regions, they may serve other functions in advancing the energy transition agenda including bringing down long-term technology costs, and at the local level supporting energy security, market development and air quality improvement.

Structural flexibility can help keep policy packages in alignment with objectives

Policy flexibility can also be incorporated at the structural level, whereby a flexible policy framework or package can facilitate policy adjustments so they remain in line with their intended objectives. Experience of numerous cap-and-trade systems has shown that allowance prices may be suppressed as a result of overlapping policies or economic conditions that reduce emissions under the cap and thus reduce demand for allowances.

One example of structural flexibility to address such interactions is in the design of the WCI cap-and-trade system in which Ontario and Quebec participate. The WCI system has established a minimum auction allowance price (a "price floor") below which allowances will not be auctioned.[45] To guard against excessively high prices, a price containment reserve has been designed to release allowances if allowance prices reach pre-determined levels (acting as a soft "price ceiling").[46] These built-in mechanisms can help the system automatically respond to factors that may create undue upward or downward pressure on allowance prices, ensuring a predictable band for prices (and policy stringency). Looking beyond cap-and-trade systems, such flexibility can also be envisioned for complementary policies to allow them to be adjusted, withdrawn or added, based on their performance. However, structural flexibility must be balanced with long-term policy certainty, where the possibility of large and/or frequent policy adjustments could reduce policy certainty for investors and market players.

Periodic review is a critical first step in maintaining adequate structural flexibility in policy packages. Canada's *Pan-Canadian Framework* commits to reporting on policy impacts, including emissions, and assessment of policy effectiveness. A specific review of the overall carbon pricing approach is also planned for early 2022 to provide certainty on the path forward. Work remains to be done on defining the scope of these reporting and review processes, as well as the need for new institutions or strengthening of existing ones to support them. Where policy packages exist to meet multiple objectives, periodic reporting and review can be even more valuable in a policy landscape with many "moving parts" seeking to fulfill various end goals. Built-in reporting and

[43] Vehicle emissions standards in Canada allow manufacturers compliance flexibility to meet an emissions standard, which is calculated as a fleet average of vehicles manufactured across all regions and models. Manufacturers have the flexibility to use an array of technologies or measure to meet the emissions standard.

[44] This result is achieved even where cheaper imports from linked cap-and-trade programmes under the WCI are excluded. Where allowances from California are accepted in Quebec and Ontario, GDP impacts are cut in half in 2030.

[45] The floor price in 2012 was 10 (CAD or USD, with the jurisdiction applying the higher floor price setting the level across both jurisdictions). It rises 5% annually above inflation.

[46] A pre-determined quantity of allowances is set aside that can be sold or allocated freely to emitters if prices reach a tiered price ceiling, with a third of reserve allowances released at each tier. In Quebec the price ceiling in 2013 was CAD 40/45/50, rising 5% annually above inflation to 2020.

review mechanisms can ensure that the policy framework remains in line with intended objectives while maintaining transparency and accountability in meeting stated goals.

Key takeaways from the Canada case study

The objective of this case study has been to illustrate the opportunities and challenges in formulating policy packages to address the various domains of sustainable energy transition (Section 1), in the "real world" national context of Canada. The key takeaways of this study may be relevant for other countries facing similar circumstances and constraints, such as shared national and sub-national jurisdiction over energy and climate policy, a strong contribution of energy and fossil fuel sectors to the economy and employment, and resource and political diversity across sub-national regions.

Carbon pricing remains a critical policy tool in driving the sustainable energy transition. In recognition of carbon pricing as the "most efficient way of reducing GHG emissions", Canada has placed carbon pricing at the centre of the Pan-Canadian Framework on Clean Growth and Climate Change. Canada's backstop carbon price seeks to be as efficient as possible while recognising constraints: applying economy-wide, rising over time, and establishing a tradeable performance standard for large emitters in recognition of the special need to facilitate transition in these industries and protect competitiveness. Even at low-to-moderate levels, it is reasonable to expect that carbon pricing in Canada could play a central role in creating incentives to decarbonise across the economy, including through the switch to cleaner fuels and moderating energy demand. Low-to-moderate prices in the short term could also help build public acceptability in paving the way for higher price levels in the medium-to-long term. Meanwhile, uncertainty of the federal carbon price path beyond 2022 can reduce certainty for businesses and investors in long-lived assets.

Multiple policy objectives require a package of policies, but attention must be given to policy interactions. While achieving emissions reductions is a central goal of Canada's sustainable energy transition agenda, it is the not the only one. Other objectives include economic development in clean energy sectors, transition for affected workers and sectors, and clean air. Policies for energy transition will almost certainly overlap (i.e. cover the same sources of emissions) and interact: they can be supportive and reinforcing, or undermine one another's intended outcomes. Overlap itself is not inherently problematic if policies fulfil a unique function or objective. For instance, a carbon price and coal phase-out (which also seeks to reduce air pollution) may both cover emissions from coal-fired generation, but they have different sets of objectives. The challenge for policy makers is to map policy interactions, determine whether the costs of overlap outweigh benefits, and make adjustments to the policy package to ensure it continues to meet its objectives.

