19 October 2023

The hidden cost of carbon

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Carbon pricing mechanisms impose costs that are deeply—and subtly—embedded in supply chains, affecting companies' profitability and competitiveness. We look at how these costs can add up, and what leaders can do to manage them.

Facing expectations from stakeholders to help address the climate challenge, more and more businesses are making efforts to monitor the carbon emissions of their operations and supply chains. Less obvious than the emissions themselves, though, are the financial costs of those emissions—in particular, the costs embedded in the price of goods as a result of carbon taxes, cap-and-trade systems and other mechanisms that charge companies for the greenhouse gases (GHGs) they produce. Because those costs can be difficult to track, we've come to think of them collectively as the *hidden cost of carbon*.

To shed light on carbon's hidden cost, we developed a global model covering 65 economic sectors in 141 countries and regions. The model provides an indicative estimate of the hidden cost of carbon at current carbon prices, along with the hidden cost under two alternative carbon price scenarios. The findings suggest that in the G20's individual member countries, the hidden cost of carbon today can amount to more than 1.5% of the production value of carbon-intensive goods such as steel, cement and chemicals, and as much as 10% for electricity.

What's more, carbon costs look likely to rise—and would have to rise even further if the world is to meet the Paris Agreement's net-zero targets. More than 40 national jurisdictions, in addition to many subnational governments, accounting for almost one-quarter of global emissions, already put a direct price on carbon.[1] Of these, Canada, Denmark, the Netherlands and others have scheduled price increases. The EU Emissions Trading System (EU ETS), for one, is set to decrease the amount of free emissions allowances, which will tend to raise their price. Another 35 jurisdictions are considering implementation of a carbon price, including major economies such as Brazil, India and Indonesia.

[1] World Bank Carbon Price, https://www.worldbank.org/en/programs/pricing-carbon.

New carbon pricing mechanisms are also emerging—notably, carbon tariffs. These levies require importers to pay the same carbon price as domestic producers, as a way of eliminating the cost advantage that carbon-intensive imports might otherwise enjoy. The first carbon-tariff system, the EU Carbon Border Adjustment Mechanism (CBAM), takes effect in October 2023 for reporting purposes, and it becomes chargeable in 2026. As the CBAM ramps up, our model estimates that it would increase the hidden cost of carbon for many goods by a factor of five or more.

As carbon prices rise, businesses that produce or purchase carbon-intensive goods could find their competitive position shifting. But by anticipating movement in the hidden cost of carbon, executives can begin to prepare. In this article, we look at some examples of how the hidden cost of carbon builds up in supply chains today, how it might change as carbon pricing expands and evolves, and how companies can maintain an edge amid these dynamics.

The basics of carbon pricing

Some companies choose to offset some or all of the carbon they emit by purchasing carbon credits in the voluntary market. The costs of those credits, which can be significant, are outside the scope of this article, because companies can elect not to pay them. Here we look at those carbon costs that companies cannot avoid: the direct costs that businesses pay when governments establish pricing mechanisms with policy mandates and regulations. Such pricing mechanisms include carbon taxes (levied per metric ton of emissions) and emissions trading systems (in which companies buy or sell government-issued emissions permits).

Governments also use other mechanisms to price carbon. These are designed to reduce carbon emissions through regulations that affect the cost of production, but they do not place a price directly on emissions. Such regulations might, for example, require that companies fix leaks of methane, a powerful GHG. The expense of stopping methane leaks constitutes an indirect cost on emissions.

Revealing carbon's hidden cost

To show how carbon pricing affects the cost of various goods, we used an economic input–output model that describes manufacturing and trading activities for 65 sectors in 141 countries and regions, with their related GHG intensities.

Then we layered emissions and carbon price data onto the value chains represented in the model. In this way, we can estimate how much carbon is emitted, on average, at each step of the value chain of a given sector in a particular country or region and how much companies are charged, on average, for those emissions by various carbon pricing mechanisms. Adding up those current carbon pricing charges lets us estimate the average hidden cost of carbon per dollar of sales.

Then, to illustrate how much the hidden cost of carbon might change if carbon prices were to go up, we also modelled carbon costs under two alternative scenarios. One, which we call the “CBAM scenario,” envisions full implementation of the EU’s CBAM. For this scenario, we estimate the cost of carbon only for goods imported to the EU. The other scenario, which we call the net-zero scenario, models global application of the carbon prices that are set out for the year 2030 in the International Energy Agency’s (IEA’s) economic scenario for reaching net-zero emissions by 2050. With these scenarios, we apply alternative carbon prices to current value-chain patterns, emissions levels and emissions intensities—in other words, we simulate the effect of an instant change in carbon price and hold all other factors constant. (In the real world, emissions intensities are likely to decrease over time. Any such decreases would cause the eventual hidden cost of carbon to be less than the static estimates from our model. For more, see “Methodology,” page 20.)

