Sure, one can invent fanciful scenarios that involve extreme global depopulation or economic collapse that leads to dramatic emissions reductions. One can even invent seemingly more realistic scenarios involving the deployment of a new nuclear power station somewhere in the world every day for the next four decades or the deployment of 2 million wind turbines (see Chapter 4), but these are not practically realistic scenarios. The fact is that no one knows how to decarbonize a large economy, much less the world, using existing technology on timescales implied by emissions-reduction targets currently suggested by policy makers. Throwing everything we can think of (for example, see again Table 2.1) at the problem is not nearly enough.

A review of "what we know for sure, but just ain't so" provides a few boundary conditions that suggest design criteria for any successful policy focused on decarbonization of the global economy:

1. Climate policies should flow with the current of public opinion rather than against it.
2. Efforts to sell the public on policies that will create short-term economic discomfort cannot succeed if that discomfort is perceived to be too great. The greater the discomfort, the greater the chances of policy failure. Short-term costs must be commensurate with short-term benefits.
3. Innovation in energy technology—related both to the production of energy and to its consumption—necessarily must be at the center of any effort to accelerate decarbonization of the global economy.

I'll return to these design criteria in Chapter 9 when I outline a perspective on how climate policy might be different, and perhaps more likely to show progress. The next two chapters will reinforce these design criteria by looking at the simple mathematics of real-world challenges of decarbonizing the global economy. Wisdom in policy analysis begins with a clear-eyed view of the scope of a challenge, and that is where we turn next.

CHAPTER 3

Decarbonization of the Global Economy

As explained in Chapter 1, the accumulation of carbon dioxide in the atmosphere influences the climate, changes the chemistry of the oceans and causes them to rise, and influences the growth of vegetation, among other things. All of these effects lead to further effects in the earth system. Some of these effects may be predictable, and some may not; some could be benign, or even beneficial, but others might be far less acceptable. Much attention in the field of climate science in recent decades has been focused on trying to gain a clearer view of the future impacts of accumulating carbon dioxide (and other greenhouse gases, as well as other natural and human influences). The literature on this topic is so vast that one could easily cherry-pick a few studies suggesting that the impacts may be benign or, in contrast, that those impacts may be catastrophic. Science cannot presently adjudicate between these possibilities, or even give reliable odds on particular outcomes, leaving what Steve Schneider calls a "lingering frustration" (see Chapter 1). Many, if not most, scientists believe that the impacts will be on balance negative and significant.

For some people the mere fact that significant negative impacts are possible is all they need to know to support policies focused on accelerating decarbonization of the global economy. Undoubtedly in some cases, the issue of climate change simply adds weight to actions that they would support for other reasons, such as expanding alternative energy or redistributing wealth. But for others the science by itself provides an insufficient basis for action, especially costly and aggressive action. Here as well science is filtered through preexisting views and commitments. Climate change is a bit like a policy inkblot on which people map onto the issue their hopes and values associated with their vision for what a better world would look like. In such a circumstance it should not be a surprise that scientific information cannot lead to political consensus.

Even so, the political battle over climate change has been waged through science. Advocates for action typically seek to compel the recalcitrant by offering up ever more certain scenarios of an apocalyptic future. Those seeking to prevent action highlight the uncertainties in climate science, some going so far as to call the issue a myth or a hoax. Some of those on each side of this debate have misrepresented climate science in political debates. For those advocating action, this strategy has failed; instead, the strategy has contributed to a problematic politicization of climate science and increased opposition to action. As argued in more depth in Chapter 7, waging a political battle through science tilts the playing field in the direction of those opposing action and threatens the integrity of climate science as well.

But science need not carry all of the weight of advocacy for action to accelerate decarbonization of the global economy, as there are other, far less controversial, reasons that decarbonization makes sense. Together these other reasons may not be sufficient to justify decarbonization to levels implied by very low targets for stabilizing concentrations of carbon dioxide, but they are certainly strong enough to motivate the first steps on that path, which so far have been very difficult to take. And after the first steps are taken, the ones that follow might then come a bit easier.

The World Needs Vastly More Energy

Energy experts use a dizzying array of units and jargon to talk about energy. In this chapter and the next I use some back-of-the-envelope approximations to help make better intuitive sense of energy and its relationship with carbon dioxide emissions. I also use a standard set of units. One of these units is the "quad"—a useful concept for discussing

the consumption of energy. The term "quad" is shorthand for 1 quadrillion (1,000,000,000,000,000) British thermal units. A Btu refers to the amount of energy required to elevate the temperature of one pound of water by one degree Fahrenheit.[1] But a more intuitive conversion is to think about a quad in terms of power plant–equivalent electricity generation. One quad is equivalent to about 11 gigawatts (GW) of electricity (over one year).[2] How much is 11 gigawatts? It is the amount of electricity produced by about fifteen typical power plants, each generating 750 megawatts (MW) of electricity.[3] In recent years the United States as a whole consumed about 100 quads of energy each year.[4]

In a 2009 report the U.S. Energy Information Agency estimated that the world would consume 508 quads of energy in 2010. The EIA estimated that by 2030 the world would consume a total of 678 quads of energy, which represents a growth rate of about 1.5 percent per year in the context of global economic growth expected to be perhaps twice as great. Thus, the EIA scenario for future energy consumption already factors in aggressive improvements in energy efficiency. Consider that if demand were to increase by 2 percent annually to 2030 (instead of 1.5 percent), the world would need an additional 77 quads in 2030, for a total of 755 quads. To reach this level of total energy consumption would be the equivalent of adding more than 3,700 new power plants![5] And the demand for energy is likely to continue to increase well beyond 2030.

