The ingenuity of humans to manipulate dynamics of nature to add value to biophysical resources has resulted in unparalleled comforts, convenience, consumption, and life expectancy. This has produced a population surge. That very success of human rationality has, however, caused unmatched degradation of the global environment and is unleashing powerful and threatening new forces of nature, which constitute inadvertent and paradoxically irrational consequences (Murphy 1994). The most insidious impacts are those where causes are invisible and harm slow onset, which lull populations into believing all is normal even as abnormality creeps forward. Arguably the most serious and pervasive danger consists of extracting and combusting fossil fuels, which causes long-lasting carbon pollution of the atmosphere, a greenhouse effect, global warming, and climate change.

Anthropogenic global warming has been socially caused by giving priority to near-term economic interests at any environmental cost. It can either be suffered or mitigated by social action. Hence social science is needed to analyse causes, consequences, and possible resolution. Nevertheless, the social action consists of interaction with properties and dynamics of nature, including unleashing its threatening forces. The
social science analysis of such action must be grounded on a solid foundation of natural science knowledge to understand the depth of the problem. Natural science is necessary to make visible global atmospheric warming and distinguish climate change from weather change. The best available evidence is needed to transform aspirations for solutions into reality rather than underestimating problems and falling into wishful thinking or greenwashing. A cooperative relationship between social science and natural science is needed.

The Natural Science of Anthropogenic Climate Change

Science is admittedly fallible, and the evidence and understanding could change in the future. Nevertheless, natural science is the unsurpassed source of knowledge of such a biophysical problem where the connections between cause and effects extend across centuries and oceans, and are largely invisible to the senses. Even the admitted fallibility of science is a positive feature in that it involves non-dogmatic, self-corrective features. A brief summary of current natural science understanding of human-made climate change is warranted because there are misunderstandings in society which crept into some social science.

Industrialization led to the massive combustion of coal, and later modernization was powered by combusting oil and natural gas. Fossil-fuel combustion and land use changes such as deforestation emit large amounts of carbon dioxide, which is the principal greenhouse gas. Fossil-fuel extraction and transport release methane. Nitrous oxide is emitted mainly through agricultural activities. Carbon dioxide, methane, nitrous oxide, and a few other gases cause a greenhouse effect trapping heat in the atmosphere. Properties of specific greenhouse gases (GHG) vary. Methane is a potent greenhouse gas, but is removed from the atmosphere by nature’s chemical reactions in about 12 years. Carbon dioxide is more complicated, with about two-thirds remaining in the atmosphere between 20 and 200 years, and the remainder removed by slower processes that take a hundred thousand years. Emissions accumulate carbon in the atmosphere; therefore it is crucial to reduce
emissions promptly. Vegetation growth absorbs carbon dioxide from the atmosphere, as do oceans and soil. Land use changes, particularly deforestation and some types of agriculture (IPCC 2019), diminish nature’s capacity to withdraw atmospheric carbon dioxide. The US Environmental Protection Agency presented the evolution of greenhouse gases in the atmosphere in Fig. 2.1 and concluded as follows. ‘This graph shows the increase in greenhouse gas (GHG) concentrations in the atmosphere over the last 2000 years. Increases in concentrations of these gases since 1750 are due to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion molecules of air. … Carbon dioxide is the primary greenhouse gas that is contributing to recent climate change’ (EPA 2017a).

Given the complexities and interactions, and because Earth is a huge planet, it took evidence, increased understanding, and time to convince scientists that human activities are producing planetary warming. Early on, they raised the question everyone is now asking: how can actions of humans change the Earth’s climate. Being closest to the evidence, they were first to answer affirmatively. In 1971, Rasool and Schneider (1971) ran a computer model that omitted to include the stratosphere, which resulted in the inference that cooling by aerosols outweighed warming
by carbon dioxide. After scientific debate, Schneider (2009) corrected his model, redid the calculations, and became a leading scientist investigating how greenhouse gases result in global warming. Similarly, Heal (2017: 31) in the late 1970s didn’t believe humans could change the climate. But when he checked the theories and calculations, he understood the threat. ‘What convinced me was that burning a ton of coal releases about two and a half tons of CO₂. A large power station can burn 10,000 tons of coal daily, releasing 25,000 tons of CO₂ daily, or more than 7 million tons annually. This amounts to billions of tons of greenhouse-gas emissions each year when you take into account that there are thousands of coal power stations around the world. Throw in other types of fossil fuel power stations as well as cars, planes, boats and trains, and it’s not hard to see that this all adds up to a huge amount of CO₂, quite sufficient to change the composition of the atmosphere’. He then became a leading environmental economist. This evolution is similar to initial disbelief about smoking cigarettes slowly causing lung cancer. As scientific evidence mounted, doctors were closest to the evidence and were first to stop smoking.

Impact science is needed to understand how common social practices, like driving a car 100 miles by combusting 5 gallons of gasoline, which weigh about 31 pounds, produce 100 pounds of CO₂ when combusted. The remaining 69 pounds come from oxygen in the air. Combustion enables each carbon atom to combine with two oxygen atoms, which have greater atomic weight, from surrounding air thereby producing CO₂ much heavier than the original gasoline. Non-scientists need to learn how much greenhouse gases their common fossil-fuelled social practices pump into the atmosphere. The manufacture of concrete, used extensively in buildings, bridges, roads, dams, pipes, etc., results in eight per cent of global emissions of carbon dioxide. Concrete is bound together by cement, which is manufactured by combusting fossil fuels to very high temperatures causing calcium carbonate to break down into the binding agent lime and emitted carbon dioxide. Hence cement is a double jeopardy carbon polluter, with carbon dioxide emitted both in combusting fossil fuels and the ensuing thermal chemical decomposition of calcium carbonate, such that the weight of carbon dioxide emitted
is equal to the weight of the cement. Given all the cement used in the world, this weight of CO$_2$ emitted is enormous.

NASA (2018) found ‘the planet’s average surface temperature has risen about 1.62 degrees Fahrenheit (0.9 degrees Celsius) since the late 19th century, a change driven largely by increased carbon dioxide and other human-made emissions into the atmosphere. Most of the warming occurred in the past 35 years’. Over the last 136 years, 17 of the 18 warmest years occurred since 2001. Global warming is speeding up. CO$_2$ emissions increased from 2 billion tons annually in 1900 to 35 billion tons in 2010, a 2.6% annual increase which is compounded and cumulative (Nordhaus 2013: 21 Fig. 2). Scientists at the American Environmental Protection Agency (EPA 2017a) documented that ‘worldwide, net emissions of greenhouse gases from human activities increased by 35 percent from 1990 to 2010. … Concentrations of carbon dioxide and other greenhouse gases in the atmosphere have increased since the beginning of the industrial era. Almost all of this increase is attributable to human activities. Historical measurements show that the current global atmospheric concentrations of carbon dioxide are unprecedented compared with the past 800,000 years, even after accounting for natural fluctuations’. Human activities have loaded the atmosphere with an unparalleled amount of greenhouse gases, and despite talk about transitioning to low-carbon economies, the trajectory continues towards an atmosphere even more carbonized. The carbon dioxide content of the atmosphere prior to the industrial revolution was 280 parts per million (ppm), by 2008 it had risen to 387 ppm, humans are currently adding 3 ppm each year and this rate of added carbon dioxide is increasing.

