ENVIRONMENTAL AND NATURAL RESOURCE ECONOMICS: A CONTEMPORARY APPROACH

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CHAPTER 13

Global Climate Change: Policy Responses

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CHAPTER 13 FOCUS QUESTIONS

- What are the possible policy responses to global climate change?
- How can economic theory help in developing climate policy responses?
- What climate policies have been proposed and implemented at local, national, and global levels?

13.1 RESPONDING TO A CLIMATE EMERGENCY

As discussed in Chapter 12, the scientific evidence regarding the seriousness of global climate change supports strong policy action. The Stern Review on the Economics of Climate Change called for "an urgent global response," and other economic analyses of climate change have placed emphasis on insurance against catastrophic risks and the need to adapt to inevitable climate change impacts.[1] As the severity of the problem has grown, economic analysis has focused on increasingly ambitious economy-wide responses. A recent statement by prominent economists asserted that "we can and must end the carbon economy. . . governments must actively phase out the fossil fuel industry."[2] A growing number of countries and major corporations have committed to net-zero emissions by 2050. These goals imply a large-scale transformation of the global energy economy and other economic sectors such as agriculture and forestry.

preventive measures actions designed to reduce the extent of climate change by reducing projected emissions of greenhouse gases.
adaptive measures actions designed to reduce the magnitude or risk of damages from global climate change.

Policy responses to climate change can be broadly classified into two categories: **preventive measures** intended to lower the magnitude or timing of climate change, and **adaptive measures** to deal with the consequences of climate change. Major preventive policy approaches include:

- Reducing emissions of greenhouse gases by meeting energy demands from sources with lower or zero greenhouse gas emissions (e.g., switching from fossil fuels to solar, wind, and geothermal energy).
- Reducing overall energy demand by increasing energy efficiency (e.g., demand-side management, as discussed in Chapter 11).
- Enhancing natural **carbon sinks**. Carbon sinks are areas where carbon may be stored; natural sinks include soils and forests. Human intervention can either reduce or expand these sinks through forest management and agricultural practices.
- Artificial **carbon capture and storage (CCS)**. Technologies for large-scale CCS are still in the process of development and have yet to prove economically viable. But proponents argue that CCS is increasingly well-placed to make a significant and necessary contribution to achieving net-zero emissions around mid-century.[3]

carbon sinks portions of the ecosystem with the ability to absorb certain quantities of carbon dioxide, including forests and oceans.
carbon capture and storage the process of capturing waste carbon dioxide (CO_2), and storing it where it will not enter the atmosphere.

Most of this chapter focuses on mitigation policies, but it is becoming increasingly evident that mitigation policies need to be supplemented with adaptation policies. Climate change is already occurring, and even if significant mitigation policies are implemented in the immediate future, warming and sea-level rise will continue well into the future, even for centuries.[4]

Adaptive measures include:

- Construction of dikes and seawalls to protect against rising seas and extreme weather events such as floods and hurricanes.
- Shifting cultivation patterns in agriculture to adapt to changing weather conditions.
- Creating institutions that can mobilize the needed human, material, and financial resources to respond to climate-related disasters.

Economic analysis can provide policy guidance for nearly any preventive or adaptive measure. **Cost-benefit analysis**, discussed in Chapters 7 and 12, can present a basis for evaluating whether a policy should be implemented. However, as discussed in Chapter 12, economists disagree about the appropriate assumptions and methodologies for cost-benefit analyses of climate change. A less controversial conclusion from economic theory is that we should apply **cost-effectiveness analysis** in considering which policies to adopt. The use of cost-effectiveness analysis avoids many of the complications associated with cost-benefit analysis. While cost-benefit analysis attempts to offer a basis for deciding upon policy goals, cost-effectiveness analysis accepts a goal as given by society and uses economic techniques to determine the most efficient way to reach that goal.

cost-benefit analysis (CBA) a tool for policy analysis that attempts to monetize all the costs and benefits of a proposed action to determine the net benefit.
cost-effectiveness analysis a policy tool that determines the least-cost approach for achieving a given goal.

In general, economists usually favor approaches that work through market mechanisms to achieve their goals. Market-oriented approaches are considered cost effective; rather than attempting to control market actors directly, they shift incentives so that individuals and firms will change their behavior to take external costs and benefits into account. Examples of market-based policy tools include **pollution taxes** and **transferable**, **or tradable**, **permits**. Both of these are potentially useful tools for greenhouse gas reduction. Other relevant economic policies include measures to create incentives for the adoption of renewable energy sources and energy-efficient technology, such as solar and wind tax credits.

market failure a situation in which an unregulated market fails to produce an outcome that is the most beneficial to society as a whole.
pollution tax(es) a per-unit tax based on the level of pollution.
transferable (tradable) permits tradable permits that allow a firm to emit a certain quantity of a pollutant.

13.2 Climate Change Mitigation: Economic Policy Options

The release of greenhouse gases in the atmosphere is a clear example of a negative externality that imposes significant costs on a global scale. In the language of economic theory, the current market for carbon-based fuels such as coal, oil, and natural gas takes into account only private costs and benefits, which leads to a market equilibrium that does not correspond to the social optimum. From a social perspective, the market price for fossil fuels is too low and the quantity consumed too high, as discussed in Chapter 11.

Carbon Taxes

A standard economic remedy for internalizing external costs is a per-unit tax on the pollutant. In this case, what is called for is a **carbon tax**, levied on carbon-based fossil fuels in proportion to the amount of carbon associated with their production and use. Such a tax will raise the price of carbon-based energy sources and so give consumers incentives to conserve energy overall (which would reduce their tax burden), as well as shifting their demand to alternative sources of energy that produce lower carbon emissions (and are thus taxed at lower rates). In economic terms, the level of such a tax should be based on the **social cost of carbon**—an estimate of the financial impact on society of carbon emissions. The U.S. Environmental Protection Agency estimated the social cost of carbon in 2016, based on varying assumptions, as being between $11 and $212, with a median range around $50.[5] (As noted in Chapter 12, a major reason for differing estimates is assumptions regarding discount rates and risk/uncertainty).

Since the impact of carbon taxes may fall more heavily on lower-income families who spend a higher proportion of their income on fuel, many economists advocate the return of the revenues generated by a carbon tax to taxpayers through a lump-sum rebate. The objective of the tax is not to raise revenue, but to create incentives to reduce the use of fossil fuels and adopt substitutes. A statement by over 3,000 economists including 28 Nobel laureates, 15 former chairs of the Council of Economic Advisers, and 4 former Federal Reserve chairs, called for a carbon tax with rebate, known as a **carbon dividend** (Box 13.1).

carbon tax a per-unit tax on goods and services based on the quantity of carbon dioxide emitted during the production or consumption process.
social cost of carbon an estimate of the financial cost of carbon emissions per unit, including both present and future costs.
carbon dividend return of the revenues from a carbon tax to taxpayers as a lump-sum payment.

Box 13.1 Economists' Statement on Carbon Dividends

Global climate change is a serious problem calling for immediate national action. Guided by sound economic principles, we are united in the following policy recommendations.

I. A carbon tax offers the most cost-effective lever to reduce carbon emissions at the scale and speed that is necessary. By correcting a well-known market failure, a carbon tax will send a powerful price signal that harnesses the invisible hand of the marketplace to steer economic actors towards a low-carbon future.

II. A carbon tax should increase every year until emissions reductions goals are met and be revenue neutral to avoid debates over the size of government. A consistently rising carbon price will encourage technological innovation and large-scale infrastructure development. It will also accelerate the diffusion of carbon-efficient goods and services.

III. A sufficiently robust and gradually rising carbon tax will replace the need for various carbon regulations that are less efficient. Substituting a price signal for cumbersome regulations will promote economic growth and provide the regulatory certainty companies need for long-term investment in clean-energy alternatives.

IV. To prevent **carbon leakage** and to protect U.S. competitiveness, a border carbon adjustment system should be established. This system would enhance the competitiveness of American firms that are more energy-efficient than their global competitors. It would also create an incentive for other nations to adopt similar carbon pricing.

V. To maximize the fairness and political viability of a rising carbon tax, all the revenue should be returned directly to U.S. citizens through equal lump-sum rebates. The majority of American families, including the most vulnerable, will benefit financially by receiving more in "carbon dividends" than they pay in increased energy prices.

Source: https://www.econstatement.org, published in the *Wall Street Journal* January 17, 2019.

carbon leakage a shift in production or consumption in response to a carbon tax or other carbon reduction policy that evades or reduces the effectiveness of the original measure.

What would be the effect of a carbon tax? Table 13.1 shows the impact that different levels of a carbon tax would have on the prices of coal, oil, and natural gas. The tax here is given in dollars per ton of CO_2 (taxes are sometimes stated per ton of carbon; to convert to dollars per ton of carbon, multiply by 3.667).[6] Based on energy content, measured in British Thermal Units (Btus), coal is the most carbon-intensive fossil fuel, while natural gas produces the lowest carbon emissions per Btu (Figure 13.1). Calculating the impact of a carbon tax relative to the standard commercial units for each fuel source, we see that a carbon tax of $50 per metric ton of CO_2, for example, raises the price of a gallon of gasoline by about 45 cents, or about 20 percent, based on 2021 prices (Figure 13.2). A tax of $100 per metric ton of CO_2 equates to an increase in gasoline prices of about 89 cents per gallon.

The impact of a carbon tax would be even greater for coal prices—a tax of $50 per ton of CO_2 would increase coal prices by over 200 percent. And a $100 per ton tax would raise coal prices by over 400 percent. For natural gas, although its carbon content is lower than that of gasoline, its low price (as of 2021) means that the percentage impact on price is about the same as for gasoline.

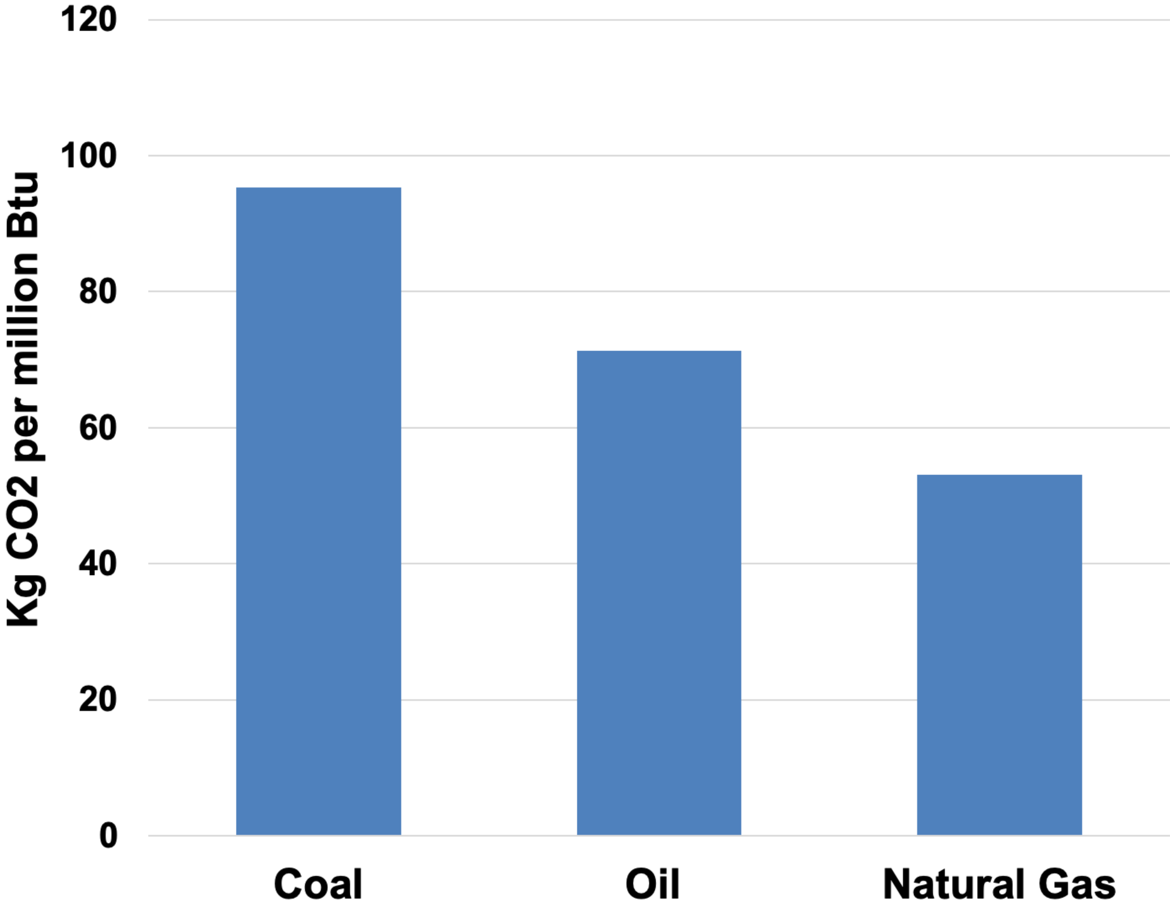
Table 13.1 Alternative Carbon Taxes on Fossil Fuels

Impact of Carbon Tax on Retail Price of Gasoline	
kg CO_2 per gallon	8.89
tonnes CO_2 per gallon	0.00889
$/gal., $50/tonne tax	$0.45
$/gal., $100/tonne tax	$0.89
Retail price (2021) per gallon	$2.20
% increase, $50/tonne tax	20.5%
% increase, $100/tonne tax	41%
Impact of Carbon Tax on Retail Price of Coal	
kg CO_2 per short ton	2100
tonnes CO_2 per short ton	2.1
$/short ton, $50/tonne tax	$105
$/short ton, $100/tonne tax	$210
Retail price (2021) per short ton	$40
% increase, $50/tonne tax	220%
% increase, $100/tonne tax	440%
Impact of Carbon Tax on Retail Price of Natural Gas	
kg CO_2 per 1000 cu. ft.	53.12
tonnes CO_2 per 1000 cu. ft.	0.05312
$/1000 cu. ft., $50/tonne tax	$2.66
$/1000 cu. ft., $100/tonne tax	$5.31
Retail price (2020)	$12
% increase from $50/tonne tax	22.2%
% increase from $100/tonne tax	44.4%

Source: Carbon emissions calculated from carbon coefficients and thermal conversion factors available from the U.S. Department of Energy. All price data from the U.S. Energy Information Administration.