The precise total amount of energy that the world needs in coming decades will be determined by how fast the global economy grows and the nature of that economy, including the global mix of activities (e.g., services versus manufacturing) and the efficiency with which those activities are conducted. As the simple exercise above shows, small differences in any of the variables that shape the economy and its use of energy can lead to dramatically divergent outcomes over decades. It is for this reason that Vaclav Smil of the University of Manitoba summarizes the track record of energy forecasting as follows: "With rare exceptions, medium- and long-range forecasts become largely worthless in a matter of years, often just a few months after their publication."[6] Smil recommends "contingency scenarios" to explore "what ifs" and "no-regret normative scenarios" that shape a course in a desired political direction.

From the what-if perspective, it is essential to realize that under all plausible scenarios, in the coming decades the world is going to need more energy—vastly more energy. Meeting the increasing global demand will be facilitated by an increasing diversification of energy supply beyond coal, gas, and oil. Wherever one falls on the spectrum of debate about peak energy supply—that is, the debate over the finite nature of fossil fuels (oil, gas, and coal) and when production will peak and then decline—it is clear that the demand for a robust global energy supply to meet ever-increasing demand will be largely insensitive to the point, if and when it is reached, of peak production. Beyond hydrocarbons there is also debate about peak uranium to supply nuclear reactors and peak rare-earth minerals such as dysprosium and terbium, used in technologies such as wind turbines and energy-efficient lightbulbs.[7] Uncertainties about the future marginal costs of various forms of energy supply support the need for a more robust energy supply. And having a robust energy supply thus means diversification. In many respects (but, as will be seen, not all), diversification of supply means accelerating the pace of decarbonization of the global economy.

Energy Dependence Exacerbates Insecurities

It is not an overstatement to observe that the benefits of contemporary modern society are due in large part to cheap energy supply from oil, gas, and coal. An energy-industry venture capitalist guest lecturing in one of my courses once commented on the "near-miraculous" feat of bringing a gallon of gasoline to your car, distilled from crude oil from thousands of feet below the ocean floor, enabling near-unlimited mobility at a price of only a few dollars per gallon. And he was right. The modern energy economy is a testament to human know-how and ingenuity. But is it possible to both celebrate the accomplishments of a world built on carbon dioxide–emitting sources of fuel and recognize that there are reasons to look forward to a future with a different energy mix than the one that has brought us to today?

One important issue facing nations around the world is energy security, which can refer to both security of supply and the security that results when energy is supplied reliably and at low cost. For instance, Raja Pervez Ashraf, Pakistan's minister for water and power, commented in 2009 that "Pakistan has to make a choice whether to develop electricity or face power cuts that result in unemployment, low economic growth, and protests."[8] He views securing access to energy as central to enhancing Pakistan's domestic security. The view from Pakistan is no different from the view from Africa, Southeast Asia, or other locales where energy supply is neither readily available nor inexpensive.

Consider that in 2008 approximately 1.5 billion people worldwide lacked access to electricity. About 600 million of these people were in sub-Saharan Africa and 800 million in Asia. The International Energy Agency (IEA) explains why access to electricity matters: "It is impossible to operate a factory, run a shop, grow crops, or deliver goods to consumers without using some form of energy. Access to electricity is particularly crucial to human development as electricity is, in practice, indispensable for certain basic activities, such as lighting, refrigeration and the running of household appliances, and cannot easily be replaced by other forms of energy."[9] The lack of access to electricity helps explain why it is that countries with large and poor populations provide little support for efforts to reduce emissions of carbon dioxide if such efforts imply any extra costs. In October 2009 during the lead-up to the December Copenhagen climate conference, Indian prime minister Manmohan Singh explained simply that "developing countries cannot and will not compromise on development."[10] This, of course, is another invocation of the iron law of climate policy.

