THE *SUNDAY TIMES* BESTSELLER

HANNAH RITCHIE

Not the End of the World

Surprising facts, dangerous myths and hopeful solutions for our future on planet Earth

'Truly essential'
Margaret Atwood

'Shines with positivity'
Rutger Bregman

'Uplifting'
The Times

'Inspiring'
David Wallace-Wells


VINTAGE

About the Author

Dr Hannah Ritchie is Senior Researcher in the Programme for Global Development at the University of Oxford. She is also Deputy Editor and Lead Researcher at the highly influential online publication Our World in Data, which brings together the latest data and research on the world's largest problems and makes it accessible for a general audience. Her research appears regularly in the *New York Times*, *Economist*, *Financial Times,* BBC, *WIRED*, *New Scientist* and *Vox* and in bestselling books including Steven Pinker's *Enlightenment Now*, Hans Rosling's *Factfulness* and Bill Gates's *How to Prevent a Climate Disaster*. In 2022, Ritchie was named Scotland's Youth Climate Champion and *New Scientist* called her 'The woman who gave COVID-19 data to the world'.

Hannah Ritchie

NOT THE END OF THE WORLD

How We Can Be the First Generation to Build a Sustainable Planet

VINTAGE

Contents

For my parents,
the perfect mix of heart and mind

Introduction

It has become common to tell kids that they're going to die from climate change. If a heatwave doesn't get them then a wildfire will. Or a hurricane, a flood, or mass starvation. Incredibly, many of us hardly blink before telling our children this story. It shouldn't, then, come as a surprise that most young people think their future is in peril. There is an intense feeling of anxiety and dread about what the planet has in store for us.

I see this daily in the emails that land in my inbox. But it's also reflected in research from across the world.[1] A recent global survey asked 100,000 16- to 25-year-olds about their attitudes to climate change.[2] More than three-quarters thought the future was frightening, and more than half said 'humanity was doomed'. The feelings of pessimism were widespread, from the UK and US to India and Nigeria. Regardless of wealth or security, young people the world over feel like they're hanging on for dear life.

In the same survey, two in five were hesitant to have children. In a 2020 poll of American adults (of all ages) without children, 11% said climate change was a 'major reason' for not having them, and 15% more said it was a 'minor reason'.[3] In younger adults, aged 18 to 34, the share was even higher. One respondent said she felt 'like I can't in good conscience bring a child into this world and force them to try to survive what may be apocalyptic conditions'.[4] Of those surveyed, 6% said they regretted having children because they felt despair about their future in a changing climate.