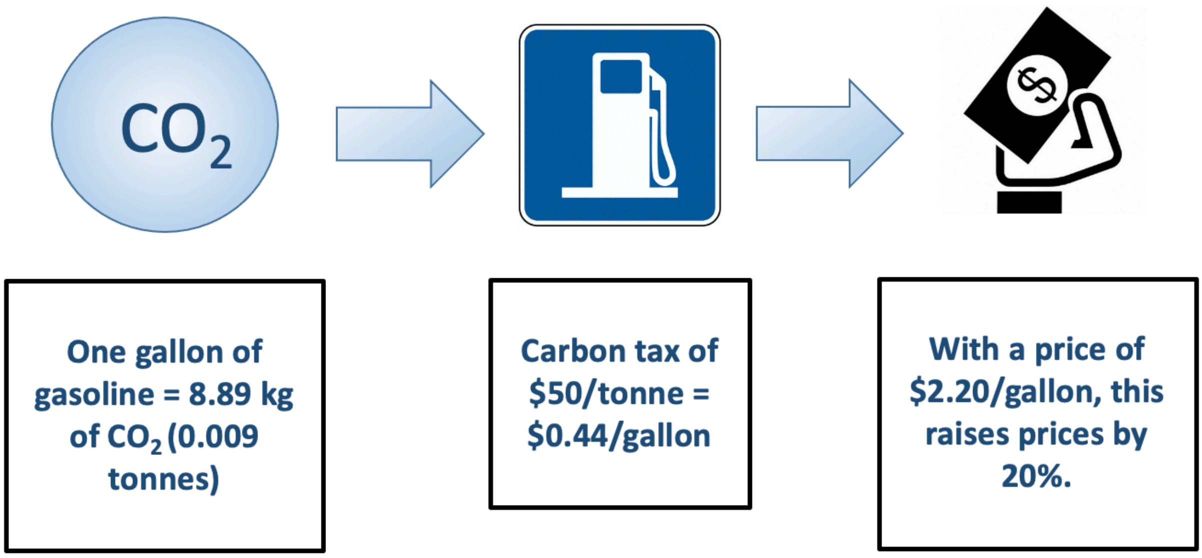
Note: tonne = metric ton, equal to 1.1 U.S. short tons.

Figure 13.1 Carbon Content of Fuels



Source: Calculated from U.S. Department of Energy data.

Figure 13.2 Impact of a Carbon Tax on Gasoline Price



Source: Calculated from U.S. Department of Energy data.

Will these tax amounts affect people's driving or home heating habits very much, or impact industry's use of fuels? This depends on the **elasticity of demand** for these fuels. As noted earlier (see Chapter 3 Appendix), elasticity of demand is defined as:

$$Elasticity\ of\ demand = \frac{Percent\ change\ in\ quantity\ demanded}{percent\ change\ in\ price}$$

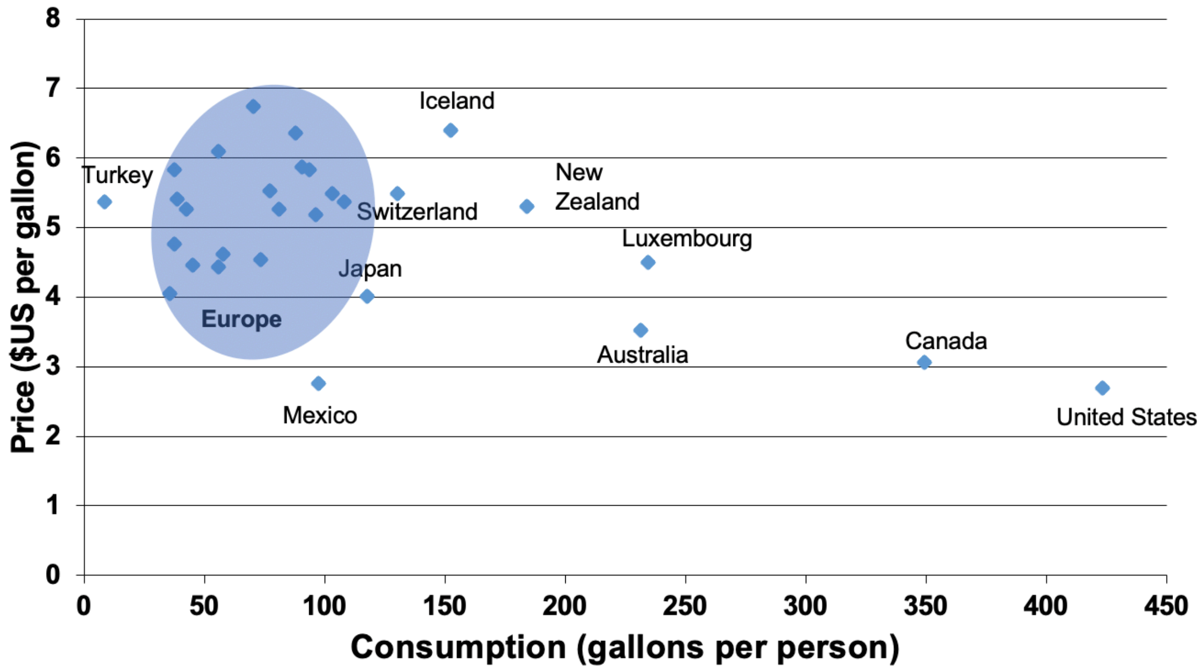
Economists have measured the elasticity of demand for different fossil fuels, particularly gasoline. (Elasticity of demand is generally negative, since a positive percent change in price causes a negative percent change in quantity demanded.) Studies indicate that in the short term (about one year or less) elasticity estimates ranged from −0.03 to −0.25. This means that a 10 percent increase in the price of gasoline would be expected to decrease gasoline demand in the short term by about −0.3 to −2.5 percent.[7]

In the long term (about five years or so) people are more responsive to gasoline price increases, as they have time to purchase different vehicles and adjust their driving habits. The average long-term elasticity of demand for motor fuels, based on 51 estimates, is −0.64.[8] According to Table 13.1, a tax of $50 per ton of CO_2 would increase the price of gasoline by about 20 percent, adding 45 cents per gallon to the price of gasoline based on 2021 prices. A long-term elasticity of –0.64 suggests that after people have time to adjust fully to this price change, the demand for gasoline should decline by about 13 percent.

Figure 13.3 shows a cross-country relationship between gasoline prices and per capita consumption. (Since the cost of production for a gallon of gasoline varies little across countries, variations in the price of a gallon in different countries is almost solely a function of differences in taxes.) Note that this relationship is similar to that of a demand curve: higher prices are associated with lower consumption, and lower prices with higher consumption.

The relationship shown here, however, is not exactly the same as a demand curve; since we are looking at data from different countries, the assumption of "other things equal," which is needed to construct a demand curve, does not hold. Differences in demand may, for example, be in part a function of differences in income levels rather than prices. Also, people in the United States may drive more partly because travel distances (especially in the western United States) are greater than in many European countries, and public transportation options fewer. But there does seem to be a clear price/consumption relationship. The data shown here suggest that it would take a fairly big price hike—in the range of $0.50–$1.00 per gallon or more—to affect fuel use substantially.

Figure 13.3 Gasoline Price versus Consumption in Industrial Countries, 2020



Sources: Gasoline Price: https://data.worldbank.org/indicator/EP.PMP.SGAS.CD?end=2016&start=2015; Gasoline Consumption: Global Petrol Prices, https://www.globalpetrolprices.com/data/

Note: Shaded area represents price/consumption range typical of European countries.

Would a large gasoline tax increase, or a broad-based carbon tax, be politically feasible? Especially in the United States, high taxes on gasoline and other fuels would face much opposition. As Figure 13.3 shows, the United States has by far the highest gasoline consumption per person and the lowest prices outside the Middle East. But let us note two things about proposals for substantial carbon taxes:

- First, revenue recycling could redirect the revenue from carbon and other environmental taxes to lower other taxes. Much of the political opposition to high energy taxes comes from the perception that they would be an *extra* tax—on top of the income, property, and social security taxes that people already pay. If a carbon tax were matched, for example, with a substantial cut in income or social security taxes, it might be more politically acceptable, and also more equitable (see Box 13.2). Rather than a net tax increase, this would be **revenue-neutral tax shift**—the total amount that citizens pay to the government in taxes is essentially unchanged. Alternatively, the tax revenues could be returned to taxpayers as a lump-sum payment (as suggested in Box 13.1).

- Second, if such a revenue-neutral tax shift did take place, individuals or businesses whose operations were more energy efficient would actually save money overall. The higher cost of energy would also create a powerful incentive for energy-saving technological innovations and stimulate new markets. Economic adaptation would be easier if the higher carbon taxes (and lower income and capital taxes) were phased in over time.

revenue-neutral tax shift policies that are designed to balance tax increases on certain products or activities with a reduction in other taxes, such as a reduction in income taxes that offsets a carbon-based tax.

Box 13.2 A Distributionally-neutral Carbon Tax in the United States

Placing a price on carbon emissions would result in unequal impacts on households of different income levels. Specifically, a carbon tax would be a **regressive tax**, meaning that as a percentage of income the tax would affect lower-income households more than higher-income households. The reason is that lower-income households spend a higher percentage of their income on carbon-intensive goods, such as gasoline, electricity, and heating fuels. A carbon tax, implemented alone, would therefore increase overall levels of income inequality.

But a carbon tax could be coupled with a decrease in one or more existing taxes such that the overall amount of taxes paid by the average household stays about the same. The distributional impacts will depend on which tax is reduced. Some taxes are regressive, affecting lower-income households more heavily, while other taxes are **progressive taxes**, affecting higher-income households more heavily. Most proposals for a revenue-neutral carbon tax suggest achieving revenue neutrality by decreasing a regressive tax. In the United States, regressive taxes include sales taxes, the payroll tax, and excise taxes.[9] Offsetting a carbon tax in the United States with a decrease in the payroll tax could produce a result that is approximately **distributionally neutral**, meaning that the impact on households at different income levels would be nearly the same as a percentage of income.[10]

regressive tax a tax in which the rate of taxation, as a percentage of income, decreases with increasing income levels.
progressive taxes taxes that comprise a higher share of income with higher income levels.
distributionally neutral tax shift a change in the pattern of taxes that leaves the distribution of income unchanged.