In 2009 the IEA published an aggressive emissions-reduction scenario, consistent with ambitious targets for stabilizing concentrations of carbon dioxide in the atmosphere as called for by many environmental campaigners. Incredibly, the scenario, which if followed would no doubt be greeted as a "success" by many campaigners for action on climate change, reduced the number of people worldwide without access to electricity by less than 14 percent from 2008 levels, leaving 1.3 billion people in the dark.[11] To the extent that the IEA scenario is broadly representative of the climate policies of developed nations, the scenario represents a total refusal on those countries' part to countenance the circumstances facing developing ones. Connie Hedegaard, Denmark's energy and climate minister and host of the 2009 Copenhagen climate meeting, expressed this view when she explained with respect to the need for developing countries to reduce their emissions that "China and other emerging nations must accept it even if it isn't fair."[12]

Here Hedegaard runs smack into the iron law of climate policy. As we have seen, if development is viewed as a trade-off of emissions reductions, then development will always win out. Creating a climate policy in which development and emissions reductions go hand in hand thus far has not been a focus of climate policy, regardless of the rhetoric of policy debate. If it were, then increasing access to energy via a diversification of supply would be a much more prominent feature of policy proposals, and organizations like the IEA would not advance scenarios with more than a billion people still lacking access to electricity in 2030. An approach focused on expanding access to energy while also diversifying supply would almost certainly be better received by developing countries than one that implicitly or explicitly questions their desire for continued economic growth.

Energy is necessary for development, but it is also, thanks to its cost, an obstacle to the same. Author and journalist Robert Bryce estimates in back-of-the-envelope fashion that the direct costs of fuel alone resulted in about $5 trillion of expenditures in 2008, which is about 8 percent of global GDP.[13] Bryce's estimate assumed a price of oil of $60 per barrel. At two or three times that value, the proportion of global GDP devoted to energy increases in similar fashion. The trillions of dollars spent meeting basic energy needs are not available for investments in education, health, and other important aspects of development. Improving access and security of the supply of energy will necessitate reducing the costs of energy relative to global GDP over the long run, a tall order given the energetic punch packed by fossil fuels and the prospects of their limited supply. Innovation in energy technologies offers the promise of lower costs, and thus prospects for increased access and supply. The IEA has suggested that the world will need to invest more than $500 billion per year until 2030 to transform the global energy system. This number seems large, and of course it is in an absolute sense. But relatively it is not so large, representing an added cost of only about $6 per barrel of oil.[14] Whether the actual investment needed is larger or smaller than that suggested by the IEA, the number does suggest a level of effort comparable in scope to the U.S. military budget during the years of the cold war.

The high costs of energy have tangible, real-world effects today. The UN's Food and Agricultural Organization explained that the high costs of food in 2009, exacerbated by the global financial crisis, contributed to an increase in the number of undernourished people around the world to the highest levels since 1970, with more than 1 billion people classified as undernourished.[15] The FAO argued that, because the energy market is so much bigger than the grain market, energy prices may be as or more important for determining the cost of food than the food supply is.[16] Securing the energy supply, and with it certainty in cost and access, has a key role in dealing with the global challenges of food security and malnutrition. From this perspective, it can easily be seen why biofuels based on food grains can serve to undermine food security when they are in economic competition with food. This is one reason advocates of biofuels have increased their attention to those plants that are not in direct competition with food.

It is not just poor countries that are sensitive to issues of energy security. In the winters of 2006 and 2008–2009, Russia shut off gas deliveries to eastern Europe during a dispute with Ukraine.[17] Because Europe receives a considerable amount of gas from Russia, effects on gas supplies were felt as far west as France.[18] An EU spokesperson complained, "It is unacceptable that the EU gas supply security is taken hostage to negotiations between Russia and Ukraine."[19] Ironically enough, according to the *Financial Times*, the expansion of wind power in western Europe exacerbated its dependence on gas from the East, because gas-fired power plants are needed during periods of low wind.[20] Efforts to diversify supply can have counterintuitive consequences.

It is also important to observe that security of supply is not always consistent with efforts to decarbonize. For instance, the United States has vast reserves of coal, which could provide an opportunity to reduce energy dependence, but at the same time would also increase carbon dioxide emissions. In order for coal-powered electricity to be compatible with goals of rapid decarbonization, it would be necessary to develop and deploy technologies to capture and store carbon dioxide emitted from power plants. There is simply no alternative. A different sort of trade-off is implied by nuclear power, which offers an appealing path toward diversifying energy supply while not increasing carbon dioxide emissions. But nuclear power is also the subject of intense domestic and international concern for reasons of security, in this case not associated with energy supply but the risks of nuclear power, waste, and associated nuclear technologies falling into the hands of those with bad intentions. All technologies of energy supply face trade-offs among various competing interests. Consequently, increasing energy security thus involves balancing a range of concerns. For many countries without significant oil, gas, and coal supplies, diversifying supply may in fact mean a move away from these sources to ones that can be sourced locally. The extent to which such diversification proves feasible will depend a great deal on the cost of alternative energy supply, with less expensive alternatives to fossil fuels aiding efforts to achieve greater diversification.

But perhaps the most compelling reason to accelerate decarbonization of the global economy is that, as discussed below, the world has already been decarbonizing for more than a century. Decarbonization—defined in Chapter 1 as the process of growing the economy at a rate faster than the rate of growth in carbon dioxide emissions—has historically been associated largely with increased efficiency in the use of energy, and to a somewhat lesser degree in the decarbonization in the energy supply. Efforts to secure a diverse energy supply and to improve the efficiency of energy use together provide a compelling reason to at least get started on the challenge of accelerating the decarbonization of the global economy. Whether such justifications are sufficient to carry an effort forward to 2050 is uncertain (keep in mind the pitfalls of energy forecasting), but they are sufficient to encourage building a broad coalition for starting the job now. The push to improve global energy policies thus has both climate- and non-climate-related justifications; together they provide a broad footing for making the case for accelerating the decarbonization of the economy. So far debate over climate policies has focused too much on climate and too little on the benefits of diversification of, access to, and costs of the energy supply.