The 2015 Paris goal of limiting atmospheric temperature increase to 2 °C implies limiting its carbon dioxide content to 450 ppm (Dyer 2008: 14, 231, 177), hence societies are rapidly reaching their hoped-for limit. The IPCC (2018: SPM-4) calculated that ‘global warming is likely to reach 1.5 °C between 2030 and 2052 if it continues to increase at the current rate’ and rise beyond 1.5 °C after that. To limit the increase to 1.5 °C, net global human-caused emissions of carbon dioxide would have to decrease from their 2010 level by 45% by 2030, and achieve net zero around 2050. This is so socioeconomically challenging most leaders have weakened the goal to an increase of 2 °C.
Nevertheless, ‘the hard choices have to be made now. We are poised to set in motion irreversible alterations to the climate and the natural world around us. Because climate changes slowly in response to CO₂ concentrations, the effects of what we do in the next twenty-five years will play out over the next hundred in terms of mass extinctions, sharp rises in sea level, decreases in food production, and possible other trends not yet anticipated’ (Heal 2017: 42). The World Meteorological Organization (2019) found that ‘greenhouse gas concentrations in the atmosphere have also increased to record levels, locking in the warming trend for generations to come’. It documented that those concentrations are accelerating and are on track to reach or exceed 410 ppm by the end of 2019, and caused sea level rise, shrinking ice in the Arctic, Antarctic, and Greenland, increased the heat content and acidity of the oceans, and extreme weather like wildfires which release massive amounts of carbon dioxide into the atmosphere. The IPCC (2019: SPM-8 A2) similarly found ‘it is virtually certain that the global ocean has warmed unabated since 1970 and has taken up more than 90% of the excess heat in the climate system (high confidence). Since 1993, the rate of ocean warming has more than doubled (likely). Marine heatwaves have very likely doubled in frequency since 1982 and are increasing in intensity (very high confidence). By absorbing more CO₂, the ocean has undergone increasing surface acidification (virtually certain). A loss of oxygen has occurred from the surface to 1000 m (medium confidence)’. The World Meteorological Organization (2019) concluded that ‘to stop a global temperature increase of more than 2 degrees Celsius above pre-industrial levels, the level of ambition needs to be tripled. And to limit the increase to 1.5 degrees, it needs to be multiplied by five’. The emissions gap report (UNEP 2019) found that, even with current promises to cut emissions, temperature will increase by 3.2 °C this century, resulting in widespread destructive consequences, and the promises are not being implemented.

Aren’t fossil fuels being replaced by low-carbon renewable energy? The International Energy Agency (2018) documented that strong global economic growth in 2017 resulted in a 2.1% increase in energy consumption, and that 70% of the increase occurred for oil, natural gas, and coal, with all types of renewable energy only accounting for 30%.
Combustion of coal increased by 1% and improvements in energy efficiency slowed. The result was (i) a 1.4% rise in energy-related carbon dioxide emissions to a historical high of 32.5 gigatonnes in 2017 and (ii) fossil fuels accounting for 81% of total energy consumption which, despite fluctuations due to economic growth or recessions and increases in low-carbon energy, has not decreased over the last three decades. By 2016, 96 million barrels of oil were being pulled out of the ground and combusted globally each day, which equals 7.5 billion litres daily. And the rate is increasing. Little wonder this massive transfer of carbon from ground to sky is changing the climate.

Scientific projections are based on empirical data and confirmed knowledge. ‘Sea level continues to rise at an increasing rate. Extreme sea level events that are historically rare (once per century in the recent past) are projected to occur frequently (at least once per year) at many locations by 2050 in all RCP scenarios, especially in tropical regions’ (IPCC 2019: SPM-22 B3). IPCC’s expected scenario assumes rapid economic growth in China, India, and other developing countries, moderate global population growth, substantial implementation of non-fossil-fuel energy, and greater fossil fuels efficiencies. Despite these improvements, the carbon dioxide content of the atmosphere will be almost 700 ppm in 2100. That is not far away: the increase will occur in the lifetime of infants born now. This results in an estimated atmospheric temperature increase of 2.8 °C above its temperature in 1990, which was already above the pre-industrial level. This scenario is dangerous. If population growth is higher and if efficiencies, use of non-fossil-fuel energy, reduction of fossil-fuel emissions are less than hoped for, then the carbon dioxide content could hit 800 ppm in 2100. This is exceedingly threatening. Paleontologists documented there were five mass extinctions (Kolbert 2014). Only one was caused by an asteroid striking Earth, namely when dinosaurs disappeared. The others involved high levels of carbon dioxide in the atmosphere causing runaway chains of positive feedback loops destroying habitats of most species. ‘That last greenhouse extinction occurred when there were only about eight hundred parts per million of carbon dioxide in the atmosphere, a level we might well achieve in this century on a “business-as-usual basis”’ (Dyer 2008: ...
The long view is so menacing for the habitat of humanity that it is excluded from consideration by all but natural scientists.

Emissions and Withdrawal: The Net Change in Atmospheric Carbon

NASA (2007) documented that capping greenhouse-gas emissions at today’s rates would not stop global warming because even with that cap, humans would be emitting carbon into the atmosphere faster than natural processes put it back underground, and this has been occurring since the industrial revolution. It allows anthropogenic climate change to be aggravated, and is worse if the cap is allowed to increase to promote economic growth, as in China and Alberta where the latter’s cap of 100 megatonnes of emissions represents a 50% increase of its carbon pollution from 70 megatonnes. Even decreases in emissions per unit of GDP or per barrel of oil that leave emissions higher than withdrawal rates exacerbates global warming. Reducing emissions would only slow the increase of global warming, unless emissions fall below the amount of carbon that plants, the ocean, and rocks absorb from the atmosphere.

Global warming is determined by the net change in atmospheric carbon: the difference between the amount of carbon going into the atmosphere by nature’s processes (forest fires) and anthropogenic emissions (fossil fuels) compared to the amount taken out by nature’s processes (growth of forests, absorption by oceans) and humanly initiated processes (afforestation, direct air capture). Anthropogenic climate change can be worsening even as clean, renewable energy is developing and emissions are decreasing if they are still above withdrawal rates. It is aggravated not only by fossil-fuel combustion resulting in emissions but also by land use changes, such as some agricultural practices and deforestation (IPCC 2019), that reduce the capacity of nature’s dynamics to provide the free service of withdrawing carbon from the atmosphere. IPCC (2019: A3) estimated that, from 2007 to 2016, land absorbed 29% of carbon dioxide equivalent emissions, called a sink, but added that ‘the persistence of the sink is uncertain due to climate change’. Global warming is transforming parts of the huge boreal forests of Canada,
Alaska, and Russia from carbon sink to the source of carbon emissions: ‘Climate warming and drying has led to more severe and frequent forest fires, which threaten to shift the carbon balance of the boreal ecosystem from net accumulation to net loss, resulting in a positive climate feedback’ (Walker et al. 2019: abstract). The 2019 huge fires in the Amazon, many set by ranchers and farmers to clear land but made worse by hot, dry conditions caused by global warming, are changing large tracts of the Amazon from carbon sink to carbon source. This decreases services forests render in withdrawing atmospheric carbon and storing it safely in trees. Oceans are becoming more acidic as they absorb atmospheric carbon, which diminishes their capacity to absorb more carbon and act as a future carbon sink.

The concept ‘global carbon budget’ (Berners-Lee and Clark 2013) compares atmospheric carbon content with a specific target, such as the carbon that can be emitted yet remain under the 2 degrees temperature increase mandated in the Paris Agreement. The concepts net change in atmospheric carbon and global carbon budget are the most valid concepts to indicate whether climate change is lessening or worsening. They take into account greenhouse-gas emissions and human activities that weaken nature’s carbon withdrawal capacity, such as deforestation (IPCC 2019). Even decreases of total emissions give misleading indications of improvement if excess of emissions over withdrawal continues to increase atmospheric carbon and worsen the problem.

Figure 2.2, taken from the Carbon Dioxide Information Analysis Center (CDIAC 2018) at Berkley, illustrates the dynamic of a global carbon dioxide budget. Between 2006 and 2015, fossil fuels were taken from underground geological reservoirs and combusted, resulting in 34.1 gigatonnes of carbon dioxide emitted into the atmosphere yearly. Land use changes (e.g. deforestation) resulted in 3.5 gigatonnes more emissions per year. The oceans absorbed 9.7 gigatonnes of carbon dioxide each year and the land, such as forests and soil, absorbed 11.5 gigatonnes. The difference resulted in the carbon dioxide content of the atmosphere growing by 16.4 gigatonnes yearly, worsening the greenhouse effect.