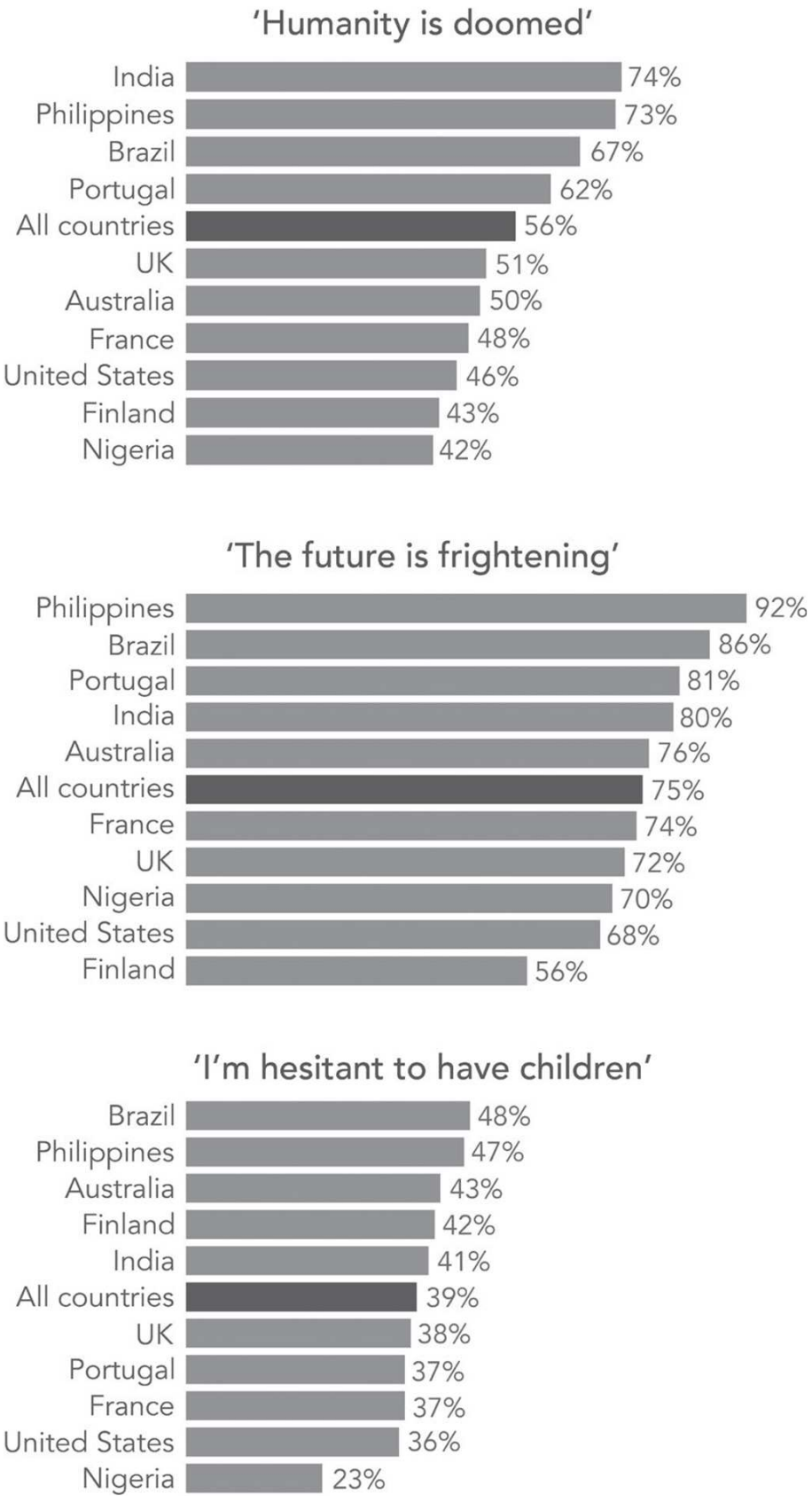
It's tempting to dismiss these views as empty words. But a recent study, not looking at surveys but actual data on people's reproductive decisions, suggests non-environmentalists are 60% more likely to have children than committed ones.[5] Of course, this may not be the *only* reason environmentalists are less likely to have children, but it gives us some concrete evidence that when people say they're anxious about having kids, they're not bluffing. If people aren't bluffing about their hesitation to have kids, they're probably not bluffing about their feelings of doom and anxiety either. Closer to home, I know these feelings are real, because I've been there. I too used to be convinced that I didn't have a future left to live for.

How to turn the world upside down

I spend most of my time thinking about the world's environmental problems. It's my job and my passion, but I nearly gave up on it.

In 2010 I started my degree in Environmental Geoscience at the University of Edinburgh. I showed up as a fresh-faced 16-year-old, ready to learn how we were going to fix some of the world's biggest challenges. Four years later, I left with no solutions. Instead, I felt the deadweight of endless unsolvable problems. Each day at Edinburgh was a constant reminder of how humanity was ravaging the planet. Global warming, sea-level rise, ocean acidification, dead coral reefs, starving polar bears, deforestation, acid rain, air pollution, overfishing, oil spills and the annihilation of the world's ecosystems. I don't remember hearing about a single positive trend.

During my time at university, I made a conscious effort to keep up with the news. I needed to be informed about the state of the world. Everywhere were images of natural disasters, droughts and hungry faces. More people seemed to be dying than ever before, more were living in poverty, and more children were starving than at any time in history. I believed I was living through humanity's most tragic period.



Many young people think the world is doomed due to climate change
Share of young people, aged 16 to 25 years old, who agreed with the following statements about our future due to climate change.

As will be seen, all of these assumptions were wrong. In fact, in nearly every case the world was moving in the opposite direction. You might think such basic misconceptions would be squashed during a four-year stint at a world-leading university. They weren't. If anything, they became even more ingrained, the shame of our ecological sins getting heavier with every lecture.