As an illustrative example from our modelling results, steel produced in the Republic of Korea (ROK) currently carries a hidden cost of carbon equivalent to 0.54% of its selling price, on average, owing to the taxes and fees assessed on production and supply chain emissions. For comparison purposes, we also applied the carbon prices that are specified for the year 2030 in the IEA’s scenario for reaching net-zero global emissions by 2050. At those carbon prices, the hidden cost of carbon for an average ton of Korean steel would reach 12.85% of the steel’s current selling prices, an increase of nearly 23 times over today’s hidden cost. This illustrates the financial risk that carbon-intensive industries may face due to rising carbon costs.

Within a country, the hidden cost of carbon will differ from one producer to another, owing to variations in the mix of inputs, the source of energy and the type of technology. The national averages expressed by the model provide a benchmark that companies can use to assess and manage their exposure to carbon pricing risk.

How the world's biggest commodity producers compare

Our work started with a simple question: how does the hidden cost of carbon vary for energy-intensive, globally traded goods? Discussed below are the results for two sectors: the ferrous metals sector, which includes steel, and the power sector, a key supplier of energy to nearly every industry.

Ferrous metals sector

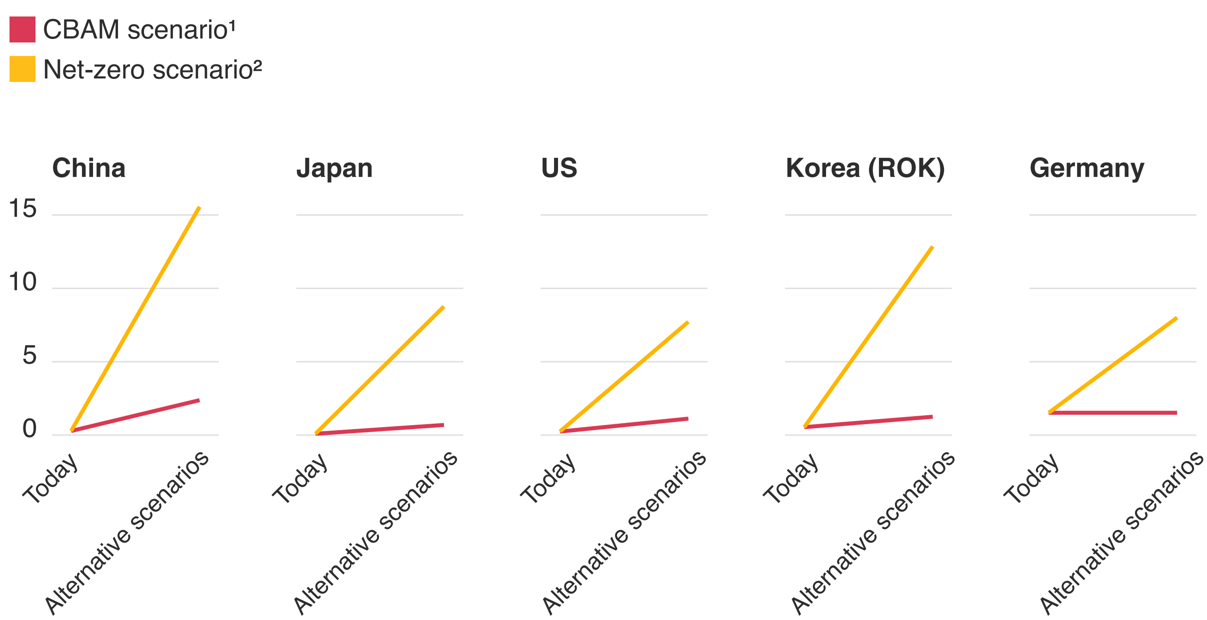
At current carbon prices, the hidden cost of carbon for the average ferrous metal producer varies by a factor of almost 17 among the top five producing countries, ranging from 0.09% of sales in Japan to 1.52% of sales in Germany (see chart, page 7). Consequently, the average producer in Germany faces a cost disadvantage of 1.43% (1.52% less 0.09%) of sales relative to the average producer in Japan.

Full implementation of the CBAM, however, would raise the cost of ferrous metals exported to the EU—reducing the carbon cost disadvantage now faced by producers in Germany. And in the net-zero scenario, in which the price of carbon is set at the 2030 level, consistent with achieving net-zero emissions in 2050, the average ferrous metals producer in Germany would no longer bear a higher carbon cost than its competitors in China, Japan and the Republic of Korea, and would nearly be at parity with US producers. This example shows how a uniform global increase in carbon prices could result in a cost advantage for companies whose products are low in emissions intensity.