Co-ordination and harmonisation of sub-national policies can reduce costs and raise ambition. In Canada, energy transition and low-carbon policies have been driven at the regional level over the last decade, allowing policy to be tailored to local circumstances and to advance in the absence of national drivers. However, the resulting "patchwork" landscape creates risks of undue policy compliance costs due to uneven carbon prices, regional gaps in policy ambition, and nationally inconsistent policy signals. Action at the national level can address these challenges by co-ordinating and harmonising sub-national action, for instance by supporting the implementation of common policy design elements across regions, encouraging linkage of regional carbon pricing systems and by establishing national policies. These actions can help harmonise emissions reduction costs and improve the cost-effectiveness of policy compliance, establish coherent policy signals nationwide, and set a minimum bar for ambition across jurisdictions. In a country with strong sub-national authority over energy and low-carbon policy making, Canada's benchmark carbon price shows one approach to balancing regional autonomy and flexibility with national policy co-ordination.

Mechanisms and processes for review are key to ensuring alignment of policies with goals. Canada's policy package as outlined in the *Pan-Canadian Framework on Clean Growth and Climate Change* is comprised of numerous policy elements intended to fulfill multiple goals, implemented at two jurisdictional levels and set to evolve over time. In this context, mechanisms for monitoring, evaluation and review are especially important to identify where policies are not serving their intended function, where policies are undermining one another, but also where policies are succeeding to inform adjustment of the policy package as needed. Ultimately, this process can serve to ensure policies are on track to meeting their intended outcomes. Canada's *Pan-Canadian Framework* commits to reporting on policy impacts (including emissions) and assessment of policy effectiveness, along with a specific review of carbon pricing systems across Canada by 2022. Work remains to be done on defining the scope of this reporting and review, as well as the need for new institutions or strengthening of existing ones.

Flexibility in policy packages can improve cost effectiveness and enhance alignment with objectives. Countries can incorporate flexibility into policy packages at the compliance level (how agents comply with individual policies) and at the structural level (ability to adjust the policy framework in response to changes). Compliance flexibility, promoted through inclusion of flexible regulations such as sector-wide performance standards, can reduce the costs of meeting an emissions reduction target compared to more prescriptive regulations by allowing lowest-cost reduction opportunities to be realised. An important caveat is that compliance flexibility will need to be balanced with the pursuit of other objectives, which could require changes in specific technologies, fuels or regions. At the structural level, mechanisms that build in period review and facilitate policy adjustments can enable misalignments between the policy package and its objectives to be identified and addressed over time.

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Acronyms, abbreviations and units of measure

Acronyms and abbreviations

CCS	carbon capture and storage
CFS	Clean Fuel Standard
CPS	Carbon Price Support
ECC	environment and climate change
EED	Energy Environment Division
EITE sectors	energy-intensive, trade exposed sectors
ETS	Emissions Trading System
EU	European Union
EVs	electric vehicles
GHG	greenhouse gas
IEA	International Energy Agency
INDC	Intended Nationally Determined Contributions
LDAR	leak detection and repair
MEPS	minimum energy performance standards
MRV	monitoring, reporting & verification
NAICS	North American Industry Classification System
NDC	Nationally Determined Contribution
NPS	New Policies Scenario
PM	particulate matter
RD&D	research, development and deployment
RDD&D	research, development, deployment and demonstration
RFR	renewable fuel regulations
RTS	Reference Technology Scenario
SEPH	Survey of Employment, Payrolls and Hours
SGER	Specified Gas Emitters Regulation
TDM	travel demand management
UNFCCC	United Nations Framework Convention on Climate Change
VRE	variable renewable energy
WCI	Western Climate Initiative

Units of measure

Gt	gigatonne
Mt	megaton
$MtCO_2$	million tonnes of CO_2
KW	kilowatt
toe	tonne of oil equivalent
tCO_2	tonnes of carbon dioxide
tCO_2e	tonnes of carbon dioxide equivalent
TWh	terawatt hour