The remainder of this chapter will argue that decarbonizing the global economy is an enormous task, requiring a much more direct approach than most national and international policies on carbon dioxide emissions have countenanced. A direct approach necessarily focuses explicitly on improving energy efficiency and decarbonizing the energy supply. In fact, it is only through these mechanisms that emissions will be reduced, whether one concentrates explicitly on those mechanisms or indirectly, such as through efforts to price carbon and establish caps on emissions. The uncomfortable reality is that no one knows how fast a major economy can decarbonize, much less the entire global economy. Consequently, policy will necessarily have to proceed incrementally and experimentally, and will succeed only if the short-term benefits of action are proportional to the short-term costs. And even then efforts to stabilize carbon dioxide concentrations at a low level may not succeed, necessitating a backstop.

Decarbonization Arithmetic

Like the arithmetic of carbon dioxide concentrations we saw in Chapter 1, the arithmetic of decarbonization policies is surprisingly simple.[21] In 2000 Paul Waggoner and Jesse Ausubel wrote that to understand our ability to influence environmental outcomes through policy requires "quantifying the component forces of environmental impact and integrating them."[22] For carbon dioxide emissions there is a very simple yet powerful relationship that describes the "component forces" that together result in carbon dioxide emissions. This relationship has been called the Kaya Identity, after Japanese scholar Yoichi Kaya, director-general of the Research Institute of Innovative Technology for the Earth in Kyoto, Japan, who first proposed it in the late 1980s.

The Kaya Identity can be used to decompose the factors that lead to carbon dioxide emissions from the production and use of energy in the global economy, but also to evaluate policies aimed at reducing those emissions to a level consistent with some specific stabilization target. The Kaya Identity is composed of two primary factors. The first is economic growth (or, if the economy shrinks, contraction), which is represented in terms of GDP as a measure of the exchange of goods and service. The second factor encompasses changes in technology (or the use of technology) and includes efficiency and energy sources. Under the Kaya Identity technology is represented as carbon dioxide emissions per unit of GDP, or carbon intensity of the economy.

Each of these two primary factors—economic growth and technology—can be broken down into two further subfactors. Economic growth (or contraction) is composed of changes in population and in per capita economic activity, measured in terms of GDP. The carbon intensity of the economy is represented by the product of energy consumed per unit of GDP, called energy intensity, and the amount of carbon emitted per unit of energy, called carbon intensity. Together the four factors of the Kaya Identity—population, per capita GDP, energy intensity, and carbon intensity—explain the various influences that contribute to increasing atmospheric concentrations of carbon dioxide. Table 3.1 shows the four factors expressed as an equation.

The Kaya Identity tells us exactly what families of tools we have in the policy toolbox to reduce carbon dioxide emissions to some desired level. Specifically, carbon dioxide accumulating in the atmosphere can be reduced only by influencing the following four levers.

1. We could reduce population.
2. We could reduce per capita GDP.
3. We could become more efficient.
4. We could switch to less carbon-intensive sources of energy.

These are the four—and the only four—means of reducing carbon dioxide emissions. All policies being discussed as climate policies must influence these levers if they are to have an effect. So debates about carbon taxes, cap-and-trade programs, offsets, energy innovation, personal carbon allowances, and on and on ultimately must eventually arrive at exactly the same place.

TABLE 3.1 Kaya Identity

(1) Carbon Emissions = Population * Per Capita GDP * Energy Intensity * Carbon Intensity

  a. P = Total Population
  b. GDP/P = Per capita GDP

(2) GDP = Economic Growth (Contraction) = P * GDP/P = GDP

  a. Energy Intensity (EI) = Total energy (TE)/GDP = TE consumption/GDP
  b. Carbon Intensity (CI) = C/TE=Carbon emissions/total energy consumption

(3) Technology = "Carbon Intensity of the Economy"
  = EI * CI = TE/GDP * C/TE = C/GDP

We can make the issue even simpler yet. As Chapter 2 argued, one of the ground rules of climate policies is that reducing economic growth or limiting development as a means to address increasing carbon dioxide is simply not an option—it is an iron law. Indeed, in rich and poor countries alike increasing GDP is a central focus of policy. Consider that even if per capita wealth were to stay constant, a growing global population alone implies a rising GDP and thus rising emissions.