Under current policies, carbon prices generally affect only a limited portion of emissions and are set at a relatively low level compared with the net-zero scenario. However, under both the CBAM and net-zero scenarios, more emissions are subject to a carbon price, and the price imposed would be higher than under current policies.

The average cost of carbon varies widely among the five largest producers of ferrous metals

Direct cost of carbon emissions, as a percentage of production value



[1] Estimates cost of carbon for goods imported to the EU if Carbon Border Adjustment Mechanism were fully implemented.
[2] Estimates cost of carbon at the 2030 carbon prices implied by the IEA's scenario for reaching net-zero emissions by 2050.
Source: PwC analysis, Global Trade Analysis Project, International Energy Agency

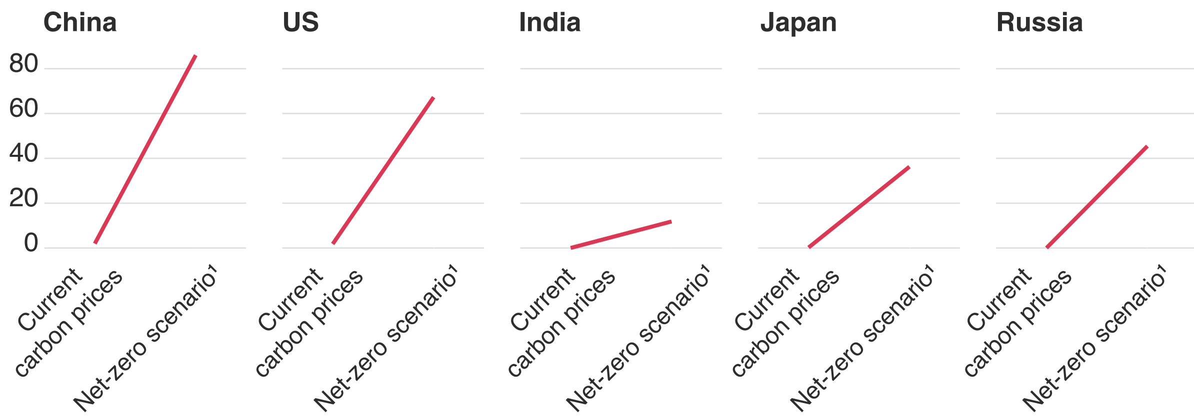
Power sector

For the five largest electricity-producing countries, the average hidden cost of carbon ranges from 0.03% of sales in Russia to 1.97% in China. The difference of 1.94% of sales (1.97% less 0.03%) creates a cost disadvantage for electricity-using companies in China that either compete with imported goods or export products to foreign markets. (Although China's current carbon price is relatively low, the hidden cost of carbon for Chinese electricity is relatively high because the power sector relies heavily on coal-fired generation.)

In the net-zero scenario, the cost of carbon for electricity in China would increase to 86% of sales—a cost disadvantage of 40 percentage points, compared with Russia (see chart, page 9). The cost of carbon in India's electricity sector in this scenario is less affected, because the 2030 carbon price in the IEA's 2021 model is lower for India and other developing countries than for major emerging market countries (including China and Russia) and advanced economies (including Japan and the US).

The cost of carbon for electricity varies widely in a net-zero scenario

Direct cost of carbon emissions, as a percentage of production value



¹ Estimates cost of carbon at the 2030 carbon prices implied by the IEA's scenario for reaching net-zero emissions by 2050.
Source: PwC analysis, Global Trade Analysis Project, International Energy Agency

The hidden-cost hotspots in supply chains

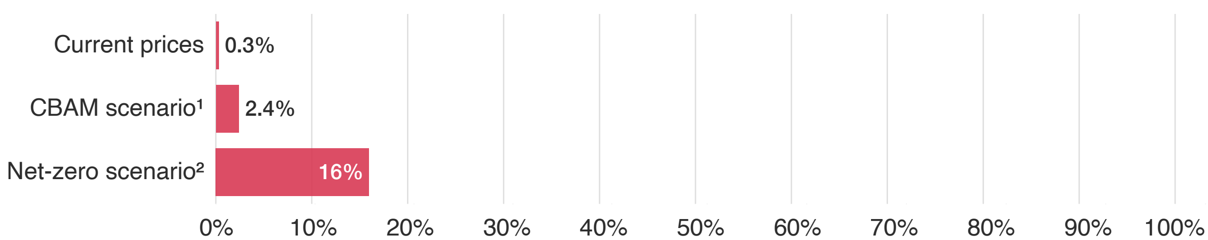
Knowing that carbon costs hide in the prices of major commodities, executives may want to determine more precisely where those costs occur across their company's operations and supply chains. Costs may be concentrated in the country where final goods are produced or at points farther upstream in the supply chain. To illustrate such patterns, we present breakdowns, by geography and by sector, of the hidden cost of carbon across the supply chains for China's chemicals sector (which leads the world in chemicals production) and the US electronics sector (the country's second-largest manufacturing sub-sector).