Those years made me feel helpless. Despite working relentlessly to get my degree, I was ready to turn my back on my obsession and find a new career path. I started applying for jobs far away from environmental science. Then, one evening, everything changed. I saw bubbles darting across the television screen. A small man was chasing after them.

'In my lifetime former colonies gained independence and finally they started to get healthier, and healthier and healthier. Now here they come! Countries in Asia and Latin America start to catch up with the Western countries.' The bubbles were red and green and superimposed on a graph that looked almost holographic. The man started waving his arms around, pushing and then dragging the bubbles across the screen. His excitement made it hard to pin down his accent but I thought he might be Swedish. 'And here Africa comes!' he shouted.

The man was Hans Rosling. If you know of him already, you can probably remember the first time you were introduced. If you don't, I'm a bit jealous: you still have the chance to discover his magic for the first time. Rosling was a Swedish physician, statistician and public speaker. A review of his work in *Nature* captures him well: 'Three minutes with Hans Rosling will change your mind about the world.'[6] It changed mine.

You see, my understanding of the world was wrong. Not just slightly wrong. I'd assumed *everything* was getting worse. Yet here was Rosling, leaping across the stage, showing me facts rooted in solid data. He was telling me that I had it all the wrong way round. But he did it in a way that meant I didn't feel like an idiot. I was *supposed* to get it all wrong. Everyone does. This became his main act. He would get crowds of intellectuals, business leaders, scientists, and even global health experts at TED, Google or the World Bank, and he'd show them that they were completely ignorant of the most basic facts about the world. And they'd love it! Watch his videos and you can hear the audience laughing at their own ignorance. He had a generosity as a teacher that is impossible to replicate.

In his lectures, Rosling explained what the data really told us about the most important metrics of human well-being: the percentage of people living in extreme poverty, the number of children dying, how many girls did or didn't get to go to school, and what percentage of children are vaccinated against diseases. We almost never step back to look at the data on these changes in global development. Instead, we watch the daily news and those headlines become part of our world view. But doing this doesn't work. The news is designed to tell us, well, something *new* – an individual story, a rare event, the latest disaster. Because we see them in the news so often, unlikely events

seem like probable ones. But they're often not. That's why they make the news and why they capture our attention.

These individual events and stories are important. They serve a purpose. But it's a terrible way to understand the bigger picture. Many changes that do profoundly shape the world are not rare, exciting or headline-grabbing. They are persistent things that happen day by day and year by year until decades pass and the world has been altered beyond recognition.

The only way to really see these changes is to step back and look at the long-run data. This is what Hans Rosling did for social problems. The same is true for our environmental ones. I've been researching, writing and shouting about these trends for almost a decade now. I'm Head of Research at Our World in Data, where we do this for every single one of the world's big problems – from poverty and health to war and climate change. I'm also a misfit scientist at the University of Oxford. We're 'misfits' because we do the opposite of what people expect academics to do. Researchers tend to zoom into a problem, to get as close as possible and pick it apart. We zoom out.

My job is not to do original studies, or to make scientific breakthroughs. It's to understand *what we already know*. Or *could* know if we studied the information we have properly. Then explain it to people: in articles, on the radio, on TV, and in government offices so they can use it to move us forward.

Just as Hans Rosling showed that news headlines don't teach us much about global poverty, education or health, I've found that trying to build an environmental world view based on the latest wildfire or hurricane is no good. Trying to understand the world's energy system and how to fix it from the latest breaking story won't get us anywhere.

If we want clarity we have to take in the full picture, and that means giving ourselves some distance. If we take several steps back, we can see something truly radical, game-changing and life-giving: humanity is in a truly unique position to build a sustainable world.

Why doomsday thinking is so damaging

'We need people to wake up. We need people to start paying attention!' People often say that is why the apocalyptic environmental story needs to be shared far and wide. Or, as they argue, the apocalyptic *truth*. I get it. On many environmental issues, we've been sleepwalking for a long time. We've pushed action further and further into the future – happy to do so because it can take decades or more for environmental impacts to hit us. Except the decades have passed and now we are here. The impacts have arrived: it's already happening.

To get this out of the way, let me make one thing absolutely clear: I'm no climate change denialist or minimiser. I spend my life – inside and outside work – researching, writing and trying to understand our environmental problems and how to solve them.