Tradable Permits

An alternative to a carbon tax is a system of tradable carbon permits, also called **cap-and-trade**. A carbon trading scheme can be implemented at the state, regional, or national level, or could include multiple countries. A permit system works as follows, as discussed in Chapter 8:

- Each emitting firm is allocated a specific permissible level of carbon emissions. The total number of carbon permits issued equals the desired emissions goal. For example, if carbon emissions for a particular region are currently 40 million tons and the policy goal is to reduce this by 20 percent (8 million tons), then permits would be issued to emit only 32 million tons. Over time, the goal could be increased, with the result that fewer permits would be issued in future periods.
- Permits are allocated to individual carbon-emitting sources. Including all carbon sources (e.g., all motor vehicles) in a trading scheme is generally not practical. It is most effective to implement permits as far "upstream" in the production process as possible to simplify the administration of the program and cover the most emissions. ("Upstream" here denotes an early stage in the production process, as discussed in Chapter 3 regarding a pollution tax.) Permits can be allocated to the largest carbon emitters, such as power companies and manufacturing plants, or even further upstream to the suppliers through which carbon fuels enter the production process—oil producers and importers, coal mines, and natural gas drillers.
- These permits could initially be allocated for free on the basis of past emissions, or could be auctioned to the highest bidders. As discussed in Chapter 8, the effectiveness of the trading system should be the same regardless of how the permits are allocated. But there is a significant difference in the distribution of costs and benefits. Giving permits out for free essentially amounts to a windfall gain for polluters, while auctioning permits imposes real costs upon firms and generates public revenues.
- Firms can then trade permits freely among themselves. Firms whose emissions exceed the number of permits they hold must purchase additional permits or else face penalties. Meanwhile firms that can reduce their emissions below their allowance at low cost are allowed to sell their permits for a profit. A permit price will be determined through market supply and demand. It may also be possible for environmental groups or other organizations to purchase permits and retire them—thus reducing overall emissions.
- In an international system, countries and firms could also receive credit for financing carbon reduction efforts in other countries. For example, a German firm could get credit for replacing highly polluting coal plants with efficient renewable electric generating equipment in a developing country.

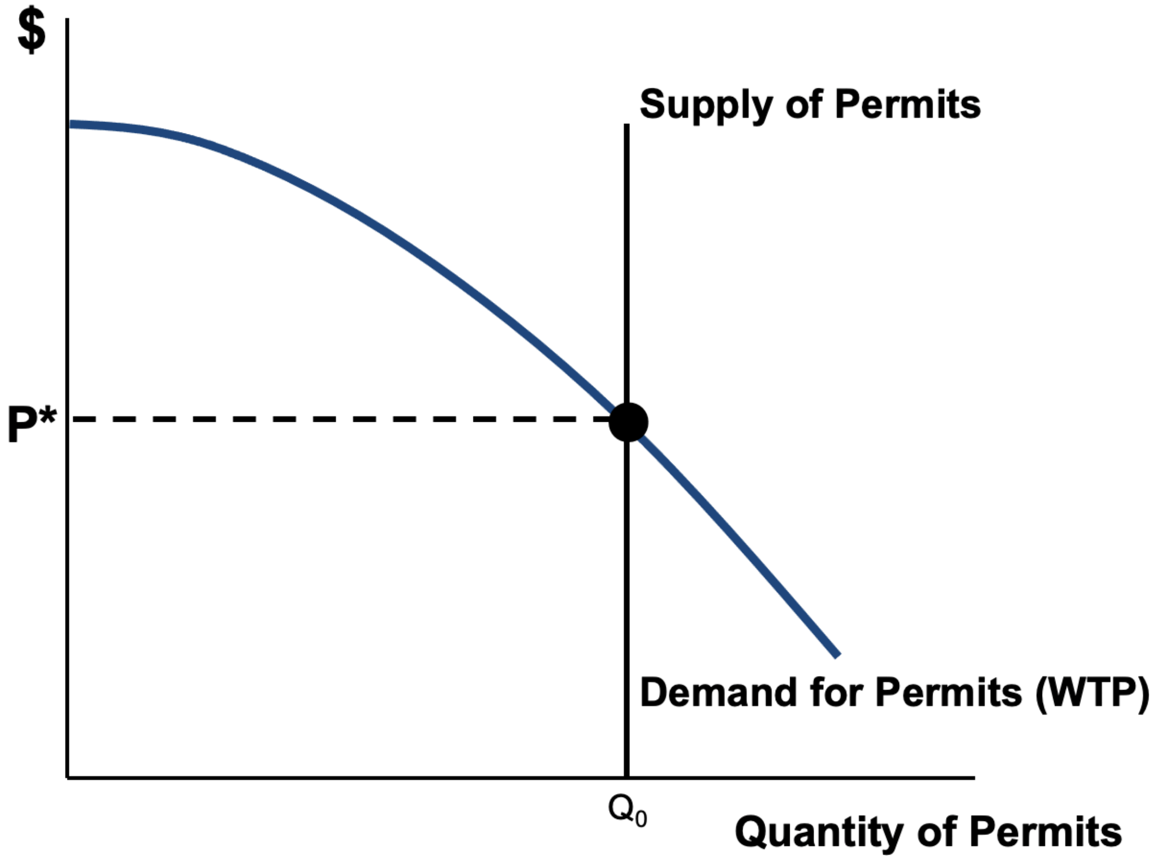
cap and trade a tradable permit system for pollution emissions.

A tradable permit system encourages the least-cost carbon reduction options to be implemented, as rational firms will implement those emission-reduction actions that are cheaper than the market permit price. As discussed in Chapter 8, tradable permit systems have been successful in reducing sulfur and nitrogen oxide emissions at low cost. Depending on the allocation of permits in an international scheme, it might also mean that developing countries could transform permits into a new export commodity by choosing a non-carbon path for their energy development. They would then be able to sell permits to industrialized countries that were having trouble meeting their reduction requirements. Farmers and foresters could also get carbon credits for using methods that store carbon in soils or preserve forests.

While the government sets the number of permits available, the permit price is determined by market forces. In this case, the supply curve is fixed, or vertical, at the number of permits allocated, as shown in Figure 13.4. The supply of permits is set at Q_0. The demand curve for permits represents firms' willingness to pay for them. Their maximum willingness to pay for permits is equal to the potential profits they can earn by emitting carbon.

A market equilibrium price will be established at *P**. We can also interpret *P** as the marginal benefit, or profit, associated with the right to emit the Q_0th unit of carbon.

Figure 13.4 Determination of Carbon Permit Price



Note: WTP = willingness to pay.

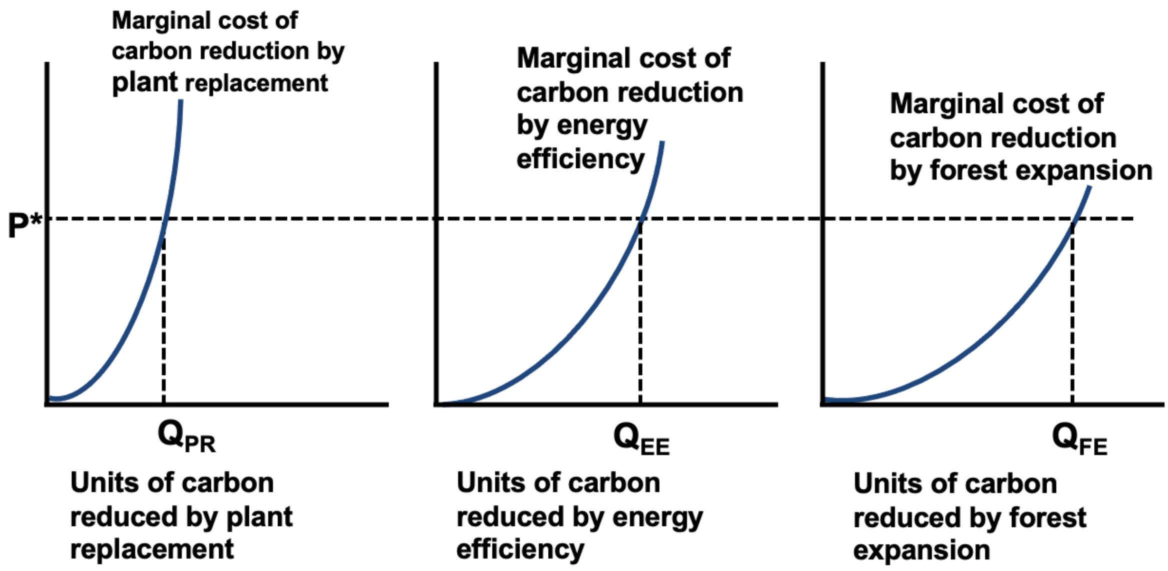
An important point about a permit trading system is that each firm can choose to reduce its carbon emissions in a cost-effective manner. Firms have various options for reducing their carbon emissions. Figure 13.5 shows an example of three carbon reduction strategies: replacing older manufacturing plants, investing in energy efficiency, and funding forest expansion to increase carbon storage in biomass. In each case, the graph shows the marginal costs of reducing carbon emissions through that strategy. These marginal costs generally rise as more units of carbon are reduced, but they may be higher and increase more rapidly for some options than others.

In this example, replacement of manufacturing plants using existing carbon-emitting technologies is possible but will tend to have high marginal costs—as shown in the first graph in Figure 13.5. Reducing emissions through greater energy efficiency has lower marginal costs, as seen in the middle graph. Finally, carbon storage through forest area expansion has the lowest marginal costs. The permit price *P** (as determined in Figure 13.4) will govern the relative levels of implementation of each of these strategies. Firms will find it profitable to reduce emissions using a particular strategy so long as the costs of that option are lower than the cost of purchasing a permit.

The analysis indicates that forest expansion would be used for the largest share of the reduction (Q_{FE}), but plant replacement and energy efficiency would also contribute shares (Q_{PR} and Q_{EE}) at the market equilibrium. Firms (and countries if the program is international) that participate in such a trading scheme can thus decide for themselves how much of each control strategy to implement, and will naturally favor the least-cost methods. This will probably involve a combination of different approaches.

In an international program, suppose that one country undertakes extensive reforestation. It is then likely to have excess permits, which it can sell to a country with few low-cost reduction options. The net effect will be the worldwide implementation of the least-cost reduction techniques.

Figure 13.5 Carbon Reduction Options with a Permit System



Note: Marginal costs shown here are hypothetical.

This system combines the advantages of economic efficiency with a guaranteed result: reduction in overall emissions to the desired level. The acid rain program in the United States, which has operated since 1995, is widely considered to be a successful emissions trading program, as discussed in Chapter 8, Box 8.2.

The major problem, of course, is achieving agreement on the initial number of permits, and deciding whether the permits will be allocated freely or auctioned off. There may also be measurement problems and issues such as whether to count only commercial carbon emissions or to include emissions changes that result from land use changes, such as those associated with agriculture and forestry. Including agriculture and forestry has the advantage of broadening the scheme to include many more reduction strategies, possibly at significantly lower cost, but it may be more difficult to get an accurate measure of carbon storage and release from land use change.

Carbon Taxes or Cap and Trade?

There is a lively debate regarding which economic approach should be used to reduce carbon emissions. Carbon taxes and a cap-and-trade approach have important similarities but also important differences.

As discussed in Chapter 8, both pollution taxes and cap-and-trade can, in theory, achieve a given level of pollution reduction at the least overall cost. Both approaches will also result in the same level of price increases to final consumers, and both create a strong incentive for technological innovation. Both approaches can raise the same amount of government revenue, assuming all permits are auctioned off, and can be implemented upstream in production processes to cover the same proportion of total emissions.

Yet the two policies have several important differences. Some of the advantages of a carbon tax include:

- In general, a carbon tax is considered simpler to understand and more transparent than a cap-and-trade approach. Cap-and-trade systems can be complex and require new bureaucratic institutions to operate.
- As we saw in Chapter 8, with technological change that lowers the cost of carbon reduction, a carbon tax will automatically further reduce carbon emissions. In a cap-and-trade program, technological change will instead reduce the price of permits, probably resulting in some firms actually emitting more carbon.
- A carbon tax can usually be implemented more quickly. Given the need to address climate change as soon as possible, it may be inadvisable to spend years working out the details and implementation of a cap-and-trade program.
- Perhaps the most important advantage of a carbon tax is that it provides greater price predictability. If businesses and households know what future taxes will be on fossil fuels and other greenhouse gas-emitting products, they can invest accordingly. For example, whether a business invests in an energy efficient heating and cooling system depends on its expectations of future fuel prices. In a cap-and-trade system, permit prices could vary considerably, leading to **price volatility** that makes planning difficult. A carbon tax, by contrast, provides a degree of price stability, especially if carbon tax levels are published years into the future.[11]

price volatility rapid and frequent changes in price, leading to market instability.