China: Chemicals sector

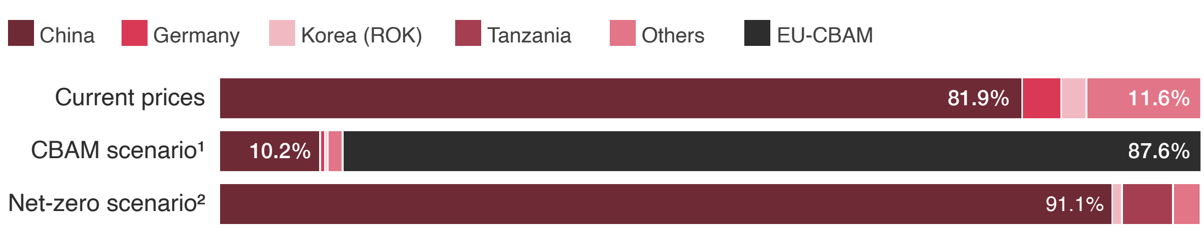
At current carbon prices, the average cost of carbon for China's chemicals sector is relatively low: less than 0.3% of the value of the sector's products. More than four-fifths of that cost is due to carbon pricing in China, and the remainder is due to the supply chain outside China. In the CBAM scenario, the cost of carbon for chemicals imported to the EU from China would increase to 2.4% of sales. Nearly nine-tenths of the hidden cost in that scenario would come from the CBAM tariff. In the net-zero scenario, the cost of carbon for chemicals produced in China would increase to 16% of the sector's production value, almost all resulting from the rise in China's carbon price (see chart below).

China's chemicals sector could see a 50-fold increase in the cost of carbon in a net-zero scenario

Cost of carbon as a percentage of production value



Cost of carbon breakdown by country in value chain

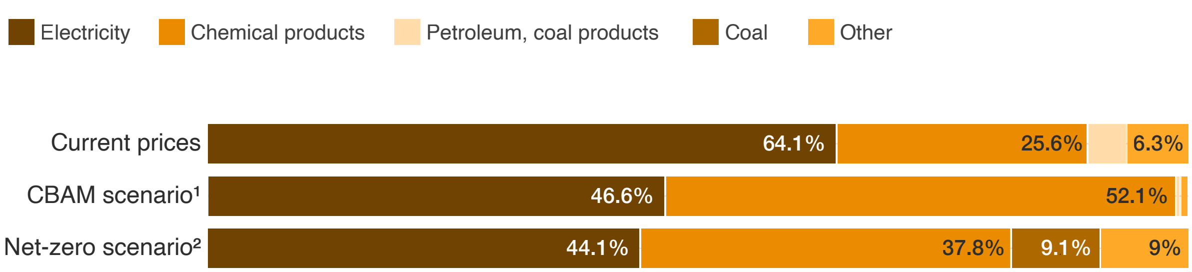


[1] Estimates cost of carbon for goods imported to the EU if Carbon Border Adjustment Mechanism were fully implemented.
[2] Estimates cost of carbon at the 2030 carbon prices implied by the IEA's scenario for reaching net-zero emissions by 2050.
Source: PwC analysis, Global Trade Analysis Project, International Energy Agency

Breaking down the cost of carbon incurred by each sector of the value chain, we find that current carbon costs for chemicals produced in China come mainly from electricity (64%) and from the chemicals sector itself (26%; see chart below). The proportions shift in the CBAM scenario: when the CBAM tariff is attributed to chemicals makers in China, their share of carbon costs rises to 52%, slightly more than the share from electricity (47%). And in the net-zero scenario, the chemicals sector's share of carbon costs would rise, relative to the base scenario, reaching 38% of the total, while the electricity sector's share would fall to 44%. Also higher in the net-zero scenario are the costs of carbon attributable to the coal sector and the petroleum and coal products sector; this is because China's production processes rely heavily on fossil fuels as a source of energy.