Figure 2.3, also taken from CDIAC (2018), shows where emissions originated and where carbon dioxide went from 1880 to 2015. Since 1900, fossil-fuel combustion constituted the principal source, and after
1945 fossil-fuel emissions have risen steeply. That is why this book focuses on fossil-fuelled climate change. Land use changes resulted in some increase, but the curve is irregular and much flatter. Concerning carbon withdrawal, land absorbed increasing but fluctuating amounts, oceans absorbed increasing amounts, and the biggest increase in carbon dioxide absorption has been in the atmosphere. Remember that carbon dioxide remains in the atmosphere a century causing global warming before descending to the land and oceans.

It is true that ‘three-fifths of countries in the EPI [Environmental Performance Index] have declining CO₂ intensities, while 85–90% of countries have declining intensities for methane, nitrous oxide, and black
Pielke (2010: 3) claims this shows ‘the world has been decarbonizing for more than a century’. This has also been called dematerialization and decoupling economic growth from emissions growth. Pinker’s (2018) climate change optimism is based on the indicator that the amount of carbon dioxide emitted per dollar of GDP has been reduced by 44%. Fossil-fuelled climate change lends itself to these misleading indicators, in some cases used naively by social scientists and the population but in others promoted by interest groups, falsely showing that the problem is being solved when it is being made worse. Such claims are based on intensity indicators of emissions per unit of economic activity as measured by GDP. But why then have emissions of carbon dioxide, methane, nitrous oxide (used in fertilizers), and black carbon increased, global warming intensified, and climate change worsened during that century? The deficiency of this way of thinking consists of the erroneous equation of decreasing carbon intensity of economic activity with mitigation of global warming, and ignores the crucial comparison documented by impact science of emissions with carbon withdrawals from the atmosphere, carbon-in versus carbon-out. Although the economy has superficially been decarbonizing for a century in terms of somewhat less
emissions per GDP, the absolute amount of emissions has been increasing because of economic growth and far exceeds carbon withdrawal, so the world has been carbonizing for a century in its atmosphere and oceans, and therefore fossil-fuelled global warming and climate change have been worsening (Murphy 2015).

Figure 2.4 corrects this misunderstanding in the social sciences. The difference between GHG emissions per GDP (intensity), which indicates economic efficiency, and overall GHG emissions, which cause global warming, is shown for Canada. The yellow line shows that, from 1990 to 2017, Canada succeeded in reducing its emissions for every unit of economic activity. But the blue line shows that nevertheless Canada’s emissions increased. Since it is overall emissions that causes global warming, Canada’s contribution increased and worsened it. Hence Canada’s environmental performance deteriorated. The yellow line of emissions intensity is used by the fossil-fuel industry to legitimate their carbon pollution of the atmosphere, which is instead accurately indicated by the blue line. The difference results from economic growth, which increases emissions even when emissions per GDP decrease. To mitigate global warming, technological innovation of emissions reduction per GDP would have to be faster than economic growth. This did not occur. York (2010, 2012a, 2012b) documented that the world’s highest emitting countries—USA, China, Russia, India, and Japan—decreased

![Fig. 2.4 Canadian greenhouse-gas emissions and indexed trend emission intensity (excluding Land Use, Land Use Change and Forestry) (Source Government of Canada 2019)](image-url)
their greenhouse-gas emissions per unit of GDP between 1980 and 2005, but increased their total emissions because of economic growth, which is typical for almost all countries. Social science conceptions of decarbonization, dematerialization, decoupling, ecological modernization, etc., using intensity indicators have been misleading.

Pielke (2010: 230) states: ‘If there is a single variable that will serve as a measure of progress toward emissions reduction or carbon-intensity goals, it will be the proportion of global energy consumption that comes from carbon-neutral (or even negative) sources’. He asserts that the proportion has been well under ten per cent and will need to exceed ninety per cent to stabilize global warming at low levels. Even if the proportion of carbon-neutral global energy were to increase to twenty per cent, a worsening of the carbon content of the atmosphere and of global warming would result if economic growth produces more emissions than withdrawals. That could even be true at ninety per cent carbon-neutral energy if there is enormous global economic growth without much growth in carbon withdrawal. Social science analysis of fossil-fuelled climate change needs to build upon natural science understanding of emissions compared to carbon withdrawals. If carbon emissions exceed withdrawals, then global warming worsens because of carbon’s physical properties of (i) causing a greenhouse effect when in the atmosphere, and (ii) remaining there for 100+ years and accumulating. Both carbon emissions and withdrawals can have natural causes (forest fires and forest growth, respectively) and human causes (fossil-fuel combustion and purposive afforestation, respectively), but so far anthropogenic withdrawals are infinitesimal compared to anthropogenic emissions.

**Limiting Anthropogenic Global Warming to 2 °C**

There is massive scientific consensus that fossil-fuel combustion, land modification (e.g. deforestation), and other human activities have increased global surface temperatures since the pre-industrial period. The precise amount depends on what is taken as the pre-industrial period. Different years have been used as reference points yielding variable
amounts of increase, and even the IPCC has left ‘pre-industrial period’ undefined. Hawkins, Ortega, and Suckling (2017) argue that 1720–1800 is the most suitable starting period. Their assessment shows that ‘this preindustrial period was likely 0.55 °C–0.80 °C cooler than 1986–2005 and that 2015 was likely the first year in which global average temperature was more than 1 °C above preindustrial levels’. Some studies use the Kyoto reference year of 1990 as the benchmark rather than the pre-industrial period. Since greenhouse gases are accumulating in the atmosphere and increasing the temperature, the end date also determines the exact figure of global warming. Despite these technical differences yielding slightly different figures, there is vast agreement fossil-fuelled climate change is occurring and accelerating.

Superficially 1 °C seems trivial, but it nevertheless consists of global warming that has already melted the Arctic ice cover, glaciers, permafrost, destroyed coral, etc. The change from reflective white ice on the Arctic Ocean to dark water absorbs more of the sun’s radiation. Melting permafrost releases the powerful greenhouse-gas methane which had been trapped safely in the ground. Both unleash nature’s own runaway processes of global warming which will be exceedingly difficult to reverse. Steffen et al. (2018) documented the trajectory that fossil-fuelled social practices are on, which are resulting in ‘the risk that self-reinforcing feedbacks [of nature’s dynamics] could push the Earth System toward a planetary threshold that, if crossed, could prevent stabilization of the climate at intermediate temperature rises and cause continued warming on a “Hothouse Earth” pathway even as human emissions are reduced. Crossing the threshold would lead to a much higher global average temperature than any interglacial in the past 1.2 million years and to sea levels significantly higher than at any time in the Holocene’, namely the last 12,000 years which have been so favourable to human development. Bringing emissions in line with carbon withdrawals is urgent because if the threshold is crossed, our planet could enter into an irreversible state much less advantageous to humans.

Despite the urgency and gravity of fossil-fuelled global warming, so little progress has been made to bring emissions in line with carbon withdrawal that decision-makers have given up on renaturing to the pre-industrial global temperature, and instead aim to limit global warming
to 1.5 °C–2 °C. Preventive action would have been required globally at the Rio Earth Summit in 1992 to halt fossil-fuelled global warming. The question now is whether further social practices will make it bad or very bad, leading to either limited or extensive degradation of the present human-supporting habitat.

No evidence exists that cost-effective technology will be promptly innovated to massively withdraw and safely store carbon dioxide from the atmosphere. Hence ‘to have at least a 50 percent chance of keeping the world below two degrees of warming, global emissions must steadily decline to zero and ultimately become negative (i.e. removing more CO₂ from the air than is added) in the second half of the century. … there is no way around the need to reduce emissions to near-zero or below’ (Harvey and Orbis 2018: 290). But annual emissions are currently about 35 gigatonnes or 70 trillion pounds of carbon dioxide and increasing (1 gigatonne = 1 billion tonnes; 1 tonne = 2000 pounds; hence 35 gigatonnes = 35 × 1,000,000,000 × 2000 = 70 trillion pounds). Emissions need to be reduced quickly to avoid tipping the planet into runaway global warming. If global warming had not caused drought in California and Australia, their wildfires would have been easily and inexpensively extinguished. Like the Notre Dame Cathedral fire and the corona (COVID-19) virus, if caught early, fossil-fuelled global warming would have been relatively easy and inexpensive to mitigate, but left to intensify, it is costly and hard to stop destructive dynamics of nature that have been unleashed.