The advantages of a cap-and-trade system include:

- Even though a cap-and-trade system ultimately results in the same level of price increases to consumers and businesses, it avoids the negative connotations of a “tax.” A cap-and-trade system thus often generates less political opposition than a carbon tax.
- Some businesses favor cap-and-trade because they believe that they can successfully lobby governments for free permits, rather than having to purchase them at auction. Distributing permits for free in the early stages of a cap-and-trade program can make it more politically acceptable to businesses.
- The greatest advantage of a cap-and-trade approach is that emissions are known with certainty because the government sets the number of available permits. Since the policy goal is ultimately to reduce carbon emissions, a cap-and-trade approach does this directly while a carbon tax does it indirectly through price increases. Using a cap-and-trade approach, we can achieve a specific emissions path simply by setting the number of permits. In a carbon tax system, achieving a specific emissions target may require numerous adjustments to the tax rates, which may be politically difficult.

The choice of instrument—carbon tax or cap-and-trade—mainly depends on whether policy makers are more concerned with price uncertainty or emissions uncertainty. (Recall the discussion on price versus quantity instruments in Chapter 8). If they take the perspective that price certainty is important because it allows for better long-term planning, then a carbon tax is preferable. If they believe that the relevant policy goal is to reduce carbon emissions by a specified amount with certainty, then a cap-and-trade approach is preferable, although it may lead to some price volatility.

Another practical difference appears to be that carbon tax revenues are more often refunded to taxpayers or used in general government spending, while cap-and-trade auction revenues are more often used to support such "green" investments as renewable energy, energy efficiency, and forest conservation.[12]

OTHER POLICY TOOLS: SUBSIDIES, STANDARDS, R&D, AND TECHNOLOGY TRANSFER

Political hurdles may prevent the adoption of sweeping carbon taxes or transferable permit systems. Even with implementation of a widespread carbon tax or cap-and-trade system, supplemental policies may still be necessary to reduce carbon emissions sufficiently to keep warming within acceptable levels. Policies that can contribute to a comprehensive approach to emissions reduction include:

- *Shifting subsidies from carbon-based to non–carbon-based fuels*. Many countries currently provide direct or indirect subsidies to fossil fuels, as discussed in Chapter 11. The elimination of these subsidies would alter the competitive balance in favor of alternative fuel sources. If these subsidy expenditures are redirected to renewable sources, especially in the form of tax rebates for investment (for example, tax credits for purchasing an electric vehicle), it could promote a boom in investment in renewables.
- *Infrastructure investment in energy efficiency, renewable energy, zero-emission vehicles, grid modernization, high-speed rail, public transit, and worker education and retraining.* Upgrading infrastructure is becoming more urgent as climate variability undermines and damages existing, often aging, systems (See Box 13.3). Infrastructure investments involve substantial job creation, and have long-term benefits that can extend for generations.
- ***Efficiency standards*** *for machinery and appliances*, *and fuel-economy standards or requirements for low-carbon fuels*. By imposing standards that require greater energy efficiency or lower carbon use, technologies and practices can be altered in favor of a low-carbon path.
- *Research and development (R&D) expenditures promoting the commercialization of alternative technologies*. Both government R&D programs and favorable tax treatment of corporate R&D for alternative energy can speed commercialization. The existence of non-carbon "backstop" technologies significantly reduces the economic cost of measures such as carbon taxes, and if the backstop were to become fully competitive with fossil fuels, carbon taxes would be unnecessary.
- ***Technology transfer*** *to developing countries*. The bulk of projected growth in carbon emissions will come in the developing world. Many energy development projects are now funded by agencies such as the World Bank and regional development banks. To the extent that these funds can be directed toward non-carbon energy systems, supplemented by other funds dedicated specifically to alternative energy development, it will be economically feasible for developing countries to turn away from fossil-fuel intensive paths, achieving significant local environmental benefits at the same time.

efficiency standards regulations that mandate efficiency criteria for goods, such as fuel economy standards for automobiles.
technology transfer the process of sharing technological information or equipment, particularly among countries.

Box 13.3 U.S. Infrastructure Crumbles as Climate Extremes Become More Frequent

In the wake of a major 2021 winter storm causing extensive damage in Texas and other Southern states, "signs of the risks posed by increasingly extreme weather to America's aging infrastructure were cropping up across the country . . . As climate change brings more frequent and intense storms, floods, heat waves, wildfires and other extreme events, it is placing growing stress on the foundations of the country's economy: Its network of roads and railways, drinking-water systems, power plants, electrical grids, industrial waste sites and even homes . . . Much of this infrastructure was built decades ago, under the expectation that the environment around it would remain stable, or at least fluctuate within predictable bounds. Now climate change is upending that assumption . . . Sewer systems are overflowing more often as powerful rainstorms exceed their design capacity. Coastal homes and highways are collapsing as intensified runoff erodes cliffs. Coal ash, the toxic residue produced by coal-burning plants, is spilling into rivers as floods overwhelm barriers meant to hold it back. Homes once beyond the reach of wildfires are burning in blazes they were never designed to withstand."

Although it may seem strange that global "warming" would lead to unusually severe winter weather in usually warm Texas, the effects of climate change in destabilizing the polar vortex are seen by scientists as responsible for this unusual weather pattern. Developing resilient infrastructure to adapt to climate extremes means trillions of dollars in investment, but may carry great benefits both in terms of mitigating further damage through reduced emissions and protecting against the inevitable results of "locked-in" climate change.

Sources: Christopher Flavelle, Brad Plumer, and Hiroko Tabuchi, "Texas Blackouts Point to Coast-to-Coast Crises Waiting to Happen," *New York Times*, February 20, 2021; https://climatechange.ucdavis.edu/climate-change-definitions/what-is-the-polar-vortex/

13.3 Getting to Net Zero Emissions

As we have discussed in Chapters 8 and 12, in the case of cumulative pollutants such as carbon dioxide and other greenhouse gases, it is not sufficient to limit emissions. Current damages result from accumulated emissions over time, and to avoid further damages, emissions must be reduced to zero. In the case of greenhouse gases, the goal is sometimes stated as "Net Zero", meaning that any remaining emissions must be balanced by increased absorption of CO_2 from the atmosphere. We saw in Chapter 12 that in order to meet the Paris Climate Agreement targets global greenhouse gas emissions level need to fall to near zero, or even below zero, by the second half of the twenty-first century.

According to the IPCC, "global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate." Even at 1.5°C severe impacts are projected, including "increases in mean temperature in most land and ocean regions, hot extremes in most inhabited regions, heavy precipitation in several regions, and the probability of drought and precipitation deficits in some regions," but the impacts are less severe than with an increase of 2°C or more.[13] To limit warming to 1.5°C, the Net Zero goal needs to be achieved by about 2050.

Is it possible to do this, and what would be the economic costs and benefits associated with this rapid reduction of emissions? Meeting the climate change challenge requires both behavioral change and technological change. Economic policy instruments such as carbon taxes, cap-and-trade, and subsidies use incentives to motivate changes in behavior. Economic policies can create powerful incentives for technological changes. Carbon taxes or cap-and-trade systems motivate individuals and firms to seek out lower-emissions alternatives, which in turn motivates the development of new technologies for improved efficiency and renewable energy.

It is worthwhile to consider what needs to be done in response to climate change from a technical perspective—not just to gain a greater understanding of the issues but to also gain some insights for appropriate policies. Once we have a sense of which policies offer the greatest carbon reduction potential, we can analyze the economic costs and benefits associated with these policies.

Potential for Emissions Reduction

The technical potential for reduction to net zero exists, and does not depend on future technological developments. It can be done with known, existing technologies. A report from Princeton University's Andlinger Center for Energy and the Environment identified five different technological pathways to net-zero emissions by 2050 for the United States. The authors conclude:

> We find that each net-zero pathway results in a net increase in energy-sector employment and delivers significant reductions in air pollution, leading to public health benefits that begin immediately in the first decade of the transition . . . a successful net-zero transition could be accomplished with annual spending on energy that is comparable or lower as a percentage of GDP to what the nation spends annually on energy today. However, foresight and proactive policy and action are needed to achieve the lowest-cost outcomes.[14]

The Princeton study cited six major areas of high potential for emissions reduction or carbon absorption:

1. End-use efficiency and electrification, including industrial efficiency, electric vehicles, and efficient heat pumps.
2. Clean electricity, including increasing wind and solar installations by 300-500%, improved battery storage, and (in some scenarios) new nuclear capacity
3. Use of biomass and methane from agricultural wastes, with hydrogen as an energy carrier.
4. Carbon capture for industrial utilization and storage.
5. Reducing non-CO_2 emissions of methane, nitrous oxide (N_2O), and fluorocarbons.
6. Enhanced land sinks through improved forest management and regenerative agricultural practices.[15]

On a global scale, it is similarly possible to identify policies that could cumulatively add up to a reduction to net zero emissions by mid-century. Project Drawdown[16] has estimated the potential for such major reductions, including:

- Onshore wind turbines, with the potential to reduce emissions by 147 Gigatons (Gt) CO_2 equivalent between 2020 and 2050.

- Utility-scale solar photovoltaics (117 Gt reduction potential).
- Electric cars, efficient trucks and aviation (68 Gt reduction potential)
- Reduced food wastes and plant-rich diets, (185 Gt reduction potential).
- Investment in health and education, resulting in slowing population growth (85 Gt reduction potential).
- Tropical and temperate forest restoration (113 Gt reduction potential).
- Improved clean cookstoves and distributed and concentrated solar power (164 Gt reduction potential).
- Refrigerant management and alternative refrigerants (108 Gt reduction potential).
- Improved land management, including regenerative agricultural techniques, managed grazing, and agroforestry (278 Gt reduction potential).[17]

Together with other policies in transportation, industry, and land use, the total reductions could amount to 1576 Gigatons CO_2 equivalent over the 2020-2050 period, enough to achieve the goal of no more than 1.5°C global warming.

Of course, the implementation of these policies would involve a major commitment and trillions of dollars in investment. But many of these investments would have a considerable economic payback in terms of reduced fuel use, as well as other “collateral” environmental benefits such as reduced ground-level air pollution, improved public health, and improved food security and nutrition. (See Box 13.4 for some implications of the Princeton recommendations for the U.S.)

Box 13.4 Can the U.S. Reach Net Zero Emissions?

Can the United States cut its net greenhouse gas emissions to zero by 2050? That goal has been endorsed by President Biden as well as numerous states and businesses. But what would it involve?

- In 2020, energy companies installed 42 gigawatts of new wind turbines and solar panels, a record. That annual rate would need to nearly double over the next decade, and then increase further, to achieve the net zero goal.
- The capacity and sophistication of the nation's electric grid would have to be significantly expanded to accommodate the new power inputs.
- Electric vehicles would need to increase from around 2 percent to at least 50% of new cars sold by 2030.
- Almost all remaining coal-burning power plants would have to be shut down by 2030.
- Efficient electric heat pumps would need to be installed in about 25% of homes, doubling the current number by 2030.
- Facilities for carbon capture and storage and the production of hydrogen fuel would have to be developed, in preparation for wider deployment after 2030.

The task is made easier by the rapidly falling cost of wind and solar technologies. While many fossil-fuel related jobs would be displaced, millions of new jobs would be created in areas such as wind farm construction and building retrofit. Land use would be an issue: while in theory, adequate space exists for new wind farms and solar facilities, local opposition to siting could grow as the facilities become ubiquitous. For this reason, some researchers have developed scenarios in which renewable energy sources are supplemented with advanced nuclear reactors and natural gas plants equipped with carbon capture and storage—technologies that are not yet economically viable.

Sources: Brad Plumer, "To Cut Emissions to Zero, U.S. Needs to Make Big Changes in Next 10 Years," *The New York Times*, December 15, 2020; Larson et al., 2020.