Figure 3.1 shows another way to visualize climate policy's iron law from an analysis conducted by the United Nations of the distribution of global income for 1970 and 2000 along with an estimated curve for 2015.[23] A defining feature of the curve is its rightward movement over time, which indicates more people living at higher income levels, and also a higher global GDP. Indeed, success with respect to poverty is often measured by reducing the number of people living below some income threshold, such as $1 per day. In yet another trade-off of competing values, moving people out of poverty by increasing their incomes means increasing carbon dioxide emissions, all else staying equal. In 2005 the World Bank estimated that 95 percent of all people in developing countries live on less than $10 per day.[24] People everywhere will continue to try to increase their material well-being, and GDP will continue to be one measure of that increase. It is vitally important to note that the fact

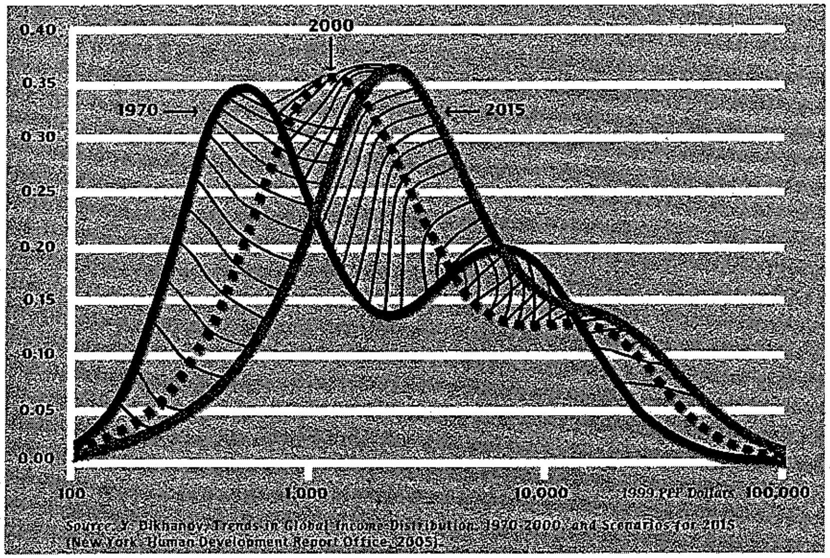

FIGURE 3.1 Evolution of global income distribution, 1970–2015 (the lines connecting the curves connect equal percentiles).

of GDP increase is quite different from the question about whether increasing GDP accurately measures what matters for human well-being. Changing how we measure and value growth won't alter the reality of emissions or its close linkage to the conventional metrics of GDP.

While it can be a useful exercise to debate the desirability of continued economic growth, its sustainability, or its expression as GDP, such debates are entirely academic from the standpoint of decarbonization. Population is expected to increase for decades, perhaps through at least midcentury, and it seems highly unlikely that policies focused on global population control (much less its managed reduction) are going to be put into place anytime soon. At the same time, people around the world are going to continue to try to improve their material standing in the world, and as they do so, an increasing GDP will result. Governments are committed to aiding their citizens in pursuing greater wealth. Consequently, climate policies will invariably be put into place in the context of a broader societal commitment to increasing GDP. As we shall see, the rate at which GDP increases makes a very big difference in how much carbon dioxide we emit into the atmosphere. So while there are those who will

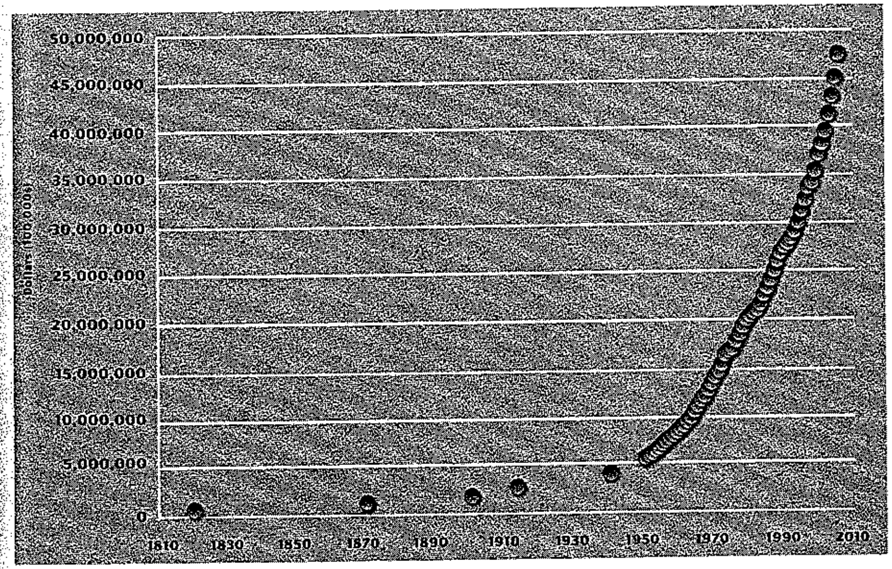

FIGURE 3.2 Global GDP, 1820–2006. Source: A. Maddison.

continue to talk about policies focused on a willful contraction or significant slowdown of global economic growth, such policies won't be further discussed in this book because they are simply not going to happen. For the foreseeable future, the iron law of climate policy is exactly that.

Figure 3.2 shows the GDP data that are used throughout the various analyses of decarbonization policies that follow in subsequent sections. The data come from research by the decorated economist Angus Maddison of the University of Groningen in the Netherlands. The data are adjusted to a common basis in U.S. dollars to allow cross-national comparisons.[25] As the figure shows, GDP growth has been sustained for the past two centuries.