In 2013, Berners-Lee and Clark (2013: xii, xiv) stated ‘scientists estimate that humans can pour roughly 565 more gigatonnes of carbon dioxide into the atmosphere by mid-century and still have some reasonable hope of staying below two degrees. … [but that] the amount of carbon already contained in the proven coal and oil and gas reserves’ is 2795 gigatonnes, namely five times more, which fossil-fuel companies and states plan to combust. Therefore 80% of proven reserves will have to be kept underground between now and 2050, and exploration halted. McGlade and Ekins (2015: abstract) distinguished types of fossil fuels and calculated that ‘globally, a third of oil reserves, half of gas reserves and over 80% of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2 °C. … [concluding that]
policy makers’ instincts to exploit rapidly and completely their territorial fossil fuels are, in aggregate, inconsistent with their commitments to this temperature limit’. Biello (2015) established that American, Russian, and Chinese coal reserves must not be exploited, nor should Middle Eastern natural gas reserves, nor Arctic oil, and that almost three-quarters of the oil in Canada's bituminous sands will have to remain in the sand. ‘At the rate we’re burning fossil fuels, we’ll have used up the entire carbon budget by 2028 – just over halfway into the budget period’ (Flannery 2015: 105–106). The International Energy Agency (IEA 2018) argued that carbon prices will have to rise substantially to reduce demand to meet the 2 °C limit, but if that is not done, global temperature increases will result in far more expensive impacts later. Necessary restraint confronts desires for fossil-fuelled economic growth by both companies and fossil fuel extracting countries.

Fossil fuels are not created equal. The combustion of coal emits more greenhouse gases than any of the others. Heavy oil and oil extracted from tar sands have higher emissions intensity per barrel than oil from wells. Natural gas emits less than the others but is still a carbon-emitting fossil fuel. Emissions could be significantly reduced while generating the same electricity by globally replacing thermal coal-fired electricity plants with renewable energy or nuclear energy, and even natural gas. Substituting natural gas for coal was the principal way the USA reduced emissions under the Obama Administration. But there are upward trends too. Since the 2000s, oil companies have been increasingly exploiting heavy crude oil, bitumen (tar sands), deepwater drilling, Arctic oil reserves, etc., and other remote locations (Hughes 2009; Davidson and Andrews 2013). These deposits require more energy to extract, upgrade, and transport, almost invariably supplied by fossil fuels, and hence emit more greenhouse gases per useful barrel. To attain a balance between emissions and withdrawal, the most energy and economic benefit must be obtained for the least emissions until carbon capture and storage or carbon removal technologies are implemented. Much of the most carbon-polluting fossil fuels, such as coal and unconventional heavy oil, will have to remain in the ground where they are safely stored to limit warming to 2 °C. The less polluting fossil fuels, like natural gas and conventional oil from wells, will have to be used first, judiciously and slowly, not rapidly.
Although different types of oil cause similar carbon pollution when combusted, they differ significantly in greenhouse-gas emissions to extract, upgrade, and transport. A Stanford University study (Masnadi et al. 2018) analysed 2015 data from 9000 oil fields in 90 countries, which accounted for 98% of global oil production, concerning extraction, and transportation of crude to refineries. It found that oil fields with the highest carbon intensity had almost triple the emissions compared to those with the lowest. Saudi Arabian oil had relatively low-carbon intensity because less energy and therefore less emissions were needed to extract oil from its wells and little flaring is done, whereas Venezuelan and Albertan tar sands oil had among the world’s highest emissions because their unconventional oil required more energy and emissions to extract. The study found that the carbon intensity of Alberta’s oil was 70% higher than the global average. Another study estimated that each barrel of oil generates 18 kilograms of greenhouse gases as the world’s average, but 44 kilograms for Alberta’s oil sands (Graney 2020).

Still another study (IHS Energy 2014) yields similar conclusions. The findings are presented in Fig. 2.5, which shows in yellow that combustion emissions for all types of oil are similar, but extraction, upgrading, and transportation emissions, called ‘well-to-retail pump’ and shown in blue,

![Fig. 2.5 Life cycle GHG emissions for various sources of crude oil (Source IHS Energy 2014)]
vary. The graph demonstrates that combining emissions from combustion with emissions from extraction, upgrading, and transportation of oil masks important differences between extractions from different sources. Calling the total “well to retail pump” is a misrepresentation of life cycle GHG emissions because many sources are not wells, because there are a variety of engines combusting it instead of just vehicles receiving it from retail gas pumps, and because the carbon ends up in the atmosphere. It would be more accurate to portray carbon as going from “ground to sky”, namely from safe storage in the ground to its threatening accumulation in the sky.

Table 2.1 gives a recalculation of Fig. 2.5’s blue part, showing emissions involved in getting the oil out of the ground, upgrading it, and transporting it to be combusted. For consistency with the previous graph, the label ‘well-to-retail pump’ is retained with the above caveat.

The concept ‘ethical oil’ could be assessed in terms intrinsic to oil, namely the extent to which its level of emissions are less likely to harm future generations by causing global warming. Table 2.1 shows that North Sea and Saudi oil are more ethical than heavy oil from California, Alberta, and Venezuela. The least carbon-polluting types of oil should be used first to give time for technical and social innovations to decrease emissions. But that is socially problematic because types of

| Source                       | GHG emissions for extracting, upgrading, and transporting various sources of crude oil (blue part ‘Well-to-retail pump’ of Fig. 2.5) |
|------------------------------|---------------------------------------------------------------------------------------------------------------|
| North Sea                    | 60                                                                                                           |
| Saudi Arabia                 | 70                                                                                                           |
| Average US Barrel Refined in USA (2005) | 80                                                                                                           |
| Alberta Oil Sands Low        | 90                                                                                                           |
| Russia Urals                 | 95                                                                                                           |
| Mexico Maya                  | 100                                                             | **California Heavy** | 160                                                            |
| Iraq Basra Light             | 115                                                             | **Alberta Oil Sands High** | 170                                                            |
| Nigeria Bonny Light          | 130                                                             | **Venezuela Petrozuata** | 180                                                            |
| Average Alberta Oil Sands Refined in USA (2012) | 135                                                            |**Source IHS Energy 2014** |
oil vary by country, implying that countries having the most polluting reserves should dramatically decrease extraction until the least polluting sources—North Sea and Saudi oil—are exhausted. Imagine the difficulty of convincing countries with high-emissions oil to slow down extraction.

The Underestimation of Global Warming

Estimates of global warming by the IPCC are consensus driven, which means they require agreement by scientists from all countries along with input by their governments. Many scientists are concerned this approach has resulted in underestimation of fossil-fuelled global warming (Heal 2017), with research showing that estimates of emissions reported by industry and government using United Nations protocols and internationally recommended methods understate the problem. This was known for methane but now has been demonstrated for carbon dioxide. Even the best bottom-up estimates of absolute emissions and intensities for Alberta’s oil sands, calculated by ground measurements and modelling, called Tier 3, underestimated emissions by 30% compared to actual top-down measurements done by aircraft flyovers of emitting facilities. The results indicate ‘64% higher annual GHG emissions from surface mining operations, and 30% higher overall OS [oil sands] GHG emissions (17Mt) compared to that reported by industry, despite emissions reporting which uses the most up to date and recommended bottom-up approaches’ (Liggio et al. 2019: abstract). They infer that emissions globally may be universally underestimated. What the authors call ‘the unaccounted emissions’ may be one factor in explaining more-rapid-than-expected global warming, including rapid melting of the Arctic ice cover.