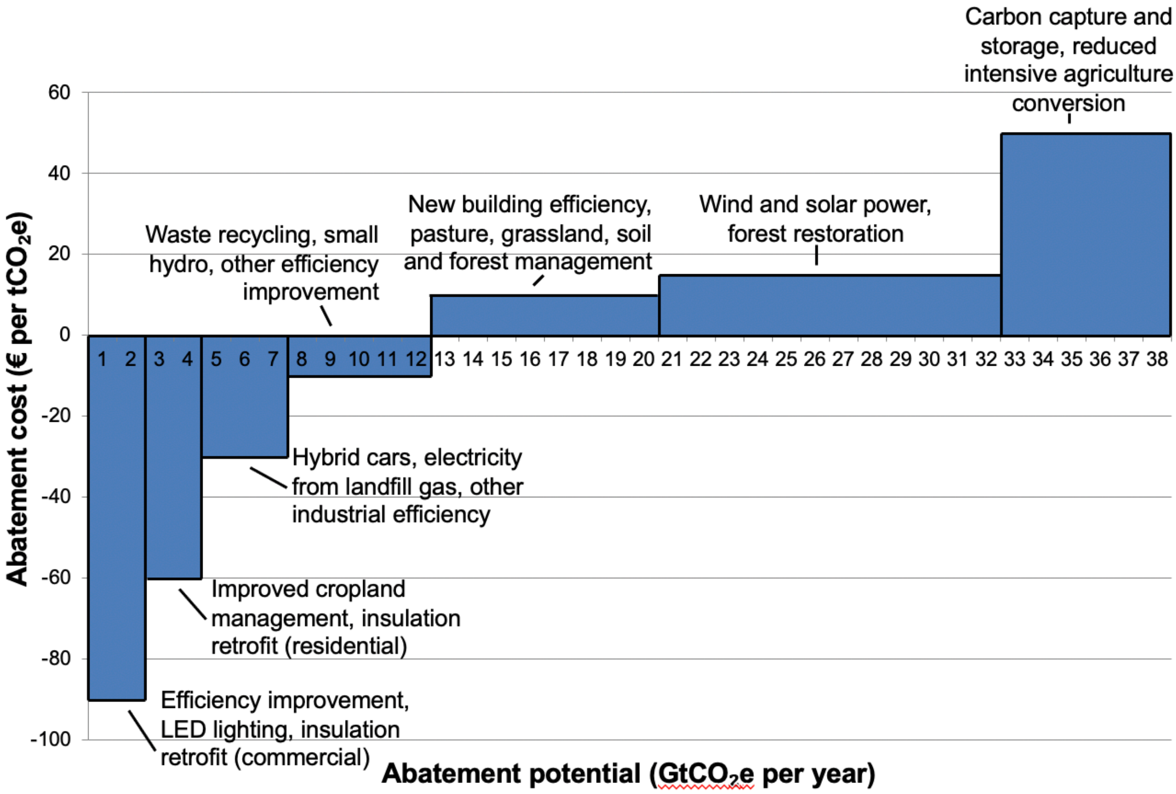
Greenhouse Gas Abatement Costs

The technical possibilities for emissions reduction have varied costs implications. Obviously, some technologies would be cheaper than others to implement. For a more complete economic analysis, we also need to consider costs.

One well-known analysis, by McKinsey & Company, estimates both the costs and the potential carbon reduction of more than 200 greenhouse gas mitigation, or abatement, options on a global scale. The various options are arranged in order of cost, from lowest cost to highest. The economic logic is that it makes sense to implement actions that reduce carbon at the lowest per-unit costs first and then proceed to more costly actions. The results of their analysis are presented in Figure 13.6. The costs are estimated in euros, but the analysis covers worldwide reduction possibilities.[18]

This figure takes a little explanation. The *y*-axis indicates the cost range for each abatement option, measured in euros per ton of CO_2 reduction per year (or an amount equivalent to one ton of CO_2 for reductions in other gases such as methane). The thickness of the bar represents the amount of CO_2 emissions that can be avoided by each action. The cost of policies such as building insulation, increased efficiency, improved cropland management, and waste recycling is in the *negative* range. This means that these policies would actually save money, regardless of their effect on CO_2 emissions. So even if we did not care about climate change and the environment, it would make sense to insulate buildings, increase appliance efficiency, develop regenerative agriculture, and recycle wastes, solely on long-term financial grounds.

Figure 13.6 Global Greenhouse Gas Abatement Cost Curve for 2030



Source: Adapted from McKinsey & Company, 2009.

The *x*-axis tells us the cumulative reduction in CO_2 equivalent emissions, relative to a BAU ("business-as-usual") scenario, if we were to implement all the actions to the left of any point on the axis. Thus if we were to implement all negative-cost options, including improving efficiency of air-conditioning, lighting systems, and water heating, improving cropland management, and waste recycling, total CO_2 equivalent reduction would be about 12 billion tons (Gt) per year, all while saving money!

Moving farther to the right, actions are identified that do entail positive costs. In other words, for all these other actions it does cost us money to reduce CO_2 emissions. Figure 13.6 shows all actions that reduce CO_2 emissions for a cost of less than €60 per ton, including expanding wind and solar energy, improved forest management and reforestation, expanding nuclear energy, and implementing carbon capture and storage (CCS).

If all these actions were implemented, total CO_2-equivalent reduction would be 38 billion tons per year. Total global CO_2 equivalent emissions, including all greenhouse gases and emissions from land use change, are currently about 50 billion tons per year, projected to rise to about 70 Gt by 2030 in a business-as-usual scenario. Thus instead of emitting 70 Gt per year in 2030, we would be emitting only 32 Gt—a decrease of 18 Gt below current levels and more than 50% below business-as-usual projected levels. Further reduction could be achieved at slightly higher cost, especially by more extensive expansion of wind and solar energy. (This analysis does not take into account likely cost reductions for renewable energy, and since the analysis was developed these costs have indeed fallen further, as discussed in Chapter 11).

The total cost of implementing all options in Figure 13.6, considering that some options actually save money, is estimated to be less than 1 percent of global GDP in 2030. The report notes that delaying action by just 10 years makes keeping warming under 2°C extremely difficult.

Policy recommendations to achieve the reductions represented in Figure 13.6 include:

- Establish strict technical standards for efficiency of buildings and vehicles.
- Establish stable long-term incentives for power producers and industrial companies to invest in and deploy efficient technologies.
- Provide government support for emerging efficiency and renewable energy technologies, through economic incentives and other policies.
- Ensure efficient management of forests and agriculture, in both developed and developing countries.[19]

These recommendations imply that instituting a carbon price is only a part of a broader policy approach. A carbon tax or cap-and-trade program would create an incentive for the actions in Figure 13.6, but it does not guarantee that they will occur. In theory, we should already be using all the negative-cost options even in the absence of a carbon price, yet we are not. Standards and mandates can be an effective complement to a carbon price to ensure that cost-efficient actions are implemented. Potential policies could include efficiency standards for appliances, lighting, and building insulation.

How reliable is this abatement cost curve analysis? The McKinsey study has been subject to criticism both for underestimating and overestimating some costs.[20] Nonetheless, abatement costs curves such as those presented in the McKinsey study illustrate the basic principle that many low-cost or no-cost actions could be taken to reduce carbon emissions. A more recent study reviewing estimates of abatement costs found that options with costs less than $100/ton included solar, wind, reforestation, controlling methane flaring, land use management, soil and livestock management, and the Obama administration's Clean Power Plan (abandoned under the Trump administration but likely to be reinstituted in the Biden administration). The study also points out that costs are likely to fall significantly over time with increased investment in areas such as wind and solar power.[21]

13.4 Climate Change Policy in Practice

Climate change is an international environmental issue. In economic theory terms, as we noted in Chapter 12, climate change is a public good issue, requiring global collaboration to achieve effective results. Since the United Nations Framework Convention on Climate Change (UNFCCC) was first established in 1992, there have been extensive international discussions, known as "Conferences of the Parties" or COPs, aimed at reaching a global agreement on emissions reduction (see Table 13.2).

Table 13.2 Important Events in International Climate Change Negotiations

Year, Location	**Outcome**
1992, Rio de Janeiro	UN Framework Convention on Climate Change (UNFCCC). Countries agree to reduce emissions with "common but differentiated responsibilities."
1995, Berlin	The first annual Conference of the Parties to the framework, known as a COP. U.S. agrees to exempt developing countries from binding obligations.
1997, Kyoto	At the third Conference of the Parties (COP-3) the Kyoto Protocol is approved, mandating developed countries to cut greenhouse gas emissions relative to 1990 baseline emissions by 2008-2012 period.
2001, Bonn	COP-6 reaches agreement on terms for compliance and financing. Bush administration rejects the Kyoto Protocol; U.S. is only an observer at COP-6.
2009, Copenhagen	COP-15 fails to produce a binding post-Kyoto agreement, but declares the importance of limiting warming to under 2°C. Developed countries pledge $100 billion in climate aid to developing countries.
2011, Durban	(COP-17) Participating countries agree to adopt a universal legal agreement on climate change as soon as possible, and no later than 2015, to take effect by 2020.
2015, Paris	(COP-21) 195 nations sign the Paris Agreement, providing for worldwide voluntary actions (known as Nationally Determined Contributions or NDCs)

The Paris Agreement of 2015

At the Copenhagen COP-15 conference in 2009, developed and developing countries reached deadlock on how to allocate requirements for emissions reduction. After encountering resistance to mandatory emissions reductions, negotiators came up with the idea that countries would instead propose their own voluntary goals, no matter how low or high—the hope being that countries would eventually feel "peer-pressure" to set the most ambitious possible goals within their reach. This new negotiating strategy laid the foundations for the global agreement reached at the twenty-first Conference of the Parties (COP-21) in Paris in 2015. In the months that preceded the COP-21, 186 countries submitted their NDCs—**nationally determined contributions**—indicating their willingness to contribute to the reduction of global CO_2 emissions.

nationally determined contribution (NDC) a voluntary planned reduction in CO_2 emissions, relative to baseline emissions, submitted by participating countries at the Paris Conference of the Parties (COP-21) in 2015.

The Paris Agreement, negotiated by 195 national delegations, formally expressed the global aim of holding temperatures to no more than 2°C above preindustrial levels, with a more ambitious target of 1.5°C. Since the total of country pledges (NDCs) was not sufficient to secure the global goal of keeping warming under 2°C, the agreement included five-year cycles for countries to review their goals and ratchet up their targets, in order to reach more ambitious goals. The negotiating process has been designed to put pressure on every country to comply with its own pledges and to increase them over time.

A strong transparency and accountability regime is built into the agreement, based on regular inventories, regular reporting of the progress countries are making toward their targets, and regular review by expert teams. The Paris Agreement entered into force, with over 80 countries representing over 60 percent of global emissions ratifying the agreement by the end of 2016, just a year after it was negotiated, a record speed for international agreements. It remains in force—though compliance with the targets is voluntary. (In November 2020 the Trump administration formally withdrew from the Paris Agreement, but the incoming Biden administration immediately re-joined in January 2021.) A related binding agreement establishing specific timetables to eliminate the production of hydrofluorocarbons (HFCs), powerful greenhouse gases used in air-conditioners and refrigerators, was agreed on in October 2015.[22]

The Paris Agreement also provides for continuing financial and technical support to developing countries to help them adapt to the disruptive consequences of climate change, as well as support for a transition away from fossil fuels toward cleaner renewable energy sources. The agreement included a loss-and-damage clause recognizing the importance of addressing the adverse effects of climate change in developing countries. While the agreement does not accept liability or provide for compensation, it does offer several conditions where support may be given. Starting in 2020, industrialized nations have pledged $100 billion a year in financial and technical aid to developing countries to fight climate change.[23]

Advocates of equitable climate policy have warned that $100 billion will fall far short of what is really needed, and that a conservative figure would be closer to $600 billion, which is about 1.5 percent of the GDP of industrialized nations. Some of the estimates, by organizations from the World Bank to the International Applied Systems Analysis in Vienna, suggest that the sums needed would be as high as $1.7 or even $2.2 trillion per year.[24]

Country Commitments for Action

Because the Paris commitments were made on a voluntary basis, there are discrepancies in the approaches adopted by different countries. Some countries have chosen their baseline year as 2005, and others as 1990, and calculate their future emissions with reference to that baseline. Other countries have calculated their future emissions compared to what they would have been emitting in a business-as-usual (BAU) scenario. Some countries have pledged reductions of CO_2 emissions in absolute terms, i.e., reductions in actual volumes of emissions, and others in relative terms, or reductions in **carbon intensity** (carbon emissions per unit of GDP).

carbon intensity a measure of carbon emissions per unit of GDP.

Reductions in carbon intensity partly "decouple" emissions from growth, but overall emissions can still increase with economic growth. This option has generally been chosen by developing countries, including the biggest ones, such as China and India, as they are unwilling to commit to measures that would slow down their economic growth. They seek an increasing decoupling between economic growth and the growth of CO_2 emissions, but in the meantime CO_2 emissions will continue to grow in most of these countries. This introduces the important idea of "peaking" emissions in developing countries—allowing total emissions to grow only for a specific period, after which they must decline. China has committed to peaking emissions by 2030.