All proposals advanced by governments and in international negotiations to reduce emissions of carbon dioxide focus (directly or indirectly) on actions that will lead to the reduction of the carbon intensity of the economy (whether they are explicitly presented as such or not), which is a more technical term for decarbonization. Thus, the Kaya Identity provides a straightforward and useful basis for evaluating the proposed and actual performance of policies focused on decarbonization, which are often called *mitigation* policies by those who focus on climate policy.

In 2009 the U.S. Energy Information Agency estimated total global emissions of carbon dioxide in 2010 from the combustion of fossil fuels to be about 31 Gt and projected them to rise to about 40.4 Gt by 2030.[26] The IPCC in 2007 reported a median scenario for global emissions in 2100 to be 220 Gt carbon dioxide, with its baseline scenarios ranging from 36.7 to 916.8 Gt carbon dioxide, reflecting enormous uncertainties about the future.[27] The future is unpredictable, of course, because it will (in part) be determined by the choices that we make.

Figure 3.3 shows the relationship of GDP and emissions for the period 1980 to 2006. It shows that while the relationship is not a straight line, it is pretty close. When GDP increases, so too do carbon dioxide emissions. If you take a close look at the graph you will also see that the four or five data points at the highest levels of GDP are much more spread out than the points representing earlier years (and thus lower levels of GDP). What this indicates is that during the first decade of the twenty-first century (i.e., 2000 to 2006 based on available data), the world has been *recarbonizing*: For every additional $1,000 of GDP activity, the amount of carbon dioxide generated is higher than it was during the 1990s and earlier. So even as the world's attention has been focused on climate policy, the global economy became ironically and frustratingly more carbon intensive for every additional dollar of economic activity.

In these sobering data, there is also some good news to report. Figure 3.4 shows that for about 100 years the global economy has been decarbonizing, meaning that on average globally we successively emit less carbon dioxide per unit of GDP, with values dropping by about half in 100 years, from 1.27 tonnes of carbon dioxide per $1,000 GDP in 1910 to 0.62 in 2006. This decarbonization has taken place without any attention to climate policy or explicit attention to a global decarbonization policy. Noting this trend in the 1980s and 1990s, some scholars predicted that the world was on its way to a decreasing dependence on hydrocarbon-based fuels that would result in the continued decarbonization of the global energy system during the twenty-first century.[28] Even if such scenarios come to pass, they won't help much in addressing the challenge of stabilizing concentrations of carbon dioxide at low

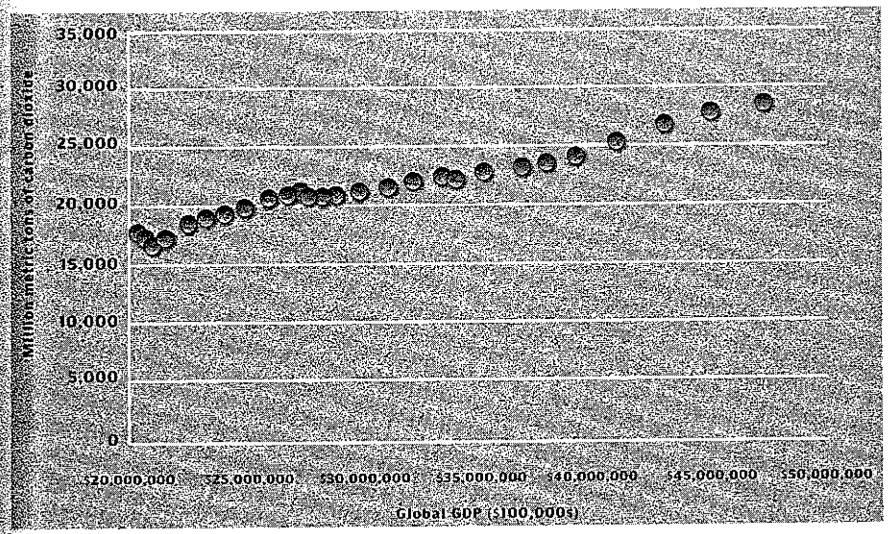

FIGURE 3.3 Relationship of GDP and emissions, 1980–2006. Source: A. Maddison and U.S. Energy Information Administration.

levels, as we shall see, because the historical rate of decarbonization is far too slow to be consistent with a low stabilization target. A considerably greater acceleration would be necessary.

Figure 3.5 shows that the primary reason for decarbonization since 1980 has been improvements in energy efficiency (i.e., energy intensity of GDP), while improvements in the carbon intensity of energy have contributed a smaller amount. If the world is going to simultaneously provide much more energy and meet aggressive targets for decarbonization, then decreases in the carbon intensity of energy supply are necessarily going to have to play a much larger role in future decarbonization than in the past. The good news is that reductions in the carbon intensity of energy can also contribute to diversifying supply and improving energy security.