Wagner and Weitzman (2015) demonstrated that the possibility of catastrophic outcomes of fossil-fuelled global warming is not being taken into account, even in modelling by environmental economists, because the probability is relatively small. But it is not zero and low probability high-impact events occur all the time in nature (think of the COVID-19
pandemic). Hence in what is called the Dismal Theorem, they conclude that estimates of the threat are understated, rosy cost–benefit analyses are dubious, and that it is essential to take into account catastrophic, low probability consequences of global warming.

Most attention concerning greenhouse-gas emissions has been paid to the combustion of fossil fuels for the production of electricity and transportation. However the fastest growing sector of oil consumption, especially high-emissions heavy oil, involves petrochemicals: fertilizers, plastics for packaging, digital devices, car parts, clothing, etc. Petrochemical refineries are particularly profitable and being built rapidly. The executive director of the International Energy Agency stated: ‘Petrochemicals are one of the key blind spots in the global energy [and emissions] debate, especially given the influence they will exert on future energy [and emissions] trends’ (quoted in Willis 2019: B5).

What Is Needed to Limit Global Warming to 2 °C?

The president of the International Institute for Sustainable Development (Vaughan 2014: 4) concluded that a ‘40 per cent to over 60 per cent decrease in greenhouse gas emissions in the near term and net zero emissions must be achieved between 2050 and 2100 to keep under the 2 degree Celsius cap’. Flannery (2015: 202) quoted a United Nations study showing ways how the 15 highest emitting countries, which total 70% of global emissions, could reduce their emissions in half while tripling their economic output. In an article in Science, Rockström et al. (2017) present the following schedule, which they call a roadmap, of specifically what is needed and when it is needed to limit warming to 2 °C.

2017–2020
Global carbon emissions need to peak by 2020 and decline thereafter. Emissions trading needs to increase to a price of $50/ton, much more than triple what California emissions traded at in 2017. The Paris agreement needs to be enhanced.

2020–2030
Short-haul air traffic needs to be replaced by rapid rail, carbon taxes imposed on air transport and shipping, development of alternate aircraft
propulsion must begin, and technical removal of CO\textsubscript{2} from the atmosphere must be scaled up from zero at present.

**2030–2040**

By 2040 oil will need to exit the global energy mix. Road transportation, shipping, and aircraft will have to become carbon neutral. Emissions-free concrete and steel need to become omnipresent.

This roadmap estimates what is needed and when it is necessary. Jaccard (2018: A13) is somewhat less stringent arguing that oil demand needs to be reduced about 33% by 2050 to meet the 2 °C target. Nevertheless, there is broad scientific consensus oil demand needs to be dramatically reduced soon. These changes will be difficult, annoying, and expensive. To pay for them, Rockström et al. (2017) suggest appropriate international corporate taxes and inheritance taxes on historical wealth generated by fossil fuels to retroactively include previously externalized costs in their price. Such political-economic innovations do not currently exist and would be fiercely opposed in a tax reticent world, which underscores that fossil-fuelled climate change is a social problem, not just a physical one. This roadmap demonstrates the depth and urgency of the problem, and the socioeconomic difficulty of dealing with it. If decision-makers and populations refuse to take a road like this towards emancipation from excessive carbon emissions compared to withdrawals, science forecasts fossil-fuelled social practices will increase global warming more than 2 °C compared to the pre-industrial period, with all the dangers that entails. The 2017–2020 specification in the roadmap provides a valuable near-term reference marker to make visible whether humanity globally and individual countries are on the road to limiting global warming to 2 °C or on the path to making it much worse.

Building sufficient windmills, solar panels, geothermal equipment, batteries to store energy, etc., requires materials. It has been estimated that three billion tons of minerals and metals will be needed by 2050 to build this low-carbon energy infrastructure to limit global warming to 2 °C: graphite, lithium, cobalt, copper, aluminum, nickel, molybdenum, and chromium (World Bank Group 2020). These are found only
where nature’s processes put them, in some cases in only one country such as the war-torn Democratic Republic of Congo for cobalt and China for graphite. The minerals extraction industry is itself a significant carbon emitter, but the report estimated that its emissions would only be 6% of fossil-fuel emissions, a significant reduction. Nevertheless this would be equal to the 2018 emissions of the USA and China. Recycling would have to be scaled up greatly, but even then, additional materials would have to be dug out of the ground. Aluminum is widely used in low-carbon energy production, but requires much energy for its production, which would have to be low carbon. The demand for energy by a 7.7 billion human population has a huge impact on the planet’s climate, but it can be made less damaging.

The Anthropocene

Science and technology, greater organizational efficiencies, market capitalism, and modern legal systems, what Weber (1930, 1978; see also Murphy 1994) called rationalization, have led to much greater consumption, conveniences, and life expectancy. This resulted in rapid population growth, increased extraction of raw materials transformed into commodities, and a globalization of pollution into the atmosphere and oceans. Fossil fuels have been the inanimate energy source for all this. Although there has been a long slow increase of the impact of human activities throughout evolution, the inflection point to an exponential rise is very recent in geological terms. The increasing impact of human activities on the biosphere of planet Earth has led to debate among scientists (Crutzen and Stoermer 2000; Steffen et al. 2011, 2015; Finney and Edwards 2016) concerning whether the present epoch should be characterized as the Anthropocene, that is, fundamentally different from the Holocene which lasted 12,000 years and was propitious for the development of humanity and societies. ‘The Anthropocene is a proposed new geological epoch (1) based on the observation that human impacts on essential planetary processes have become so profound (2) that they have driven the Earth out of the Holocene epoch in which agriculture, sedentary communities, and eventually, socially and technologically complex
human societies developed’ (Steffen et al. 2018). When pressed to give a starting point to the Anthropocene, 1945 is usually the designated year. Since 1945 was also the first time in human history that nature’s forces were reconfigured into atomic bombs and deployed to kill hundreds of thousands of civilians in cities, this should alert us that the development of human rationality and technology is not only a major accomplishment with beneficial consequences but also brings significant risks of harmful and irrational consequences.

Agreed that social practices are now having an impact on our planet unlike any other epoch in its existence. But notes of caution are needed before welcoming the concept “Anthropocene” into the social sciences (for others see Lidskog and Waterton 2016). Acceptance of the postulate that we are now in the Anthropocene does not give warrant to popular conceptions of the mastery of nature by human reason, the ‘ultimate resource’ (Simon 1981, 1996), nor does it support reliance on the premise that technological innovation will always give humans the capacity to adapt to anything nature throws at us as a result of human activities, such as global warming. Neither does it support social science narratives in the 1990s about the social construction of nature (Eder 1996; Evernden 1993). Even scientific proponents of the concept Anthropocene see humanity as at most a force equal in impact to other processes of nature. Nature’s dynamics are still there, with human activities superimposed upon them (Adam 1995, 1998, 2000; Adam, Beck, and Loon 2000). Natural scientists must avoid naturalizing our present epoch, and social scientists must resist sociologizing it.

Far from entering the driver’s seat of planetary change, it is equally possible that the enormous consequences of social practices are tipping the planet into new dynamics of nature’s driverless transformations beyond human control. Even if humanity were to become the driver, it does not imply that the cliff ahead has been eliminated. The fact that social practices are causing global warming and climate change (IPCC 2013, 2018), degradation of oceans, biodiversity loss, etc., implies that this could result in nature’s forces becoming more threatening by unleashing more powerful cyclones, flooding, droughts, wildfires, ocean level rise, dead zones in the ocean, etc. The Anthropocene could paradoxically usher in a subsequent biophysical epoch where nature’s
autonomous dynamics would be less propitious for sustaining human
life and prosperity than in the Holocene. That is the concern of many
scientists who argue that sustainability in the Anthropocene requires that
humans modify their impacts on their biophysical environment.