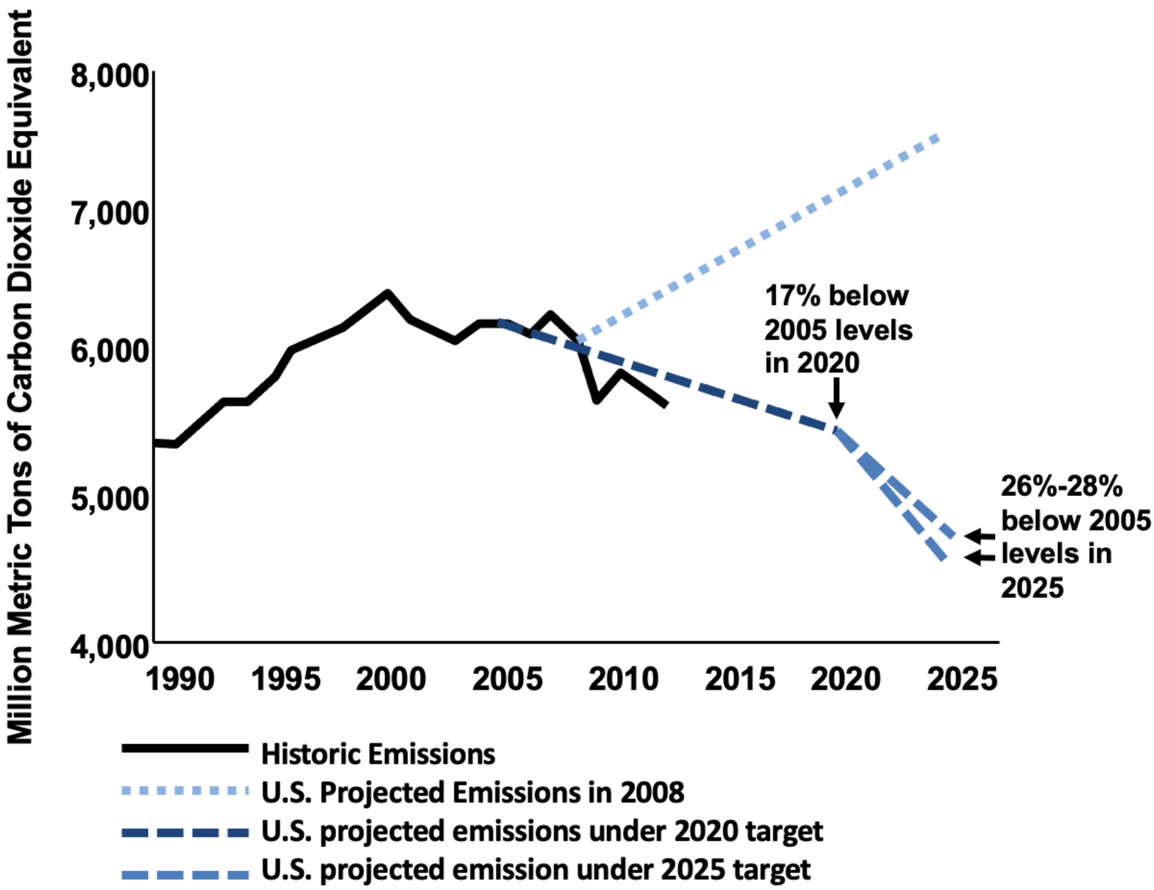
Commitments of Major Emitters

The NDC submitted in March 2015 by the U.S. to the UNFCCC states that "the United States intends to achieve an economy-wide target of reducing its greenhouse gas emissions by 26−28 per cent below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%."[25] Stated U.S. emissions targets are shown in Figure 13.7. These would continue and accelerate a declining trend already evident in actual U.S. emissions. In August 2015, the Obama administration announced the Clean Power Plan, which aimed to reduce CO_2 emissions from the power sector to 32 percent below 2005 levels by 2030.[26] In March 2017, the Trump administration issued an executive order to repeal the Clean Power Plan, throwing U.S. climate actions into doubt—although U.S. emissions continued to decline based on market developments and state and regional policies (see, for example, discussion of the Northeast and California commitments in the section on "Regional, National, and Local Actions" below). By 2018, US emissions of CO_2 equivalent were 10% below 2005 levels, and they have continued to fall (see Box 13.5).[27] The Biden administration is committed to further reductions, aiming for net zero emissions in 2050.

China's official commitment includes:

- Peaking carbon dioxide emissions by around 2030 and making best efforts to peak earlier.
- Lowering carbon intensity (carbon dioxide emissions per unit of GDP) by 60 percent to 65 percent from the 2005 level.
- Increasing the share of non-fossil fuels in primary energy consumption to around 20 percent.
- Increasing forest stock volume by around 4.5 billion cubic meters above the 2005 level.[28]

Figure 13.7 U.S. Emissions Targets



Source: U.N. Framework Convention on Climate Change, http://unfccc.int/2860.php.

Note: In 2018, actual U.S. emissions were 10% below 1995 levels.

The European Union and its Member States are committed to a binding target of reducing greenhouse gas emissions at least 55 percent by 2030 compared to 19. According to the European Commission:

> The EU is well on track to meet its 20% emissions reduction target for 2020. EU greenhouse gas emissions were reduced by 24% between 1990 and 2019, while the economy grew by around 60% over the same period. From 2018 to 2019, emissions declined by 3.7%.[29]

Commitments by the U.S., China, the E.U. and other major emitters are shown in Table 13.3. As noted in Box 13.5, the year 2020 saw a major decline in global emissions as a result of the COVID-19 crisis, but it is not clear if this is a one-time event or if it could serve as a starting point for continued lower emissions trajectories.

Table 13.3 National Commitments by Major Emitters

	Base Level	**Reduction Target**	**Target Year**	**Land-Use and Technology**
China	2005	Emissions peaking; 60-65% reduction in carbon intensity	Before 2030	Increase forest stock volume by around 6 billion cubic meters; increase installed capacity of wind and solar power to 1,200 GW
United States	2005	26-28%	2030	“Net-net” approach including land use emissions and removals
EU	1990	55%	2030	Includes land-use and forestry
India	2005	33-35% reduction in carbon intensity	2030	Includes land use and forestry
Russia	1990	25-30%	2030	Target depends on the “maximum absorption capacity of forests”
Japan	2013	26%	2030	Includes forest and agricultural sectors

Source: climateactiontracker.org/

Box 13.5 A Big 2020 Emissions Decline – and a Green Recovery?

In 2020 the global economy was hit heavily by the COVID-19 crisis, with a significant decline in GDP and also in energy demand. According to the International Energy Agency: "In our estimate for 2020, global electricity demand falls by 5%, with 10% reductions in some regions. Low-carbon sources would far outstrip coal-fired generation globally, extending the lead established in 2019. Global CO_2 emissions are expected to decline by 8%, or almost 2.6 gigatonnes (Gt), to levels of 10 years ago. Such a year-on-year reduction would be the largest ever, six times larger than the previous record reduction of 0.4 Gt in 2009 – caused by the global financial crisis – and twice as large as the combined total of all previous reductions since the end of World War II. As after previous crises, however, the rebound in emissions may be larger than the decline, unless the wave of investment to restart the economy is dedicated to cleaner and more resilient energy infrastructure."

A report by the Rhodium Group found that, "2020 was an unusual year—in more ways than we can count—with lives upended by a global pandemic and its economic fallout. With emissions down 21% below 2005 levels, this means the U.S. is expected to far exceed its 2020 Copenhagen Accord target of a 17% reduction below 2005 levels. However, 2020 should not in any way be considered a down payment toward the U.S. meeting its 2025 Paris Agreement target of 26%-28% below 2005 levels."

The shape of the post-COVID economic recovery will determine whether emissions targets can be met. The pandemic created a one time "bonus" of carbon emissions reduction—for all the wrong reasons. It will be up to policymakers to seize the opportunity to "build back greener" with a massive shift to energy efficiency and renewable energy sources.

Sources: IEA, 2020; Rhodium Group, 2020; Caitlin O'Kane, "Greenhouse gas emissions in the U.S. saw largest drop since World War II due to COVID-19 shutdowns", CBS News, January 12, 2021, https://www.cbsnews.com/news/greenhouse-gas-emissions-drop-united-states-covid-19/

How Adequate or Inadequate are the Commitments?

An independent organization, Climate Action Tracker, provides assessments and ratings of submitted NDCs. According to its grading system, most countries are falling well short of reaching their specified targets. The USA was rated "critically insufficient" as of 2020 (but this preceded new policies by the Biden administration). China was rated as "highly insufficient," and the European Union was rated as "insufficient." The Climate Action Tracker has also rated Japan and South Africa as "highly insufficient" and Canada, Australia, Mexico, and Brazil as "insufficient." India is one of the few countries that receives a "2° compatible" rating.[30]

As we saw in Chapter 12 (Figure 12.8), even if all countries meet their existing pledges under the Paris Climate Agreement, the global average temperature would likely rise 2.3 to 2.6°C. Considerable strengthening of the pledges would clearly be needed to keep overall emissions on a 2°C track—let alone 1.5°C.[31] (For a scientific perspective on the importance of reaching a 2°C or even 1.5°C target, see Box 13.6.)

To see what is required to achieve a 2°C or 1.5°C target, the concept of a **global carbon budget** is useful. A global carbon budget attempts to quantify the cumulative emissions of carbon that can be added to the atmosphere without exceeding specified temperature increases. To reach a 2°C target, it is necessary to keep within a cumulative global carbon budget of no more than 225 additional gigatons of carbon above 2020 levels—about 25 years of emissions at current rates. To reach the 1.5°C target, the budget would have to be a mere

65 gigatons—about 7 years of emissions at current rates.[32] The current Paris commitments are inadequate to meet these goals without a significant strengthening of the commitments in future rounds of negotiation.

global carbon budget the concept that total cumulative emissions of carbon must be limited to a fixed amount in order to avoid catastrophic consequences of global climate change.

Box 13.6 Avoiding Catastrophic Losses

The Paris Agreement codified a goal of no more than 2°C of temperature increase, with a more ambitious goal of no more than 1.5°C. What is the reason for these targets? The urgency of reaching the temperature targets selected in Paris is indicated by a scientific study comparing these targets to the probability that various catastrophic and irreversible losses will occur, such as the loss of alpine glaciers or the Amazon rainforest. The authors assessed the available research to determine the temperature range at which each impact is expected to occur. This is shown in Figure 13.8.

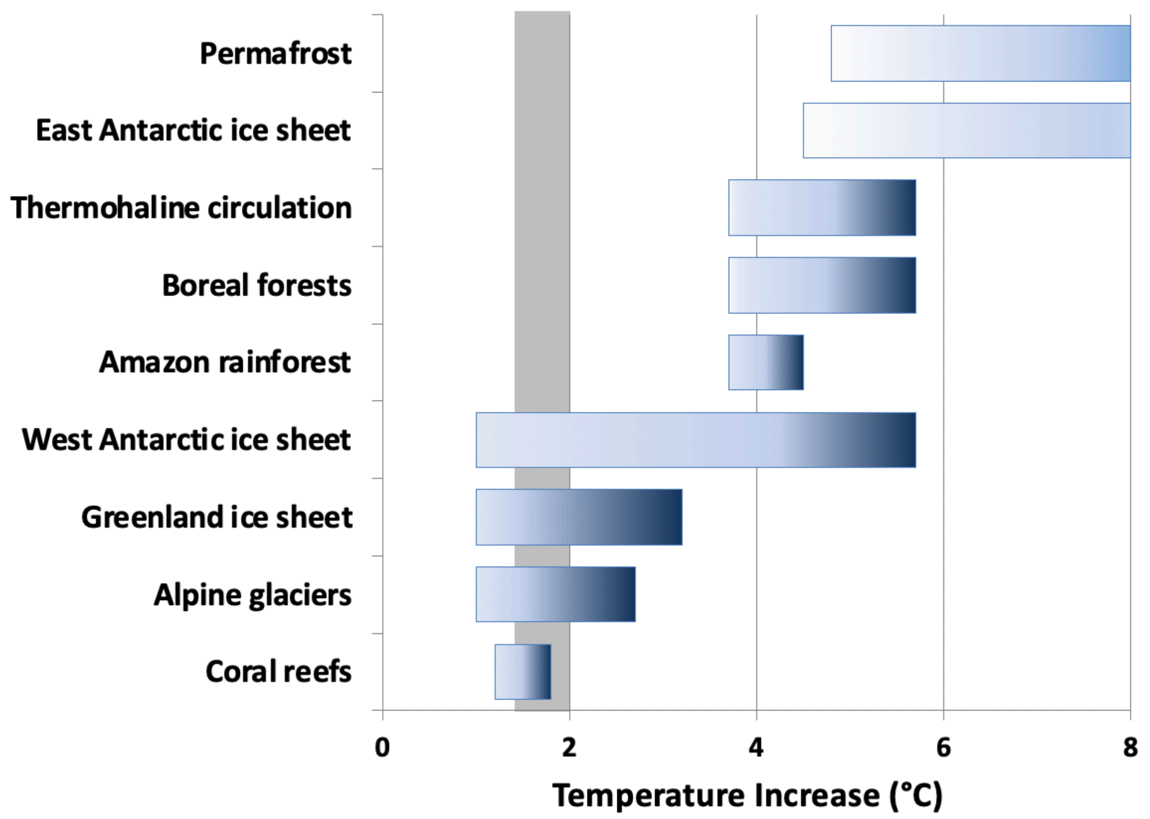
The horizontal bar for each impact reflects scientific uncertainty about how much temperatures must increase to make that impact inevitable. The darker the shading, the higher the probability the impact will occur. So, for example, if global average temperatures increase only 1°C there is a small probability that alpine glaciers will be lost. But if temperatures increase more than 2.5°C it is nearly certain that alpine glaciers will be lost based on the current research.