The world has lacked urgency to act. Bringing attention to the magnitude of potential impacts is essential if we want things to change. But that is a long way from telling kids they're ruined.

Let's, for now, say that total doom is an exaggeration. Does that really do *harm*? If it makes people take these issues seriously, that can only be a good thing, surely, and the exaggeration simply acts as a counterbalance to those who underplay the issue. But I'm convinced that there is a better, more optimistic and honest way forward.

There are several reasons why I think these doomsday messages do more harm than good. First, the doom narratives are often untrue. I don't expect you to believe me on that straight away, but I hope that by the end of the book I will have convinced you that while these problems are big and pressing, they are solvable. We will have a future. By 'we' I mean us, collectively, as a species. Yes, many people could be severely impacted, or even have that future taken away from them, so it's up to us to decide *how many* people, based on the actions we take. If you believe people have the right to the truth, then you should be against these exaggerated doomsday stories.

Second, it makes scientists look like idiots. Every doomsday activist that makes a big, bold claim invariably turns out to be wrong. Every time this happens it chisels another bit of public trust away from scientists. It plays right into the hands of deniers. When the world *doesn't* end in 10 years, deniers turn around and say, 'Hey, look, the crazy scientists got it wrong again. Why should anyone listen to them?' In nearly every chapter of this book I'll list doomsday claims that turned out to be completely untrue.

Third, and perhaps most importantly, our impending doom leaves us feeling paralysed. If we're already screwed, then what's the point in trying? Far from making us more effective in driving change, it robs us of any motivation to do so. I recognise this from my own dark period when I nearly walked away from the field entirely. I can assure you that after reframing how I saw the world, I have had a *much*, *much* bigger impact on changing things. When it comes down to it, doomsday attitudes are often no better than denial.

This option of 'giving up' is only possible from a place of privilege. Let's say we stop trying and temperatures climb by another degree or two, taking us well past our climate targets. If you live in a wealthy country, you'll probably be okay. It won't be plain sailing, but you can buy your way out of serious danger. That's not true for many less fortunate people, though. Those in poorer countries cannot afford to protect themselves. Accepting defeat on climate change is an indefensibly selfish position to take.

Climate scientists are not accepting defeat. Most climate scientists I know have children. They spend every day studying and thinking about climate change. Yet they're obviously not resigned to the idea that we will face a climate apocalypse in the next century. They think there is still time to ensure a liveable future for their children. As Dr Kate Marvel, a climate scientist at NASA, puts it: 'I unequivocally reject, scientifically and personally, the notion that children are somehow doomed to an unhappy life.'[7]

It's not that they don't think the impacts of climate change are worrying. If they didn't, they wouldn't be working on them. They also don't think the world is doing enough to tackle it – they've been begging people to act for decades. Nearly every one of them will say that we are moving too slowly, and if we don't get our act together, things could get very bad. Why, then, are they optimistic that we can still do something? There are several possible reasons. One is that there has been a miscommunication about what our climate targets – of 1.5°C and 2°C – actually mean. It is wrong to think of these as *thresholds* – that as soon as we pass 1.5°C, we're toast. That's not true. There is nothing special about the number 1.5°C; it's not that things are liveable at 1.499°C and as soon as we hit 1.501°C the planet becomes unbearable. There is a significant increase in the risk of tipping points and non-linear climate impacts once we start to get into the 1.5°C–2°C range. But that doesn't make 1.5°C an all-or-nothing threshold. In fact, it makes every 0.1°C even more important once we start to move into that zone. The difference is that many climate scientists view these numbers as *targets*. It would be incredible to meet them, but we need to keep going even if we don't.

This might seem like a pedantic point, but it's an important one. The reality is that we're almost certainly going to pass 1.5°C. Most climate scientists expect that. So, if people view it as an end-of-the-world threshold then *of course* it's going to feel apocalyptic.

Another reason some climate scientists are less pessimistic is that they believe that things can change. The last few decades have been an uphill battle for them. They've been mostly ignored. Often *they* were the ones framed as apocalyptic scaremongers. But, finally, the world has woken up to the reality of climate change, and people are taking action. The climate scientists know change is possible because they've seen it happen. Against the odds, they've driven much of it.