The Anthropocene could be short if social practices trigger the emergence of stronger forces of nature which overpower human control. It could even be a mirage—more apparent than real and always receding from control—which is why specialists hesitate to label the period ‘the Anthropocene’. Although it is improbable that the impact of social practices could throw the planet back to a Paleocene–Eocene Thermal Maximum, their interaction with the global forces of nature results in uncertainty rather than predictability. The interaction leads to not only nature’s future dynamics that we know we do not know (known unknowns) but also to other forces of nature that we can’t even image at present and don’t even know that we don’t know (unknown unknowns). This uncertainty concerning never before experienced powerful forces of nature is another reason why it is folly to presume that market-based technological innovation will always be able to master nature’s dynamics.

**Limitations of Science**

Undeniably science has limitations. Its applications enable the extraction of bountiful fossil fuels in deep oceans, the Arctic, shale, tar sands, etc., but have not enabled emissions-free combustion. It can document the carbon buildup in the atmosphere, the resulting greenhouse effect, and the occurrence of global warming due to the combustion of fossil fuels, but because planetary dynamics consist of a very complex multicausal system, science cannot specify the timing, location, and detailed impacts. For hurricanes, science can predict days in advance their trajectory and force reasonably well, but applied science is incapable of stopping or even weakening them. Hence the only action to decrease fatalities is to get out of harm’s way by evacuation. Because applied science has not yielded a cost-effective way to combust fossil fuels without emitting greenhouse gases, getting out of harm’s way for the threat caused by humans combusting fossil fuels would involve moderating the social
practices that emit greenhouse gases and cause harm. For an intense wild-
fire or hurricane or more frequent sets of them, at present science can
only conclude that such consequences fit what one would expect from
the scientific understanding of an increasingly carbon-laden, greenhouse-
engendering atmosphere. Such answers are not very satisfying, however,
for decision-makers and populations who frame questions in terms of
whether this specific wildfire or hurricane is or is not caused by global
warming. Hence the temptation is great to push the scientific under-
standing of global warming to the back of the mind and shelve annoying
and costly but necessary measures to mitigate the problem. Impact
natural science has given convincing evidence and a logical explanation
of where the climate is going because of fossil-fuelled global warming,
but there remain many uncertainties concerning the details of the threats.
The direction of travel is foreseeable but the specifics of the destinations
are unforeseeable. This creates problems for adaptation and constructing
resilience as a response because there is much uncertainty concerning
what society will need to adapt to and bounce back from. Worse still,
it is not sure that adaptation and resilience will be possible if global
warming tips the climate into a state significantly less beneficial to
humans, perhaps irreversibly so. Prevention is admittedly difficult and
bothersome, but it may turn out to be more feasible than adaptation
and resilience.

Science as Both Feckless and All-Powerful
to Master Nature

Earth system scientists have studied trajectories between different global
biophysical epochs separated by thresholds determined by feedbacks,
interactions, and non-linear processes. Their conclusions indicate the
gravity, urgency, and scope of the fossil-fuelled climate crisis. ‘Social and
technological trends and decisions occurring over the next decade or
two could significantly influence the trajectory of the Earth System for
tens to hundreds of thousands of years and potentially lead to condi-
tions that resemble planetary states that were last seen several millions
of years ago, conditions that would be inhospitable to current human
societies and to many other contemporary species’ (Steffen et al. 2018). This warning refers to discounting danger and it clearly places responsibility on social and technological trends (read fossil-fuelled ones) and decisions. It is a conclusion based on a peer-reviewed scientific study published in a renowned scientific journal presenting the best available evidence and understanding. There is no excuse for the population and especially leaders to ignore that conclusion because it and links to the study appeared in quality newspapers, television channels, and social media. The outcome could be otherwise if societies reduce their emissions to match rates of greenhouse gas withdrawal from the atmosphere, which means having the foresight to change their fossil-fuelled social practices. However, this is not being done.

Science has been portrayed as a powerful cultural force in modern societies, but in the case of the fossil-fuelled climate crisis, science seems feckless when it comes to inciting societies to change their harmful social practices. Hydrocarbons continue to be extracted in huge amounts from safe storage in the ground and combusted to accumulate in the atmosphere. Blühdorn (2011: 36) notes the strange combination of recognition of the environmental crisis and need for urgent change documented by science but the unwillingness of the population and leaders to do that change. The warnings of science are ignored when they bring troubling news that fossil-fuelled social practices threaten to incubate a global catastrophe and when it counsels changing fossil-fuelled social practices. Nordhaus (2013: 307) concludes that ‘when science collides with deep convictions (such as those on religion or politics), conviction often trumps science, even for those who are highly educated’. Scientific predictions of the incubation of climate catastrophe have not resulted in emancipation of societies from dangerous fossil fuels. Instead, the impotence of predictions of environmental catastrophe when confronting near-term economic interests have led to a type of anticipation in which little that is adequate is being done to diminish the threats.

Nevertheless, to legitimate maintaining current fossil-fuelled practices, science is assumed capable of empowering societies to adapt just in time to their unleashing of dangerous new forces of nature in the future and resiliently solving environmental problems on demand. This belief will
be examined in Chapter 9. These are two social sides of science: influence where its applications bring benefits but lack of influence when indicating the danger of fossil-fuelled climate change. A biophysical transformation of climate and the environment is occurring as a result of fossil-fuelled social practices, but a sociocultural, politico-economic, and technological transformation appropriate for dealing with its scale and urgency is lagging far behind. The focus of social science analysis must include the investigation of why the scientifically documented urgent problem of climate change is being socially defined as a non-problem (Freudenburg 2006) or a non-urgent problem that can be discounted, shelved in the back of the mind, and not incite preventive action.

A Social Science Analysis Needed

Although the impact applied natural sciences have documented what is necessary and provided a roadmap to mitigate fossil-fuelled climate change, they run up against production scientists, the power of the fossil-fuel industry, other vested interests, path dependency, habitus, and sense of entitlement to fossil-fuelled social practices. It cannot be presumed that impact science will win this confrontation. Needs are not always met. Nevertheless, it is important to keep in mind the best available understanding of problems in order to deal with them. This is especially true for anthropogenic global warming. Hardly a day goes by without the media reporting on new wind farms in China and Texas, the reduction in price of solar panels, electric vehicles, etc. There is much less reporting, if any, on whether carbon emissions are exceeding withdrawal rates, on the increase in carbon dioxide in the atmosphere, and on the rise in global atmospheric temperature. Valuable as renewable energy is, it does not reduce global warming unless it replaces the combustion of fossil fuels and reduces emissions to the level of carbon withdrawals. The upsurge in renewable energy is so far going hand in hand with the intensification of atmospheric carbon pollution. Subtraction of fossil fuels, not just addition of renewable energy, is urgently needed.
The conclusions of impact science have important socioeconomic implications. Fossil-fuelled climate change threatens to be very costly and impose involuntary economic sacrifices, lower standards of living, and downward intergenerational mobility for future generations as a result of a degraded natural environment with more dangerous forces of nature. Unless science is totally wrong or unless a safe, cost-effective, technological breakthrough is implemented promptly and globally to bring emissions in line with carbon withdrawal, which shows no sign of appearing, the pace of extraction and combustion of fossil fuels will need to slow down drastically to mitigate global warming, and the most polluting types of fossil fuels will have to be left safely in the ground. The future will bring a discontinuity from present fossil-fuelled normality. Either fossil-fuelled normality will be (i) disrupted by the unintended harmful perverse consequences of fossil-fuel combustion unleashing dangerous new forces of nature through global warming, or (ii) disrupted by the socially purposive emancipation from fossil fuels thereby intentionally changing to low-carbon polluting societies. Destruction of present fossil-fuelled normality is coming, but we don’t know when. The issue is whether it will be harmful destruction, injurious to societies and their members, or creative destruction leading to safer, more sustainable relations with the natural world.

The ideal solution based on the evidence from impact science would consist of an immediate leap to an economy having dramatically reduced emissions and/or radically enhanced carbon withdrawals. With current technology, the optimal way to do this is to combust fossil fuels only for functions for which there is no clean alternative, for example aviation combined with restraint in flying, and switch to non-carbon-polluting energy for other functions, such as electricity generation. On the resource side, it would be atmospherically optimal to combust only those fossil fuels whose use contributes least to emissions and leave others in the ground at least until carbon capture and storage and atmospheric carbon removal technologies are perfected and economically feasible. As shown in Fig. 2.1 and Table 2.1, this implies using natural gas first, as well as North Sea oil and Saudi oil, but leaving coal in the ground and also keeping heavy oil, bituminous sands oil, etc., underground for the
near term. Since deposits of these resources are territorially based, this provides a technical climatological answer to the question of whose resources should be used first and whose should be left in the ground at present.