Understanding the historical rate of decarbonization—the "background rate"—is central to understanding the problems with the so-called stabilization wedges that were discussed in Chapter 2. Scholars have looked at the historical rate of decarbonization, especially over the period 1980 to 2000, and assumed that it was somehow guaranteed and would thus continue into the future at the same rate as it had during

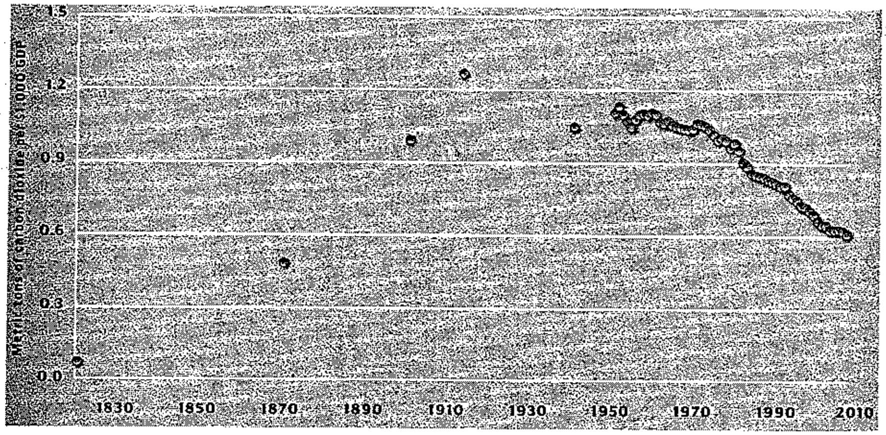

FIGURE 3.4 Carbon dioxide intensity of the global economy, 1820–2006. Source: A. Maddison and U.S. Department of Energy.

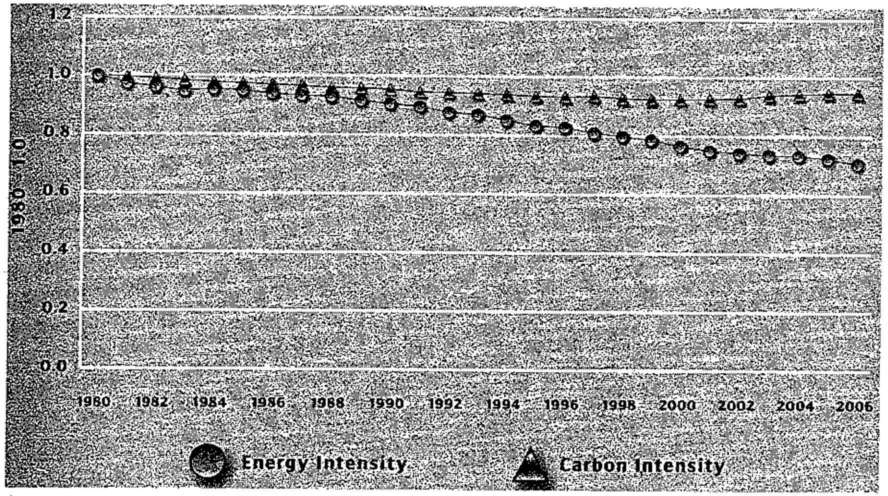

FIGURE 3.5 Energy intensity of GDP and carbon intensity of energy consumption, 1980–2006. Source: U.S. Department of Energy.

those decades (some scholars have even assumed, inexplicably, that the background rate of decarbonization would increase dramatically with no policy actions).[29] Climate policies focused on decarbonization would simply have to piggyback on that background rate, nudging it ahead a bit to meet aggressive stabilization targets.

Unfortunately, there turned out to be two major flaws in that line of thinking. First, we have learned in the first decade of the twenty-first

century that "automatic" decarbonization is not so automatic. The second major flaw is that as countries have adopted explicit policies focused on improving energy efficiency and decarbonizing energy supply, it has proven impossible to maintain a clear distinction between "background" decarbonization and that which is the focus of policy, as all policies that have positively influenced the decarbonization of the economy are counted as "climate policies," whether they were actually intended as such or not. Hence, there is a large potential for the double counting (i.e., in assumptions about background rates and a second time as additional efforts in climate policies) of the effects of such policies if they are assumed to be both part of the background and part of explicit climate policies. Double counting is problematic because it can lead us to believe that we are making progress, when we are actually just pursuing policies that approximate business as usual.

Thus, to fully understand the challenge of decarbonization and to avoid the risk of double counting, it is important to start at today's level of carbon dioxide per unit of GDP and then ask what level of decarbonization is implied by a particular stabilization target. Of course, it is not enough to specify the stabilization target; the Kaya Identity tells us that we also have to specify a rate of economic growth as well.

Figure 3.6 shows the implied annual average rates of decarbonization that would be necessary in order for the world to reduce its total carbon dioxide emissions from the burning of fossil fuels to a level 50 percent below 1990 levels by 2050, the level recommended at Copenhagen in December 2009. The figure shows that the global economy would have to decarbonize from 0.62 tonnes of carbon dioxide per $1,000 GDP in 2006 to below 0.20 in 2050 for all rates of GDP growth, and perhaps below 0.10 at higher rates of GDP growth. Global GDP growth was 3.5 percent annually from 1980 to 2006, but the exact future rate is in some respects unimportant, as for annual GDP growth rates of 1 to 5 percent all values of carbon dioxide emissions to GDP are less than 0.20, though the difference between an average 1 percent rate and 5 percent rate is a factor of about 5 in 2050.