The vertical bar represents the range of the Paris climate targets, between 1.5°C and 2°C. Comparing these targets to the various impacts, we see that limiting the temperature increase to 1.5°C offers a chance that the world's coral reefs will not be lost. But at 2°C it is virtually certain that coral reefs will not survive. If the 2°C target can be met, the outlook is better for avoiding the loss of alpine glaciers, the Greenland ice sheet, and the West Antarctic ice sheet, although considerable uncertainty remains. At 4−6°C the Amazon and boreal forests, the East and West Antarctic ice sheets, and permafrost are all endangered, as is the thermohaline circulation in the oceans, including the Gulf Stream, which keeps much of Europe relatively temperate despite high latitudes. The article concludes that achieving the Paris targets, while ambitious, is therefore essential:

> Beyond 2°C the course would be set for a complete deglaciation of the Northern Hemisphere, threatening the survival of many coastal cities and island nations. Global food supply would be jeopardized by novel extreme-event regimes, and major ecosystems such as coral reefs forced into extinction. Yet, staying within the Paris target range, the overall Earth system dynamics would remain largely intact. Progressing [further] on the other hand, with global warming reaching 3–5°C, would seriously [risk most impacts]. For warming levels beyond this range, the world as we know it would be bound to disappear.

Source: Schellnhuber *et al*., 2016.

Figure 13.8 The Paris Climate Targets and Catastrophic Global Impacts



Source: Schellnhuber *et al*., 2016.

Note: The vertical bar represents the range of the Paris climate targets, from 1.5°C to 2.0°C.

REGIONAL, NATIONAL, AND LOCAL ACTIONS

While international efforts to establish a framework for emissions reduction have continued, many effective climate policies have been implemented at regional, national, and local levels. These include:

- The European Union set up a carbon trading system that went into effect in 2005 (see Box 13.7).
- Carbon trading systems have also been established in several regions in the United States. The Regional Greenhouse Gas Initiative (RGGI) is a cap-and-trade program for emissions from power plants in nine Northeastern states. Permits are mostly auctioned off (some are sold at a fixed price), with the proceeds used to fund investments in clean energy and energy efficiency. Permit auction prices have ranged from about $2 to $5 per ton of CO_2.[33] In 2013, California initiated a legally binding cap-and-trade scheme. "The program imposes a greenhouse gas emission limit that will decrease by two percent each year through 2015, and by three percent annually from 2015 through 2020."[34]
- Carbon taxes have been instituted in more than 40 countries, including a tax on new vehicles based on their carbon emissions in South Africa (enacted in 2010), a carbon tax

on fuels in Costa Rica (enacted in 1997), a carbon tax in Chile (enacted in 2014), and carbon taxes in the Canadian provinces of Quebec, Alberta, and British Columbia, extended to all of Canada in 2019 (see Box 13.8).[35]

- In early 2021, China initiated the world's largest carbon market, "giving financial incentives to power plant operators to reduce their emissions. The government plans to expand the market in the next five years to cover about 80% of China's carbon dioxide emissions — accounting for a fifth of the world's total emissions."[36]
- Networks of cities have also organized to address climate change. The C40 network of megacities, representing 25 percent of global GDP, has focused on measuring and reducing urban emissions. Another network, the Global Covenant of Mayors, a global coalition of over 10,000 cities, has similar goals.[37] By 2050, between 65 percent and 75 percent of the world population is projected to be living in cities, with more than 40 million people moving to cities each year. Urban population will grow from approximately 3.5 billion people now to 6.5 billion by 2050. Estimates suggest that cities are responsible for 75 percent of global CO_2 emissions, with transport and buildings being among the largest contributors.[38]

Box 13.7 The European Union Carbon Trading System

In 2005 the European Union (EU) launched its Emissions Trading Scheme (EU-ETS), which covers more than 11,000 facilities that collectively emit nearly half the EU's carbon emissions. It sets a cap on emissions from emission-intensive activities (i.e. electricity and heat production, cement manufacture, iron and steel production, oil refining and other industrial activities) and aviation. Within the cap, companies can reduce their emissions and trade emission allowances, to achieve greenhouse gas emission reductions at least cost.

Despite some price volatility, the initial phases of the EU-ETS led to a reduction in emissions from large emitters of 28 percent between 2005 and 2018 , followed by a further sharp drop in 2019: "Total ETS emissions from stationary installations declined by 9.1 % between 2018 and 2019, the largest drop in a decade, driven by a strong decrease in coal use for power production." As a part of the European Green Deal, the ETS greenhouse gas emission reduction target will be increased to at least 55% by 2030.

Sources: European Environment Agency, 2020, www.eea.europa.eu/themes/climate/the-eu-emissions-trading-system/the-eu-emissions-trading-system; European Commission, http://ec.europa.eu/clima/policies/ets/index_en.htm.

Box 13.8 British Columbia's Carbon Tax: A Success Story

In 2008 the Canadian province of British Columbia, on the Pacific Coast, implemented a carbon tax of $10 per ton of CO_2 (Canadian dollars), covering approximately 70% of provincial greenhouse gas emissions. The tax rose incrementally in subsequent years, until it reached $40 in 2019.

The province has cut income and corporate taxes to offset the revenue it gets from taxing carbon. British Columbia now has the lowest personal income tax rate in Canada, and one of the lowest corporate rates among developed countries. "Additional revenues generated from increasing the carbon tax are used to provide carbon tax relief and protect affordability, maintain industry competitiveness, and encourage new green initiatives."

In the first six years of its implementation, consumption of fuels dropped by between 5 percent and 15 percent in B.C., while it rose by about 3 percent in the rest of Canada. During that time, GDP per capita continued to grow in British Columbia, at a slightly higher pace than for the rest of Canada. As of 2018, the Canadian government extended the carbon tax to the whole of Canada, allowing for flexibility by individual provinces and including a rebate of revenues to taxpayers.

Sources: The World Bank, "British Columbia's Carbon Tax Shift: An Environmental and Economic Success," Sept. 10, 2014; Government of British Columbia, "British Columbia's Carbon Tax" www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/carbon-tax; Murray and Rivers, 2015; Metcalf, 2015; www.theguardian.com/environment/climate-consensus-97-per-cent/2018/oct/26/canada-passed-a-carbon-tax-that-will-give-most-canadians-more-money.

Forests, Wetlands, and Soils

While the major focus of climate policy has been on the reduction of emissions from carbon-based fuels, the role of forests, wetlands, and soils is also crucial. Currently about 11 percent of greenhouse gas emissions come from forest and land use change, especially tropical forest loss.[39] International negotiations have also led to the adoption of a program known as **REDD (Reduction of Emissions from Deforestation and Degradation)**. The Copenhagen Accord (2009) acknowledged the need to act on reducing emissions from deforestation and forest degradation and established a mechanism known as REDD-plus. The Accord emphasizes funding for developing countries to enable action on mitigation, including substantial finance for REDD-plus, adaptation, technology development and transfer, and capacity building (discussed further in Chapter 19).

Reduction of Emissions from Deforestation and Degradation (REDD) a United Nations program adopted as part of the Kyoto process of climate negotiations, intended to reduce emissions from deforestation and land degradation through providing funding for forest conservation and sustainable land use.

In addition to reducing emissions, forests and soils have huge potential for absorbing and storing carbon. The Earth's soils store 2,500 billion tons of carbon—more carbon than the atmosphere (780 billion tons) and plants (560 billion tons) combined. But it is estimated that soils have been depleted of 50 to 70 percent of their natural carbon in the last century. Globally, those depleted soils could reabsorb between 2 and 13 Gigatons of CO_2 equivalent per year, through regenerative agriculture, including polyculture, cover cropping, agroforestry, nutrient recycling, crop rotation, proper pasture management, and organic soil amendments like compost and biochar (discussed further in Chapter 16).[40]

Forests recycle carbon dioxide (CO_2) into oxygen; preserving forested areas and expanding reforestation can have a significant effect on net CO_2 emissions. Simply allowing existing forests to continue growing rather than cutting them down could sequester about 10 Gigatons of CO_2 equivalent per year.[41] Wetlands have a very high per-acre carbon storage potential, so protecting and restoring wetlands is a crucial component of effective climate policy.[42]

It is likely that this vast unexploited potential for carbon storage will be a major focus of future climate policy—a crucial factor in the effort to move from the intermediate "pledges" path in Figure 13.8 to the "goals" path necessary to hold global temperature change to no more than 2°C.

13.5 Other Climate Issues: Adaptation and Equity

In the final section of this chapter, we look at proposals for balancing carbon reduction with equity issues on a national and international scale. One of the major inequities associated with climate change is that the heaviest burdens of damage from increased climate instability including floods, drought, and more destructive storms will fall on the world's low income people, who have been least responsible for greenhouse gas emissions. Both the costs of adaptation to climate change and the responsibility to pay for emissions reduction need to be distributed equitably on a global level, which has been a major focus of discussions in international negotiations.

Adaptation to the Climate Change

The urgency and ability to institute adaptive measures varies across the world. It is the world's poor who face the greatest need to adapt but also most lack the necessary resources.

> [Climate change's] adverse impacts will be most striking in the developing nations because of their geographical and climatic conditions, their high dependence on natural resources, and their limited capacity to adapt to a changing climate. Within these countries, the poorest, who have the least resources and the least capacity to adapt, are the most vulnerable. Projected changes in the incidence, frequency, intensity, and duration of climate extremes (for example, heat waves, heavy precipitation, and drought), as well as more gradual changes in the average climate, will notably threaten their livelihoods—further increasing inequities between the developing and developed worlds.[43]

The Intergovernmental Panel on Climate Change (IPCC) has identified adaptation needs by major sectors, as shown in Table 13.4. Some of the most critical areas for adaptation include water, agriculture, and human health. Climate change is expected to increase precipitation in some areas, mainly the higher latitudes, including Alaska, Canada, and Russia, but decrease it in other areas, including Central America, North Africa, and southern Europe. A reduction in water runoff from snowmelt and glaciers could threaten the water supplies of more than a billion people in areas such as India and parts of South America.

Providing safe drinking water in these regions may require building new dams for water storage, increasing the efficiency of water use, and other adaptation strategies.

Table 13.4 Climate Change Adaptation Needs, by Sector

Sector	**Adaptation Strategies**
Water	- Expand water storage and desalination - Improve watershed and reservoir management - Increase water-use and irrigation efficiency and water re-use - Urban and rural flood management
Agriculture	- Adjust planting dates and crop locations - Develop crop varieties adapted to drought, higher temperatures - Improve land management to deal with floods/droughts - Strengthen indigenous/traditional knowledge and practice
Infrastructure	- Relocate vulnerable communities - Build and strengthen seawalls and other barriers - Create and restore wetlands for flood control - Dune reinforcement
Human health	- Health plans for extreme heat - Increase tracking, early-warning systems for heat-related diseases - Address threats to safe drinking water supplies - Extend basic public health services
Transport	- Relocation or adapt transport infrastructure - New design standards to cope with climate change
Energy	- Strengthen distribution infrastructure - Address increased demand for cooling - Increase efficiency, increase use of renewables
Ecosystems	- Reduce other ecosystem stresses and human use pressures - Improve scientific understanding, enhanced monitoring - Reduce deforestation, increase reforestation - Increase mangrove, coral reef, and seagrass protection

Source: IPCC, 2007; IPCC, 2014b.