The world needs more urgent optimism

I used to think optimists were naive and pessimists were smart. Pessimism seemed like an essential feature of a scientist: the basis of science is to challenge every result, to pick theories apart to see which ones stand up. I thought cynicism was one of its founding principles.

Maybe there is some truth to that. But science is inherently optimistic too. How else would we describe the willingness to try experiments over and over, often with slim odds of success? Scientific progress can be frustratingly slow: the best minds can dedicate their entire lives to a single question and come away with nothing. They do so with the hope that a breakthrough might be round the corner. It's unlikely *they* will be the person to discover it, but there's a chance. Those odds drop to zero if they give up.

Nevertheless, pessimism still sounds intelligent and optimism dumb. I often feel embarrassed to admit that I'm an optimist. I imagine it knocks me down a peg or two in people's estimations. But the world desperately needs more optimism. The problem is

that people mistake optimism for 'blind optimism', the unfounded faith that things will just get better. Blind optimism really is dumb. And dangerous. If we sit back and do nothing, things will not turn out fine. That's not the kind of optimism that I'm talking about.

Optimism is seeing challenges as opportunities to make progress; it's having the confidence that there are things we can do to make a difference. We can shape the future, and we can build a great one if we want to. The economist Paul Romer makes this distinction nicely.[8] He separates 'complacent optimism' from 'conditional optimism':

> Complacent optimism is the feeling of a child waiting for presents. Conditional optimism is the feeling of a child who is thinking about building a treehouse. 'If I get some wood and nails and persuade some other kids to help do the work, we can end up with something really cool.'

I've heard various other terms for this 'conditional' or effective optimism: 'urgent optimism', 'pragmatic optimism', 'realistic optimism', 'impatient optimism'. All these terms are grounded in inspiration and action.

The reason pessimists often *sound* smart is that they can avoid being 'wrong' by moving the goalposts. When a doomer predicts that the world will end in five years, and it doesn't, they just move the date. The American biologist Paul R. Ehrlich[fn1] – author of the 1968 book *The Population Bomb* – has been doing this for decades.[9] In 1970 he said that 'sometime in the next 15 years, the end will come. And by "the end" I mean an utter breakdown of the capacity of the planet to support humanity.' Of course, that was woefully wrong. He had another go: he said that 'England will not exist in the year 2000'. Wrong again. Ehrlich will keep pushing this deadline back. A pessimistic stance is a safe one.

Don't mistake criticism for pessimism. Criticism is *essential* for an effective optimist. We need to work through ideas to find the most promising ones. Most innovators that have changed the world have been optimists, even if they didn't identify as one. But they were also fiercely critical: no one picks apart the ideas of Thomas Edison, Alexander Fleming, Marie Curie or Norman Borlaug more than they did themselves.

If we want to get serious about tackling the world's environmental problems, we need to be more optimistic. We need to believe that it *is* possible to tackle them. As we'll see in the chapters that follow, this is not a pipe dream: things *are* changing, and we should be impatient about changing them faster.

We can be the first generation to achieve a sustainable world

The Last Generation is an activist group in Germany, the name implying that our unsustainability will push us to extinction. To force their government into action, some

of the group recently went on a month-long hunger strike. It wasn't a half-hearted effort: several ended up in hospital. They're not the only ones who feel this way. The global environmental group Extinction Rebellion is also founded on this principle. And the survey results earlier show that the notion of us being the 'last generation' isn't far from the minds of many young people.

But I'd like to take the opposite framing. I don't think we're going to be the last generation. The evidence points to the opposite. I think we could be the *first* generation. We have the opportunity to be the first generation that leaves the environment in a better state than we found it. The first generation in human history to achieve sustainability. (Yes, that seems hard to believe. Stay with me and I'll explain why.) Here I'm using the term 'generation' loosely. I am from a generation that will be defined by our environmental problems. I was a child when climate change really came on the radar. Most of my adulthood will be spent in the midst of the major energy transition. I will see countries move from being almost entirely dependent on fossil fuels to being free of them. I will be 57 when governments hit the '2050 deadline' of reaching net-zero carbon emissions that so many have promised. In writing this book, I feel like I am representing a generation of young people that want to see the world change.