Figure 3.7 shows the historical decarbonization of the global economy from 1980 to 2006, as well as the decarbonization curve for 2007

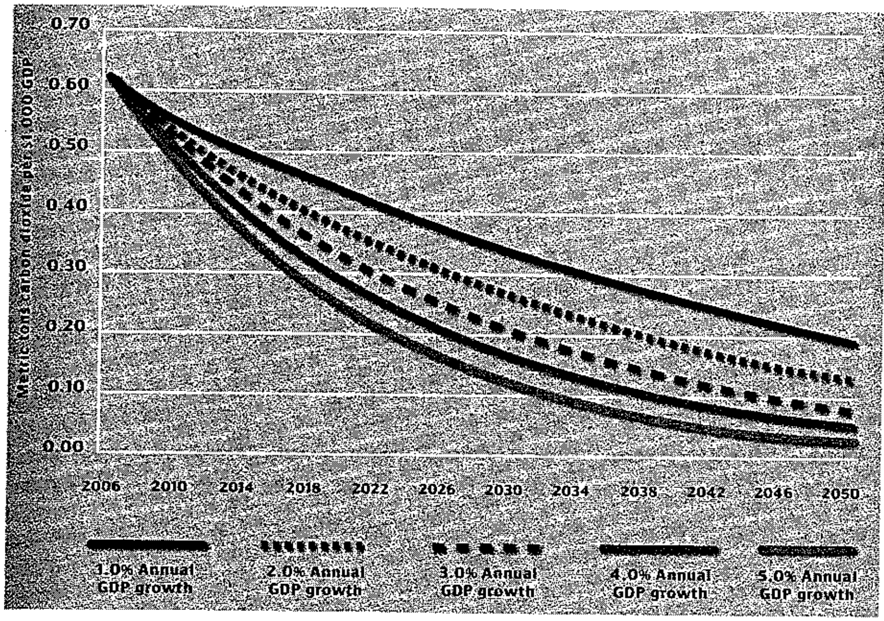

FIGURE 3.6 Implied decarbonization of the global economy. Source: Author's calculations.

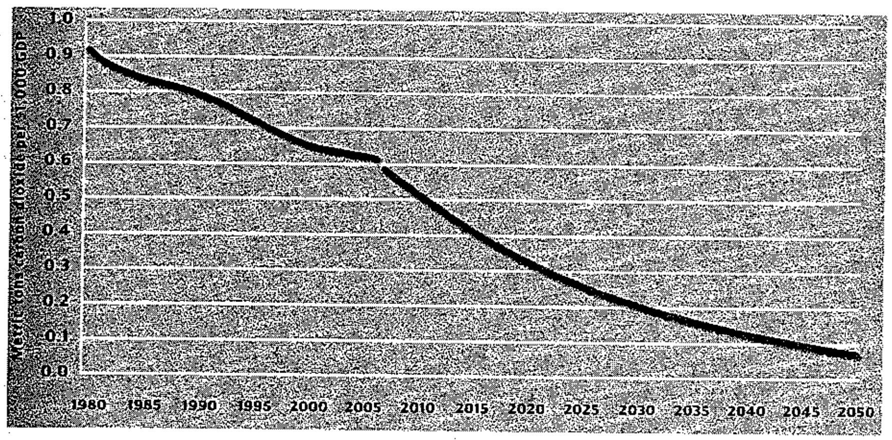

FIGURE 3.7 Historical and projected decarbonization of the global economy. Source: Author's calculations.

to 2050 based on the 3.0 percent (middle) value for future growth from Figure 3.6. It shows that a rapid increase in the average rate of decarbonization would be necessary to achieve a reduction in emissions of 50 percent below 1990 values. An important result from this type of analy-

sis is that the conclusions are qualitatively very much the same for other possible emissions-reduction targets or different assumptions about economic growth. The bottom line is that to stabilize concentrations of carbon dioxide in the atmosphere at low levels will require advances in decarbonization of the global economy beyond that observed over the past decades and even the past century. The average annual rate of decarbonization implied by a 50 percent reduction in emissions below 1990 levels by 2050 for a 3.0 percent annual GDP growth is 4.4 percent per year, whereas the world actually experienced a 1.5 percent rate of decarbonization from 1980 to 2006 while achieving a 3.5 percent average rate of GDP growth.

Is decarbonization to below 0.20 or 0.10 tonnes of carbon dioxide per $1,000 of GDP by 2050 a lot or a little? What does it mean practically? We can better assess what it really means to decarbonize to a particular level by looking at the actual decarbonization experience of countries around the world, and so this is where we go next. Chapter 4 will conclude with a far more intuitive, and sobering, answer to these questions.