Carbon costs in China's chemicals sector come mainly from electricity and from the chemicals industry itself

Cost of carbon breakdown by sector in value chain



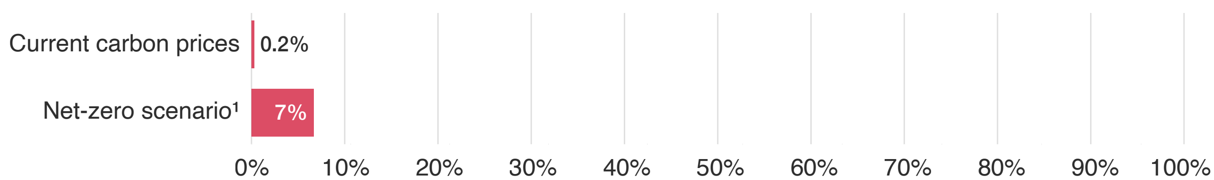
[1] Estimates cost of carbon for goods imported to the EU if Carbon Border Adjustment Mechanism were fully implemented.
[2] Estimates cost of carbon at the 2030 carbon prices implied by the IEA's scenario for reaching net-zero emissions by 2050.
Source: PwC analysis, Global Trade Analysis Project, International Energy Agency

United States: Electronics sector

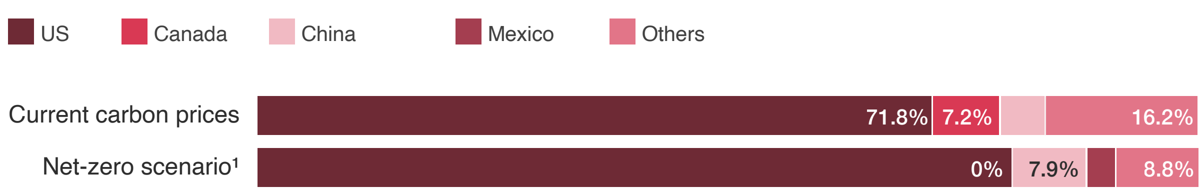
Currently, the average cost of carbon for the US electronics sector is relatively low (0.15% of sales). More than 70% of that cost results from US carbon pricing mechanisms at the state level (see chart below). In the net-zero scenario, the cost of carbon for US electronics would increase by a multiple of 33, to 7% of sales. That cost would still be largely attributable (80%) to carbon pricing in the US. The shares attributable to China and Mexico would also increase because these countries now have relatively low carbon prices. (The CBAM scenario is omitted here because CBAM does not cover the electronics sector.)

For the US electronics sector, the cost of carbon would rise in a net-zero scenario; most would still result from US carbon pricing mechanisms

Cost of carbon as a percentage of production value



Cost of carbon breakdown by country in value chain

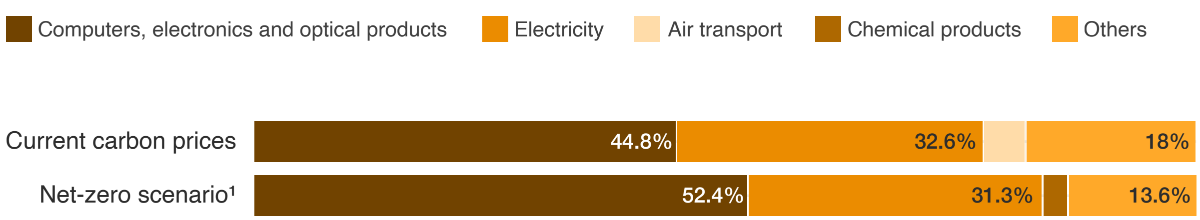


[1] Estimates cost of carbon at the 2030 carbon prices implied by the IEA's scenario for reaching net-zero emissions by 2050..
Source: PwC analysis, Global Trade Analysis Project, International Energy Agency

Sector-by-sector shares of carbon costs for the US electronics sector would change modestly between the base scenario and the net-zero scenario. These carbon costs now result mostly from pricing mechanisms that apply to the electronics sector (45%) and to the power sector (33%). In the net-zero scenario, the same two sectors would still account for about four-fifths of embedded carbon costs (electronics 52%; power 31%; see chart below).