Annex: Low-carbon energy transition policies in Canada

Policy	Sector/s	Description	Policy instrument
Federal			
Backstop carbon price (proposed)	Cross-sectoral coverage	Would apply a carbon levy with a fixed price path from 2018-2022 to jurisdictions not meeting a national benchmark. Industrial emitters would be subject to an output-based pricing system, operating as a tradeable performance standard (below)	Carbon price
Emissions-intensity performance standard with output-based allocation (proposed)	Industry and electricity	Would apply a performance standard by sector based on best-in-class performance. Permits issued to over-performing firms could be sold to those not meeting the standard	Tradeable performance standard
Clean fuel standard (proposed)	Cross-sectoral coverage (transport, buildings, industry)	Would require a percentage reduction in the life-cycle carbon intensity of fuels sold in a given year, covering fuels in all sectors	Flexible performance standard
Reduction of hydrofluorocarbon (HFC) and methane emissions (proposed)	Industry (primarily upstream oil and gas)	HFC: Would apply sector-specific mandates or gradual phase-down approach to reduce HFCs Methane: Would mandate actions targeting five key sources of methane, with a portion to come into force by 2020 and the rest by 2023	Regulations
Accelerated coal phase-out (proposed)	Electricity	Would require an emissions intensity of 420gCO_2/kWh electricity generated by 2030 for new and existing coal-fired power plants.	Performance-based regulations
National Model Energy Code for Buildings	Buildings and electricity	National building code defining energy standards for building components including building envelope, lighting and heating	Guidelines (model for mandatory provincial codes)
Appliance energy efficiency standards	Buildings and electricity	Applies energy efficiency standards for a range of appliances imported to or produced in Canada	Regulations
Light and heavy-duty vehicle emissions standards	Transport	Requires vehicle manufacturers and importers to meet a declining fleet average emissions intensity in light-duty and heavy-duty vehicles (model years 2025 and 2027 respectively)	Performance-based regulations
Renewable fuels Regulation	Transport	Requires a minimum average renewable content (5% in gasoline and 2% in distillate and fuel oil) in fuel supplied in Canada, applied to fuel importers and producers	Tradeable performance standard
Clean energy technology investment	Cross-sectoral coverage	A range of financial and other support of clean technology innovation from research and development, to commercialisation and adoption	Financial incentives and subsidies, research

Low Carbon Economy Fund	Cross-sectoral coverage	CAD 2 billion fund to support projects that reduce GHG emissions, 1.4 billion of which is available to jurisdictions that have joined the *Pan-Canadian Framework*	Financial grant
Provincial			
BC carbon tax	Cross-sectoral coverage	CAD 30/tonne on emissions from fuel combustion, including in buildings and transport	Carbon price
BC renewable and low-carbon fuel requirements	Transport	Requires fuel suppliers have minimum average renewable content (5% for gasoline; 4% for diesel) and meet a declining carbon fuel intensity to achieve 10% reduction from 2010 by 2020	Flexible performance standard
BC clean energy vehicle support	Transport	Provides point-of-sale subsidies for battery electric and hydrogen fuel cell vehicles. Invests in charging and fuel infrastructure.	Financial and other support
AB carbon levy	Cross-sectoral coverage (buildings and transport)	Applies a CAD 20/tonne carbon tax in 2017 rising to CAD 30/tonne in 2018.	Carbon price
AB intensity-based ETS (to be replaced with output-based system in 2018)	Cross-sectoral coverage (electricity and industry)	Applies an emissions intensity standard and allocates allowances based on facility-specific historical baselines. Forthcoming system will allocate allowances using an output-based performance standard at the sector level.	Tradeable performance standard
AB coal phase-out	Electricity	Aims to phase out emissions from coal-fired generation by 2030, affecting six coal plants in the province	Regulation
AB Renewable Electricity Program	Electricity	Competitive tender process to add 5 000 MW of renewable electricity by 2030. The first tender for 400 MW takes place in 2017.	Renewable energy tender
AB oil sands emissions cap	Industry	Implements a 100 Mt emissions cap in any given year on oil sands emissions	Regulation
ON cap-and-trade programme	Cross-sectoral coverage	Implements declining annual emissions caps from 2017-2020, with allowances mostly freely allocated	Carbon price
ON coal phase-out	Electricity	Phased out coal-fired generation from 2003-2014	Regulation
ON EV subsidies	Transport and electricity	Provides a subsidy of between CAD 3000 -10000 for eligible EV purchases	Financial subsidies
QC cap-and-trade	Cross-sectoral coverage	Implements declining annual emissions caps from 2013-2020 within three compliance periods. Allowances are mostly freely allocated.	Carbon price
QC zero-emission vehicles standard	Electricity and transport	Sets a target for zero-emissions vehicles sold in Quebec starting in model year 2018	Flexible standard
NS cap on electricity sector emissions	Electricity	Sets a declining cap on electricity sector emissions, resulting in 10% GHG emissions reductions from 2010-2020	Regulation
NS cap and trade (announced)	Electricity and industry	Expected to meet federal carbon pricing benchmark and be in place by 2018	Carbon price

Notes: BC – British Columbia; AB – Alberta ; SK – Saskatchewan; ON – Ontario ; QC – Quebec; NS – Nova Scotia. This is not an exhaustive list of low-carbon policies in Canada.

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