But, of course, there will be several generations involved in this project. There are a couple above me – my parents and grandparents – and a couple below me, my future children (and perhaps grandchildren). Generations are often pitted against each other: older generations are blamed for ruining the planet; younger generations are framed as hysterical and indignant. When it comes down to it, though, most of us want to build a better world, where our children and grandchildren can thrive. And we all need to work together to achieve that. All of us will be involved in this transformation.

In *Not the End of the World*, I'll explain why I think we can be the first to achieve sustainability. I'll explore each of our environmental problems one by one, looking at its history, where we are today, and how we might lay out a path to a better future. Most chapters will open with a flashy – and damaging – headline that you might have seen before. I'll explain why each of them is wrong. We are overwhelmed with information about what we shouldn't be doing when it comes to the health of our planet. I'll pull out the big things that are really making a difference and which we should all focus on, and the things we should all stress less about.

We will start high up in the atmosphere and travel downwards, encountering the seven biggest environmental crises we must solve if we are to achieve sustainability. We'll look at air pollution first, followed by climate change. Then we'll move to ground level, covering deforestation, food and the life of other species on land. Next, we'll dip underwater, looking at ocean plastics, before finally plunging deep to explore the state of our world's fish.

Our environmental problems overlap. What we eat matters for climate change, deforestation and the health of other species on our planet. If we eat more food from farms on land, we put less pressure on fish in our oceans. Burning fossil fuels doesn't

just drive climate change, it pollutes our air and damages our health. No environmental problem stands in isolation. I hope by the time you finish this book you will have a clearer understanding of this interconnectedness, the way some of the most important solutions at our disposal help address several problems at once – and just how valuable this is to our future.

Six things to keep in mind

The issues we'll explore are complex. They're uncomfortable. And, unfortunately, some of the arguments or data I put forward can be abused in the wrong hands. Here are six points to keep in mind as you read.

(1)
We face big and important environmental challenges

Surprisingly, on many environmental issues, some trends are moving in the right direction. In irresponsible hands, positive trends are often framed as 'see, relax, it's not a problem after all'.

This is not my position. The environmental challenges we face are massive. If we don't tackle them, the consequences will be devastating and cruelly unequal. We must act. It must be large-scale. And so much quicker than we have done before.

(2)
The fact that our environmental issues aren't humanity's largest existential risk doesn't mean we shouldn't work on them

I don't think climate change – or any other environmental problem – is going to wipe us out as a species. Risks that are much more likely to be existential are nuclear war, a global pandemic or artificial intelligence. Some have used this as an argument to focus less on climate change: 'Why are people working on that when they should be focused on dangerous pathogens or the threats of nuclear war?'

That's an odd way to think about it. There are eight billion of us – we can work on more than one or two problems at the same time. We might even argue that climate change increases the risk of some of these existential threats. Reduce the damage from climate change and we reduce other risks too.

Also, since when did a problem have to be existential for it to be serious enough to work on? The risks from environmental damage are severe: they're large enough to impact billions of people. And for much of the human population, it really *is* an existential risk.

(3)

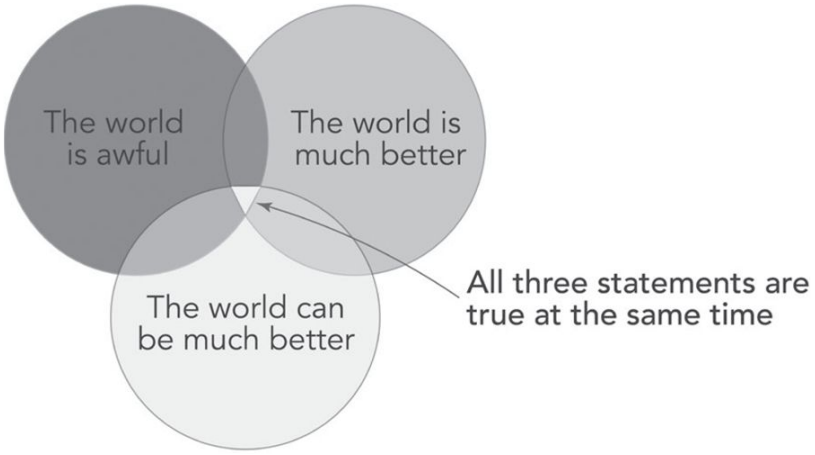
You will have to hold multiple thoughts at the same time

Doing this is essential if we're to see the world clearly and develop solutions that really make a difference. Things getting better does not mean our job is done.