Sector-by-sector shares of carbon costs for the US electronics sector would change modestly between scenarios

Cost of carbon breakdown by sector in value chain



[1] Estimates cost of carbon at the 2030 carbon prices implied by the IEA's scenario for reaching net-zero emissions by 2050.
Source: PwC analysis, Global Trade Analysis Project, International Energy Agency

Hidden carbon costs across national economies

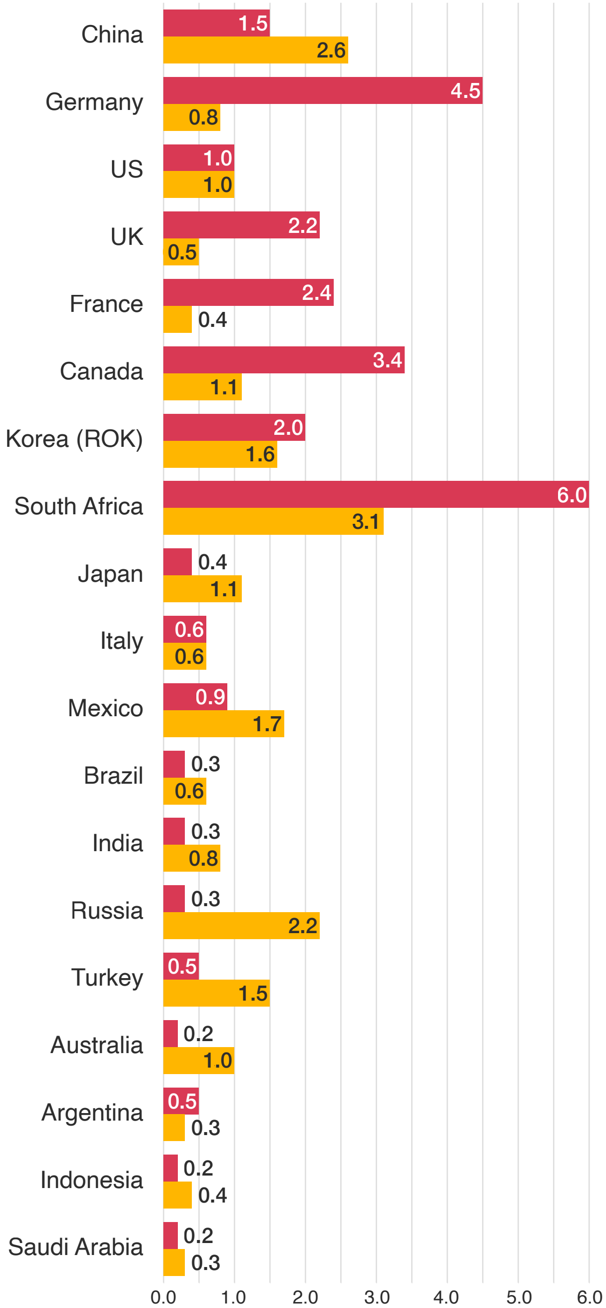
Carbon costs can affect the competitiveness of countries as well as companies. To illustrate these dynamics, we estimated the aggregate cost of carbon in the output of the G20 members (excluding the EU) under current carbon prices and under the net-zero scenario.

Under current carbon prices, the three countries with the highest total carbon cost embedded in their national output are China (US$41 billion), Germany (US$34 billion) and the United States (US$31 billion). The US presents a somewhat unusual case, because unlike China and Germany, it does not have a national carbon price. But the states of California and Washington have emissions trading systems, as do the 12 Northeast and Mid-Atlantic states that belong to the Regional Greenhouse Gas Initiative (RGGI). US companies also are affected by carbon costs imposed on their non-US suppliers.

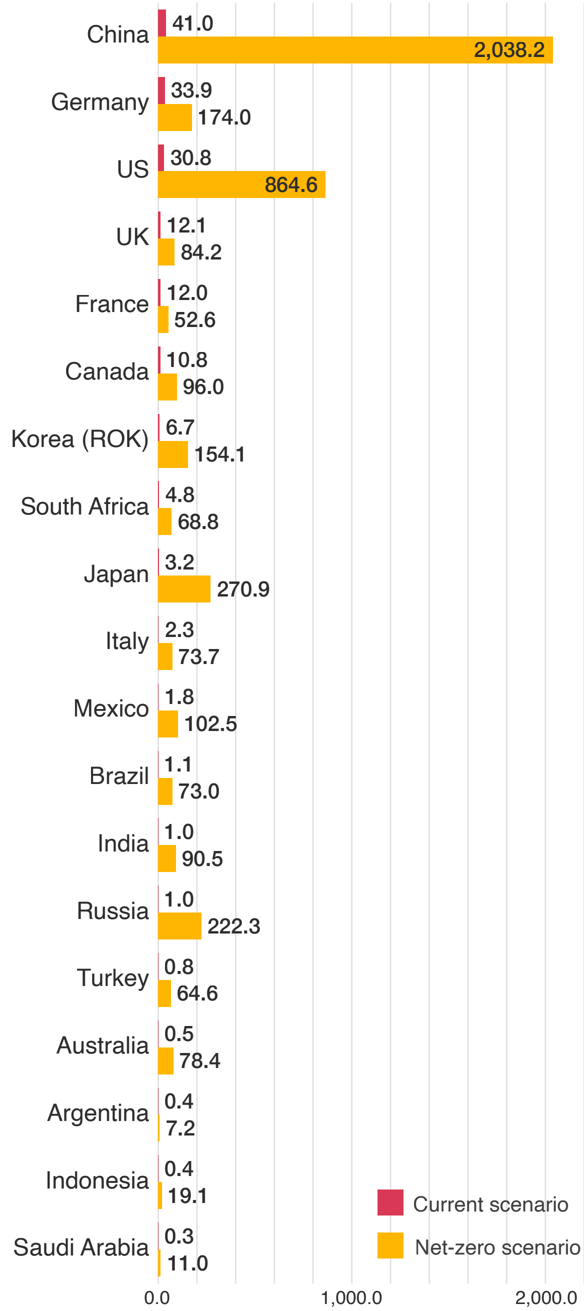
National carbon costs would increase substantially under the net-zero scenario: by a factor of 50 in China (from US$41 billion to US$2 trillion), by a factor of five in Germany (from US$34 billion to US$174 billion) and by a factor of 28 in the US (from US$31 billion to US$865 billion). The economies of countries that already have relatively high carbon prices, such as Germany, are less vulnerable to the risks of rising carbon prices than countries such as China and the US, where carbon prices are relatively low (see chart, page 15).