Changing precipitation and temperature patterns have significant implications for agriculture. With moderate warming, crop yields are expected to increase in some colder regions, including parts of North America, but overall the impacts on agriculture are expected to be negative, and increasingly so with greater warming. In the U.S., climate change has worsened and lengthened the episodes of droughts in the Western States, notably California, which, as a result, has already forced farmers to adapt to less water-intensive crops, replacing orange groves and avocado trees with other tree crops, such as pomegranates or cactus-like dragonfruit.[44] Agricultural impacts are expected to be the most severe in Africa and Asia. More research is necessary to develop crops that can grow under anticipated drier weather conditions. Agriculture may need to be abandoned in some areas but expanded in others.[45]

The impacts of climate change on human health are already occurring. According to a study by the Stanford Institute for Economic Policy Research, "increased mortality from climate change will be highest in Africa and the Middle East."[46] The World Health Organization (WHO) has estimated that more than 140,000 people per year are already dying as a direct result of climate change, primarily in Africa and Southeast Asia. The WHO estimates that after 2030, climate change will result in 250,000 additional deaths per year, caused by malnutrition, malaria, diarrhea, and heat stress. Direct damage costs to health are estimated at between $2–4 billion per year by 2030. WHO policy recommendations include strengthening public health systems, including increased education, disease surveillance, vaccination, and preparedness.[47]

Various estimates exist for the cost of appropriate adaptation measures. The United Nations Environment Program (UNEP) calculates that the cost of adaptation for developing nations could rise to between $140 and $300 billion per year by 2030, and between $280 and $500 billion per year by 2050. These sums significantly exceed the $100 billion per year pledged by developed nations in the 2015 Paris Agreement. UNEP warns that there will be a significant finance gap, "likely to grow substantially over the coming decades, unless significant progress is made to secure new, additional and innovative financing for adaptation." Adaptation costs are already two to three times higher than current international public funding for adaptation.[48]

Greenhouse Development Rights

On a global scale, equity issues relate to income differences between countries as well as income distribution within countries. What principles should be used to determine how emissions reductions and financing of mitigation and adaptation costs should be allocated among countries? Various approaches are possible, taking into account fairness, efficiency, and the concept of universally shared rights to the global commons.[49] The **greenhouse development rights (GDR)** framework proposes that only those people living above a certain economic threshold of development should be obliged to address the climate change problem.[50] Those who live below the threshold should instead be allowed to focus on economic growth, without any climate obligations.

> **greenhouse development rights (GDR)** an approach for assigning the responsibility for past greenhouse gas emissions and the capability to respond to climate change.

The GDR analysis essentially develops a methodology for assigning each country's obligation to provide financing for an international climate change mitigation and adaptation fund. It considers two factors to determine a country's obligation:

- *Capacity*: The capacity of a country to provide financing is based on its GDP, and all income below a defined development threshold is excluded. The GDR analysis sets the development threshold at $7,500 per capita, a level that generally allows people to avoid the problems of severe poverty, such as malnutrition, high infant mortality, and low educational attainment.

- *Responsibility*: The GDR approach defines responsibility for greenhouse gas emissions as a country's cumulative emissions since 1990, the same baseline year used for the Kyoto Protocol. As with capacity, emissions associated with consumption below the development threshold are excluded from the responsibility calculation. Each country's share of the global responsibility is calculated by dividing its cumulative emissions by the global total.

According to this analysis, the United States, which has the greatest cumulative responsibility for emissions, would be allocated one-third of the global bill for addressing climate change. The European Union would receive more than one-quarter of the bill. Japan would be asked to finance about 8 percent of the response, China about 6 percent, and Russia about 4 percent. The least developed countries would collectively be asked to pay a negligible share of the global bill. These shares would change over time, as developing countries' share of global emissions as well as their capacity to respond increases (assuming successful development).

Following the principles suggested by the GDR proposal would be consistent with the principle of **climate justice** but would necessitate a substantial increase in the commitments of developed nations, well beyond the $100 billion included in the Paris agreement.

climate justice equitable sharing both of the burdens of climate change and the costs of policy responses.

13.6 Conclusion: Dimensions of Climate Policy

Climate change is an issue that embodies many of the analyses discussed in this text, including externalities, common property resources, public goods, renewable and nonrenewable resources, and the discounting of costs and benefits over time. It has economic, scientific, political, and technological dimensions. Economic analysis alone cannot adequately respond to a problem of this scope, but economic theory and policy have much to offer in the search for solutions.

An effective response to the climate change problem requires much more sweeping action on a global scale than anything so far achieved. But whether we are discussing local initiatives or broad global schemes, we cannot avoid the issue of economic analysis. Economic policy instruments that have the power to alter patterns of energy use, industrial development, and income distribution are essential to any plan for mitigating or adapting to climate change. As noted in Chapter 12, evidence of climate change impacts is already clear, and the issue will become more pressing as greenhouse gas accumulation continues and costs of damages and of climate adaptation rise (see Box 13.9). The tools of economic analysis will provide critical insights as the world grapples with this continuing crisis.

Box 13.9 For U.S. Coastal Cities, Climate Adaptation Starts Now

In August 2016, torrential downpours along the Gulf Coast led to deadly floods in Southern Louisiana. With $9 billion in estimated damages, this natural catastrophe qualified as the worst in the United States since Hurricane Sandy's $70 billion damages in October 2012. Hurricanes Harvey and Maria, in 2017, brought even heavier damages to Texas and Puerto Rico, in the range of $90-$100 billion each.[51]

Linking such "off-the-charts" episodes to climate disruption is not a simple cause-to-effect relation, but scientists' models can give orders of magnitude of probabilities for such events. What was considered a once-in-a-thousand-year occurrence is becoming a new reality that coastal regions need to cope with. The National Oceanic and Atmospheric Administration found that global warming increases the chances of such intense rains by 40 percent due to increased moisture in a warmer atmosphere.

Already, coastal cities around the United States are investing massively to prepare for future floods. Fort Lauderdale, Florida, is spending millions of dollars fixing battered roads and drains damaged by increasing tidal flooding. Miami Beach increased local fees to finance a $400 million plan that includes raising streets, installing pumps, and elevating sea walls. The cost of adapting to rising seas for the medium-size town of Norfolk, Virginia, has been estimated at about $1.2 billion, or about $5,000 for every resident.

These costs for individual cities imply that the order of magnitude of costs for the whole East Coast and Gulf Coast will be several trillions. 1.9 million shoreline homes worth a combined $882 billion might be lost to rising sea levels by 2100. According to some economic analysts, the possibility of a collapse in the coastal real estate market could rival the impacts of the dotcom and real estate crashes of 2000 and 2008. The Pentagon, too, faces major adaptation issues, as many naval bases are facing serious threats and their land is at risk of disappearing within this century.

Sources: Jonah Engel Bromwich, "Flooding in the South Looks a lot Like Climate Change," *New York Times*, August 16, 2016; Henry Fountain, "Scientists See Push From Climate Change in Louisiana Flooding," *New York Times*, September 7, 2016; Justin Willis, "Flooding of Coast, Caused by Global Warming, Has Already Begun," *New York Times*, September 3, 2016; Ian Urbina, "Perils of Climate Change Could Swamp Coastal Real Estate," *New York Times*, November 24, 2016.

SUMMARY

The climate crisis has reached the level of a global emergency, with economists as well as scientists calling for a response that can reduce greenhouse gas emissions to zero to avoid continuing and increased damage. Policies to respond to global climate change can be preventive or adaptive. One of the most widely discussed policies is a carbon tax, which would fall most heavily on fuels that cause the highest carbon emissions. The revenues from such a tax could be recycled to lower taxes elsewhere in the economy, or they could be used to assist people in lower income brackets, who will suffer most from higher costs of energy and goods.

Another policy option is tradable carbon emissions permits, which can be bought and sold by firms or countries, depending on their level of carbon emissions (also known as "cap-and-trade"). Both of these policies have the advantage of economic efficiency, but it can be difficult to obtain the political support necessary to implement them. Other possible policy measures include shifting subsidies from fossil fuels to renewable energy, strengthening energy efficiency standards, and increasing research and development on alternative energy technologies.

Estimates of greenhouse gas abatement costs indicate that numerous opportunities exist for actions that could reduce carbon emissions and also save households and businesses money, and that billions of tons of additional emissions can be avoided at low cost. More ambitious policies to achieve net zero emissions would involve a major commitment and trillions of dollars in investment. But many of these investments would have a considerable economic payback in terms of reduced fuel use as well as "collateral" environmental benefits such as reduced ground-level air pollution, improved public health, and improved food security and nutrition.

International negotiations have aimed at a global agreement to achieve drastic reductions in greenhouse gas emissions. The Paris Agreement of 2015 has been accepted by almost all the world's countries, but its provisions are based on voluntary pledges. It creates a framework for substantial reductions by industrialized countries, and for reduction of emissions intensity (emissions per unit GDP) by China, India, and other developing countries, with a target date for a "peaking" of emissions by China. A review process is intended to strengthen countries' commitments over time.

In addition to international commitments, many initiatives have been taken at regional, national and local levels, involving carbon taxes, cap-and-trade, and other emission reduction measures. Great potential for additional reductions exists through improving forest and agricultural practices, resulting in less emissions and increased carbon storage in forests and soils.

It is important to design equitable national and international climate change policies. The heaviest burdens of climate damage are likely to fall on the lowest income countries, who are also least responsible for past and current emissions. The "greenhouse development rights" framework proposes allocating the financing for climate change mitigation and adaptation based on each country's responsibility for past emissions and its economic capacity, while still allowing poor countries to achieve economic development.

Key Terms and Concepts

adaptive measures
cap-and-trade
carbon dividend
carbon leakage
carbon sinks
carbon tax
cost-benefit analysis
cost-effectiveness analysis
distributionally neutral tax shift
efficiency standards
elasticity of demand
greenhouse development rights (GDR)
global carbon budget
nationally determined contribution (NDC)
pollution taxes
preventive measures
price volatility
progressive taxes
reduction of emissions from deforestation and degradation (REDD)
regressive tax
revenue-neutral tax shift

technology transfer
transferable (tradable) permits

Discussion Questions

1. What are the advantages and disadvantages of carbon taxes and cap-and-trade systems? Are there situations in which one should be favored over the other? What are the main barriers to effective climate policy implementation?
2. Many countries, states, and localities have adopted a goal of net-zero emissions, often targeting the year 2050 to achieve this. How realistic are these goals? What kinds of policies would be most effective to achieve them?
3. The Paris Agreement of 2015 sets goals for holding global climate change to no more than 2°C, with a preferred goal of 1.5°C. How effective are the commitments that countries have made towards these goals? What mechanisms and policies might strengthen these commitments in future?

Exercises

1. Suppose that under the terms of an international agreement, U.S. CO_2 emissions are to be reduced by 200 million tons and those of Brazil by 50 million tons. Here are the policy options that the United States and Brazil have to reduce their emissions:

United States:

Policy Options	Carbon Reduction (million tons carbon)	Cost ($ billion)
A: Efficient machinery	60	12
B: Reforestation	40	20
C: Replace coal-fueled power plants	120	30

Brazil:

Policy Options	Carbon Reduction (million tons carbon)	Cost ($ billion)
A: Efficient machinery	50	20
B: Protection of Amazon forest	30	3
C: Replace coal-fueled power plants	40	8

a) Which policies are most efficient for each country in meeting their reduction targets? How much will be reduced using each option, at what cost, if the two countries must operate independently? Assume that any of the policy options can be partially implemented at a constant marginal cost. For example, the United States could choose to reduce carbon emissions with efficient machinery by 10 million tons at a cost of $2 billion. (Hint: start by calculating the average cost of carbon reduction in dollars per ton for each of the six policies).
b) Suppose a market of transferable permits allows the United States and Brazil to trade permits to emit CO_2. Who has an interest in buying permits? Who has an interest in selling permits? What agreement can be reached between the United States and Brazil so that they can meet the overall emissions reduction target of 250 million tons at the least cost? Can you estimate a range for the price of a permit to emit one ton of carbon? (Hint: use your average cost calculations from the first part of the question.)

2. Suppose that the annual consumption of an average American household is 1,000 gallons of gasoline and 200 Mcf (thousand cubic feet) of natural gas. Using the figures given in Table 13.1 on the effects of a carbon tax, calculate how much an average American household would pay per year with an added tax of $50 per ton of carbon dioxide if there was no initial change in quantity demanded. (Assume that the before-tax market prices remain unchanged.) Then assuming a short-term demand elasticity of −0.1, and a long-term elasticity of −0.5, calculate the reductions in household quantity demanded for oil and gas in the short and long term. If there are 100 million households in the United States, what would be the revenue to the U.S. Treasury of such a carbon tax, in the short and long term? How might the government use such revenues? What would the impact be on the average family? Discuss the difference between the short-term and long-term impacts.

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Web Sites

Web Sites

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2. **https://unfccc.int/**. Homepage for the United Nations Framework Convention on Climate Change. The site provides data on the climate change issue and information about the ongoing process of negotiating international agreements related to climate change.
3. **https://www.rff.org/topics/**. Publications by Resources for the Future including many on issues of energy and climate change. The site includes articles on carbon pricing and the social cost of carbon.

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