However, this answer is socioeconomically challenging because of the tension between goals of near-term, local, path-dependent economic prosperity, and those of a long-term clean, global, sustainable economy, and environment. Populations and principal decision-makers insist on retaining their sense of entitlement to inexpensive fossil-fuel energy and resulting carbon-polluting practices. Leaders have been elected who roll back global warming mitigation measures already taken. Social action and practices driven by interests, predispositions, and values determine the road actually being travelled now and in the future, the direction along this road, and the speed. Hence they determine whether impact natural science and its recommendations are being acted upon or ignored and whether global warming is being mitigated or worsened.

Only emphasizing these scientific conclusions may not necessarily be the best way to accomplish emission-reduction goals, and may even cause citizens deeply attached to fossil-fuel normality to give up hope and trigger what Beck (1995: 48–49) referred to as a ‘death reflex of normality’. In the USA, the main determinant of whether one accepts the science of fossil-fuelled climate change and pricing carbon pollution to remedy it is political affiliation: Democrats accept it and Republicans don't (Dunlap, McCright, and Yarosh 2016). This division has grown over time even among the educated. It may be more strategic to proceed indirectly by underscoring near-term benefits (Pielke 2010) such as opportunities and jobs in the renewable energy sector, or energy security (Giddens 2009). Indirect approaches may be more effective in inciting social change. But strategies of what is socially acceptable in a particular conjuncture must not be mistaken for what is needed, which has to be kept in mind. Basing social science and policy analyses on the best available scientific evidence should not be portrayed as deploying scare tactics. Even if evidence is scary, social scientists, decision-makers, and populations need to face up to it and not denigrate it as scaremongering.
There is a need for a social science analysis of why so little is being done, even as carbon pollution accumulates in the atmosphere worsening the greenhouse effect, despite the compelling science of the problem. Natural science conceptions typically talk of the human impact on our planet, depicting an undifferentiated humanity as the cause, and a homogeneous humanity as suffering the effects. Hence they fail to capture the socioeconomic dynamics that are drivers of human impacts in the Anthropocene. In the next chapter, that oversimplified conception will be corrected by using the social closure theoretical framework to explain how humanity is differentiated and to help elucidate those socioeconomic drivers.

Notes

1. A simplified explanation of the greenhouse effect is given by Heal (2017: 205 fn. 2). ‘CO$_2$ blocks heat leaving the earth but not coming in because they are at different wavelengths: incoming heat is ultraviolet and outgoing heat, because it has lost energy, is mainly infrared. CO$_2$ is opaque to infrared but not to ultraviolet’.

2. Gasoline is about 87% carbon and 13% hydrogen by weight, so 5 gallons (31 pounds) contains about 27 pounds of carbon. When gasoline is combusted, the carbon and hydrogen separate, with the carbon combining with oxygen to form carbon dioxide and the hydrogen combining with oxygen to form water. A carbon atom has an atomic weight of 12, an oxygen atom 16; therefore each carbon dioxide molecule (CO$_2$) has an atomic weight of 44 (= 12 + 2 × 16). Hence 5 gallons of gasoline containing 27 pounds of carbon produces about 100 (= 44/12 × 27) pounds of carbon dioxide. See https://www.fueleconomy.gov/feg/contentIncludes/co2_inc.htm.

3. The specific figure of temperature rise varies according to the chosen starting date and end date and whether a year is chosen (e.g. 1880) or a period (1880–1920).

4. Unconventional fossil fuels refer to heavy oil, shale gas, tar sands oil, kerogen, coal-bed methane, etc.

5. Rumsfeld (2011) became notorious for making these distinctions, which are nevertheless important.
References

Adam, Barbara. 1995. *Timewatch: The Social Analysis of Time*. Cambridge, UK: Polity Press.

Adam, Barbara. 1998. *Timescapes of Modernity: The Environment and Invisible Hazards*. London: Routledge.

Adam, Barbara. 2000. The Media Timescapes of BSE News. In *Environmental Risks and the Media*, ed. S. Allan, B. Adam, and C. Carter, 117–129. London: Routledge.

Adam, Barbara, Ulrich Beck, and Joost van Loon (eds.). 2000. *The Risk Society and Beyond: Critical Issues for Social Theory*. London: Sage.

Beck, U. 1995. *Ecological Politics in an Age of Risk*. Cambridge: Polity.

Berners-Lee, M., and D. Clark. 2013. *The Burning Question*. London: Profile.

Biello, D. 2015. Where in the World Are the Fossil Fuels That Cannot Be Burned to Restrain Global Warming. *Scientific American*, 7 January.

Blühdorn, I. 2011. The Politics of Unsustainability: COP15, Post-Ecologism, and the Ecological Paradox. *Organization & Environment* 24 (1): 34–53.

CDIAC. 2018. *Carbon Dioxide Information Analysis Center*. Berkeley: U.S. Department of Energy. cdiac.Ess-dive.lbl.gov.

Crutzen, P.J., and E.F. Stoermer. 2000. The “Anthropocene”. *Global Change Newsletter* No. 41: 17–18.

Davidson, D., and J. Andrews. 2013. Not All About Consumption. *Science* 339 (6125): 1286–1287.

Dunlap, R., A. McCright, and J. Yarosh. 2016. The Political Divide on Climate Change: Partisan Polarization Widens in the U.S. *Environment Science and Policy for Sustainable Development* 58 (5): 4–23.

Dyer, Gwynne. 2008. *Climate Wars: The Fight for Survival as the World Overheats*. Toronto: Random House.

Eder, K. 1996. *The Social Construction of Nature*. London: Sage.

Evernden, N. 1993. *The Social Creation of Nature*. New Haven: Yale University Press.

EPA United States Environmental Protection Agency. 2017a. *Climate Change Indicators in the United States 2016: Greenhouse Gases*. www.epa.gov/climate-indicators/greenhouse-gases. Accessed 3 November 2017.

EPA. 2017b. Causes of Climate Change. *United States Environmental Protection Agency*. https://19january2017snapshot.epa.gov/climate-change-science/causes-climate-change_.html. Accessed 17 April 2020.
Finney, S.C., and L.E. Edwards. 2016. The “Anthropocene” Epoch: Scientific Decision or Political Statement? *GSA Today [Geological Society of America]* 26 (3): 4–10.

Flannery, Tim. 2015. *Atmosphere of Hope: Searching for Solutions to the Climate Crisis*. New York: Atlantic Monthly Press.

Freudenburg, W. 2006. Environmental Degradation, Disproportionality, and the Double Diversion. *Rural Sociology* 71 (1): 3–32.

Giddens, Anthony. 2009. *The Politics of Climate Change*. Cambridge: Polity Press.

Government of Canada. 2019. *Greenhouse Gas Sources and Sinks: Executive Summary 2019*. Ottawa: Government of Canada. https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/sources-sinks-executive-summary-2019.html. Accessed 19 April 2019.

Graney, Emma. 2020. Newfoundland Warns of Oil Exodus Without Federal Aid. *Globe and Mail*, 27 May: B1, B4.

Harvey, Hal, and Robbie Orbis. 2018. *Designing Climate Solutions: A Policy Guide for Low-Carbon Energy*. Washington: Island Press.

Hawkins, Ed, Pablo Ortega, and Emma Suckling. 2017. Estimating Changes in Global Temperature Since the Preindustrial Period. *AMS American Meteorological Society Journals Online*. https://journals.ametsoc.org/doi/full/10.1175/BAMS-D-16-0007.1. Accessed 31 May 2018.