In the net-zero scenario, the economic playing field becomes more level even as carbon costs rise in general

Carbon cost intensity (cost as a share of output), relative tothe US[1]



Carbon price paid by all sectors, 2023 US$bn



[1] Cost of carbon as a percentage of production value for all sectors relative to the US percentage.
Source: PwC analysis, Global Trade Analysis Project, International Energy Agency

Explore the hidden cost of carbon further

PwC's tool offers modelled estimates of the hidden cost of carbon for selected regions and sectors.

Use the tool

Managing the hidden cost of carbon: Actions for business leaders

Since 2010, the average global carbon price has risen, along with the proportion of the world's carbon emissions that are subject to carbon prices. Both trends will likely continue; many countries plan to increase their carbon prices or institute pricing mechanisms. Knowing this, forward-looking companies are taking steps to manage their carbon costs. Here are four practices that have proven useful at some of the world's leading organisations.

- **Map your emissions and carbon price exposure.** Efforts to manage the hidden cost of carbon begin with gathering information on carbon emissions in your company's production process, from onsite emissions to the upstream supply chain—seldom an easy task. Consumer goods companies, for example, can have thousands of suppliers. However, we find that as much as 80% of an organisation's supply chain emissions come from as little as 20% of its purchases. The key is to collect useful, actionable emissions data, rather than to gather every last data point.

Next, you'll want to determine how carbon prices apply to emissions, paying careful attention to how prices vary by sector and by type of GHG. The Canadian province of Alberta, for example, has both a regulated limit for large emitters and a general carbon tax. However, an entity is subject to only one pricing mechanism, and it has some discretion to choose which one. One auto parts manufacturer saved CA$10 million (US$7.3 million) in carbon cost by opting into the large-emitter regulation. This enabled its lower-emitting facilities to maintain their competitiveness.

- **Turn exposure into opportunity.** Now that many governments have put green incentives in place, you may be able to fund a sizeable portion of clean-energy investments with grants, low-cost loans and other forms of government assistance. For one global cement manufacturer, careful study revealed that government incentives covered 50% of the costs of the emissions-reduction projects it was considering. In addition, most emissions trading systems allow companies that reduce their emissions to generate carbon credits that can be sold, providing a further path from decarbonisation to value creation.

  Executives might also think about helping suppliers reduce their carbon costs, because our modelling results suggest these can account for a substantial portion of a company's total cost of carbon. Knowing which links in your supply chain account for most of your carbon costs, you can prompt—or require—the right suppliers to set out plans for reducing emissions and to take action.

- **Plan ahead to avoid price shocks.** Existing or forthcoming carbon pricing regulations could add significant costs to your operations. Marine shipping companies, for example, will soon start paying for the carbon emissions related to fuel consumption under the EU ETS, which could affect the price of seaborne goods. By examining your company's carbon costs under future price scenarios, you can identify opportunities for reducing carbon costs today and avoid pricing risk tomorrow. For instance, one producer of agricultural nutrients found that it could reduce its future carbon price exposure by implementing carbon capture technologies at its facilities. [2]Executives will want to integrate rising carbon prices in their enterprise risk management and capital investment assessment processes over time.

- **Engage investors.** Potential increases in the hidden cost of carbon may seem like far-off concerns, but markets are already valuing the effects that these increases could have on companies. Some banks and private equity firms, for example, make a practice of assessing the carbon pricing risk faced by borrowers and portfolio companies. Executives will want to engage with investors, lenders, insurers and other financial institutions to understand how they incorporate carbon-related risks into their analyses and valuations. They can also explain to capital providers how the company manages exposure to carbon pricing and other climate-related risks. Companies that have lowered their emissions, or plan to do so, can highlight these efforts and help financial institutions understand the effects on their enterprise value.

Successfully navigating the transition to a sustainable economy means anticipating new climate and environmental policies that could dramatically affect your business. Although uncertainty surrounds these potential developments, the price and cost of carbon will likely continue to rise. By identifying where carbon costs hide in your company's supply chain, you can factor potential price increases into business decisions in a way that helps your company create more value over the long term.

[2] See the case study for Mosaic: https://www.pwc.com/us/en/library/case-studies/mosaic-climate-modeling.html.

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The authors wish to thank Claudia Buysing Damsté, Lucas Faller, Niels Muller and Karl Russo for their contributions to this article and the underlying research.

Methodology

Carbon pricing mechanisms affect supply chain costs in ways that can be difficult to measure. We think of this cost as the hidden cost of carbon. To estimate it, we incorporated carbon prices from the World Bank's Carbon Pricing Dashboard, a consistent source of carbon price information, into PwC's environmentally extended input–output model, ESCHER. The result is a hidden cost of carbon multiplier, representing the cost of carbon taxes and emissions allowances as a percentage of sales (turnover) for 65 sectors and 141 countries and regions that make up the world economy.

ESCHER is based primarily on version ten of the GTAP (Global Trade Analysis Project) input–output data (for 2014, the most recent data available) and on GTAP data on emissions of carbon dioxide, nitrous oxide, methane and fluorinated gases. The data may reflect supply chain flows (i.e., the sourcing patterns of sectors) and emissions levels that are different from actual supply chain flows and emissions levels. Nonetheless, the model likely provides a representation of supply chains and emissions levels that is close enough to current conditions to be indicative of the carbon costs that businesses pay today. More recent data will be used to update the model as it becomes available.

As an illustration, here is how we derive the effective carbon price for Canada. The World Bank's Carbon Pricing Dashboard shows that the current price of carbon in Canada under federal regulations is US$48 per metric ton. (That is also the carbon price at the provincial level, with a few exceptions.) However, only a portion of the emissions from each sector is priced. To account for these variations, we calculate the effective carbon price by multiplying the percentage of emissions covered in each sector by the stated federal and provincial carbon prices. For example, the effective carbon price is US$19.90 per metric ton for the electricity sector and US$5.70 per metric ton for the agriculture-related sectors. Under the net-zero scenario in our model, the effective carbon price would be significantly higher than it is today, because that scenario assumes that the carbon price on all emissions from electricity, industry and energy production by a developed country such as Canada would be US$140 per metric ton in 2030.

With this model, we calculated the hidden cost of carbon multiplier under three carbon price scenarios:

Current prices. This scenario uses currently enacted carbon pricing as documented in the most recent World Bank dataset, which covers 73 regional, national and subnational carbon pricing initiatives implemented as of 31 March, 2023. The World Bank provides information on two types of carbon pricing: emissions trading systems and carbon taxes.

CBAM. This scenario assumes full implementation of CBAM: that is, imports of certain carbon-intensive products (iron, steel, aluminium, cement, fertiliser, chemicals and hydrogen) into the EU are required to pay a tariff on their Scope 1 and Scope 2 emissions. (Under EU law, the CBAM charge will be phased in over the 2026–34 period.) The tariff applied in the model is the excess, if any, of the carbon cost of Scope 1 (direct) and Scope 2 (purchased power) emissions at the current EU carbon price, over the current carbon cost in the exporting country.

Net zero. This scenario uses the carbon prices for 2030 that are defined in the IEA's 2021-version economic scenario for achieving net-zero CO2 emissions by 2050. The IEA sets different carbon price pathways for each of three country groups: advanced economies (OECD plus Bulgaria, Croatia, Cyprus, Malta and Romania), major emerging economies (China, Russia, Brazil and South Africa), and all others. [3]The sectors covered by these price pathways are electricity, industry and energy production. The model uses the current carbon price for other sectors and in cases where the current carbon price exceeds the IEA's net-zero price.

[3] See https://iea.blob.core.windows.net/assets/932ea201-0972-4231-8d81-356300e9fc43/WEM_Documentation_WEO2021.pdf, page 17, Table 5.