Heal, Geoffrey. 2017. *Endangered Economies: How the Neglect of Nature Threatens Our Prosperity*. New York: Columbia University Press.

Hughes, J.D. 2009. The Energy Issue. In *Carbon Shift*, ed. T. Homer-Dixon, 58–95. Toronto: Random House.

IEA International Energy Agency. 2018. Global Energy Demand Grew by 2.1% in 2017, and Carbon Emissions Rose for the First Time Since 2014. *International Energy Agency*. 22 March. Paris: IEA. https://www.iea.org/newsroom/news/2018/march/global-energy-demand-grew-by-21-in-2017-and-carbon-emissions-rose-for-the-firs.html. Accessed 23 March 2018.

IHS Energy. 2014. *Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil*, May. Natural Resources Canada. http://www.nrcan.gc.ca/energy/publications/18731. Accessed 20 February 2017.

IPCC Intergovernmental Panel on Climate Change. 2013. *Fifth Assessment Report Climate Change 2013*. http://www.climatechange2013.org/images/uploads/WGIAR5-SPM_Approved27Sep2013.pdf. Accessed 28 September 2013.
IPCC. 2018. *Global Warming of 1.5 °C*. http://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf. Accessed 8 October 2018.

IPCC. 2019. *The Ocean and Cryosphere in a Changing Planet*. https://report.ipcc.ch/srocc/pdf/SROCC_SPM_Approved.pdf. Accessed 25 September 2019.

Jaccard, Mark. 2018. Divisive Carbon Taxes Are Much Ado About Nothing. *The Globe and Mail*, 15 December: O4.

Kolbert, Elizabeth. 2014. *The Sixth Extinction*. New York: Henry Holt and Company.

Liggio, John, Shao-Mend Li, Ralf M. Staebler, Katherine Hayden, Andrea Darlington, Richard L. Mittermeier, Jason O’Brien, Robert McLaren, Mengistu Wolde, Doug Worthy, and Felix Vogel. 2019. Measured Canadian Oil Sands CO₂ Emissions Are Higher Than Estimates Made Using Internationally Recommended Methods. *Nature Communications* 10: 1863. https://doi.org/10.1038/s41467-019-09714-9; www.nature.com/naturecommunications. Accessed 23 April 2019.

Lidskog, R., and C. Waterton. 2016. Anthropocene: A Cautious Welcome from Environmental Sociology. *Environmental Sociology* 2 (4): 395–406.

Masnadi, M., et al. 2018. Global Carbon Intensity of Crude Oil Production. *Science* 361 (6405): 851–853. https://doi.org/10.1126/science.aar/6859.

McGlade, C., and P. Ekins. 2015. The Geographical Distribution of Fossil Fuels Unused When Limiting Global Warming to 2 °C. *Nature* 517: 187–190.

Murphy, Raymond. 1994. *Rationality and Nature*. Boulder: Westview.

Murphy, Raymond. 2015. The Emerging Hypercarbon Reality, Technological and Post-carbon Utopias, and Social Innovation to Low Carbon Societies. *Current Sociology* 63 (3): 317–338.

NASA Earth Observatory. 2007. If We Stabilized Greenhouse Gas Emissions at Today’s Rates, Would Global Warming Stop? http://earthobservatory.nasa.gov/blogs/climateqa/stabilize-gg-emissions-effects/. Accessed 28 December 2015.

NASA. 2018. Long-Term Warming Trend Continued in 2017: NASA and NOAA. *Global Climate Change Vital Signs of the Planet*. https://climate.nasa.gov/news/2671/long-term-warming-trend-continued-in-2017-nasa-noaa/. Accessed 28 April 2019.

Nordhaus, William. 2013. *The Climate Casino: Risk, Uncertainty, and Economics for a Warming World*. New Haven: Yale University Press.

Pielke, Roger Jr. 2010. *The Climate Fix*. New York: Basic Books.
Pinker, Steven. 2018. Doomsday Is (Not) Coming. *Globe and Mail*, 24 February: O1, O6–O7.

Rasool, S. Ichtiaque, and Stephen Schneider. 1971. Atmospheric Carbon Dioxide and Aerosols: Effects of Large Increases on Global Climate. *Science* 173: 138–141.

Rockström, Johan, Owen Gaffney, Joeri Rogeli, Malte Meinshausen, Nebojsa Nakicenovic, and Hans Schellnhuber. 2017. A roadmap for Rapid Decarbonisation. *Science* 355 (6331): 1269–1271.

Rumsfeld, Donald. 2011. *Known and Unknown: A Memoir*. New York: Penguin.

Schneider, S. 2009. *Science as a Contact Sport*. Washington: National Geographic.

Simon, Julian. 1981. *The Ultimate Resource*. Princeton: Princeton University Press.

Simon, Julian. 1996. *The Ultimate Resource 2*. Princeton: Princeton University Press.

Steffen, W., J. Grinevald, P. Crutzen, and J. McNeill. 2011. The Anthropocene: Conceptual and Historical Perspectives. *Philosophical Transactions of the Royal Society A* 369 (1938): 842–867.

Steffen, W., W. Broadgate, L. Deutsch, O. Gaffney, and C. Ludwig. 2015. The Trajectory of the Anthropocene: The Great Acceleration. *The Anthropocene Review* 2 (1): 81–98.

Steffen, Will, Johan Rockström, Katherine Richardson, Timothy Lenton, Carl Folke, Diana Liverman, Colin Summerhayes, Anthony Barnosky, Sarah Cornell, Michel Crucifix, Jonathan Donges, Ingo Fetzer, Steven Lade, Marten Scheffer, Ricarda Winkelmann, and Hans Joachim Schellnhuber. 2018. Trajectories of the Earth System in the Anthropocene. *PNAS Proceedings of the National Academy of Sciences of the United States of America* 115 (33) (August 6): 8252–8259. https://doi.org/10.1073/pnas.1810141115. Accessed 7 August 2018.

UNEP United Nations Environmental Programme. 2019. *Emissions Gap Report 2019 Executive Summary*. Nairobi: UNEP. https://wedocs.unep.org/bitstream/handle/20.500.11822/30798/EGR19ESEN.pdf?sequence=13. Accessed 26 November 2019.

Vaughan, Scott. 2014. The Challenge of Extreme Events and Their Impacts. *International Institute for Sustainable Development Speech*. Canadian Climate Forum’s Symposium on Extreme Weather and Adaptation 23 April: 4.
Wagner, Gernot, and Martin Weitzman. 2015. *Climate Shock: The Economic Consequences of a Hotter Planet*. Princeton: Princeton University Press.

Walker, X.J. et al. 2019. Increasing Wildfires Threaten Historic Carbon Sink of Boreal Forest Soils. *Nature* 572 (7770) (August): 520–523.

Weber, Max. (1904–1905) 1930. *The Protestant Ethic and the Spirit of Capitalism*, trans. Talcott Parsons. London: Unwin.

Weber, Max. (1922) 1978. *Economy and Society*, ed. Guenther Roth and Claus Wittich. Berkeley: University of California Press.

Willis, Andrew. 2019. The Future Is Plastics: Murray Edwards, Li Ka-Shing Add to Oil Patch Holdings as Others Flee. *Globe and Mail*, 7 July: B1, B5.

World Bank Group. 2020. Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition. *Climate Smart Mining Facility*. Washington: The World Bank. http://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf. Accessed 15 May 2020.

World Meteorological Organization WMO. 2019. *Global Climate in 2015–2019: Climate Change Accelerates*. https://public.wmo.int/en/media/press-release/global-climate-2015-2019-climate-change-accelerates. Accessed 23 September 2019.

York, Richard. 2010. Three Lessons from Trends in CO2 Emissions and Energy Use in the United States. *Society and Natural Resources* 23 (12): 1244–1252.

York, Richard. 2012a. Asymmetric Effects of Economic Growth and Decline on CO2 Emissions. *Nature Climate Change* 2 (11): 762–764.

York, Richard. 2012b. Do Alternative Energy Sources Displace Fossil Fuels? *Nature Climate Change* 2 (6): 441–443.