As an example: since 1990 the number of children dying every year has more than halved. That is a tremendous achievement. But share this important fact online and you'll often get this response: 'Oh, so you think it's fine that 5 million children die every year?' *Of course not*. That fact is one of the worst things about our world. But the two facts do not contradict each other. We have made impressive progress, but we still have a long way to go. As my colleague Max Roser puts it: 'The world is much better; the world is still awful; the world can do much better.'[10] All three statements are true.

By denying the first – that we *have* made progress – we lose out on important lessons about how we keep moving forward. Denying this fact also robs us of the inspiration that change *is* possible.

If I have to caveat every positive trend with 'but I'm not saying that everything is perfect' then this book is going to be an exhausting and repetitive read. Just assume this is always the case. When I say things are improving, I am not saying they are fine as they are.



(4)

None of this is inevitable, but it is possible

Alongside the history, and story of where we are today, I will propose a path forward. My suggestions are never predictions, they are possibilities.

That's an important distinction. I don't know what's going to happen in the future. It depends on how quickly we act, and whether we make good decisions. All I can do is lay out what I think our best options are. Hopefully this book will play a small role in inspiring us to take them.

(5)
We cannot afford to be complacent

The complacency trap is never far away. It's easy to take our foot off the pedal or to be led off course as new and short-term problems arise. We can't let this happen.

When Russia invaded Ukraine in 2022, many countries turned their back on Russian energy supplies, the price of energy rocketed and the global economy was shaken. Countries clambered to find other sources of energy, and some turned to coal, restarting their old plants.

This was a disappointing backslide on climate action. But it looks like it was a temporary one. After some months of higher CO_2 emissions, Europe's coal consumption has fallen again and its transition to renewables is as fast as ever. Russia's invasion of Ukraine has given governments even more reason to ditch fossil fuels and invest in low-carbon energy that they can control.

There are two important lessons here. The first is that, on our journey to a sustainable world, there will be blips along the way. Events that force us to stall, or maybe even regress, on fixing our environmental problems. We should expect this, and not panic when it happens. Where we end up is determined by what we do over the next few decades, not the next three months.

The second is that we need to develop systems that are resilient to world events that might throw us off course. When our economies run on fossil fuels, we're at the mercy of those that produce them.

(6)
You are not alone in this

I wish I could reach back to my younger self and hug her. For a long time, I felt alone in trying to grapple with these problems. The headwind got stronger and stronger.

If you currently feel this way, this book is me reaching out to you. To show you that you are not alone in this journey: there are *many* people who are working to build a better future. Some of them you see in the limelight. But most of them you don't: they are fighting in boardrooms to change company strategies; they are in governments trying to shape policies; they are engineering solar panels, turbines and batteries in labs; or they are in the field creating sustainable ways to grow food**.**

Look around and you will find people at all levels – from individuals in their local community to world leaders making consequential decisions – pushing into the headwind. Many are concerned but determined. Optimistic that what they do today will make a difference tomorrow.

When I started writing this book, I printed out a picture of my younger self and hung it next to my computer. This is the book that *I* needed a decade ago. It is a synthesis of

nearly a decade of research and data that allowed me to see our environmental problems more clearly and gave me the perspective that helped me dig myself out of a very dark place. If you're currently there, I hope it gives you a way out too.

1

Sustainability

A tale of two halves

The world has never been sustainable

Before we start our tour of environmental problems, I need to let you in on an unpopular truth: the world has never been sustainable. What we want to achieve has never been done before. To understand why, we need to look at what sustainability means.

The classic definition of sustainability came out of a landmark report from the United Nations. In 1987, the UN defined sustainable development as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs'. That definition has two halves. The first is making sure that everyone in the world today – the present generations – can live a good and healthy life. The second half is about making sure that we live in a way that doesn't degrade the environment for future generations. We shouldn't create environmental damage that takes the opportunity of a good and healthy life away from our great-great-grandchildren.

This perspective is not without its controversy. Some definitions of sustainability *only* focus on the environmental component. The *Oxford English Dictionary* describes sustainability as 'the property of being environmentally sustainable; the degree to which a process or enterprise is able to be maintained or continued while avoiding the long-term depletion of natural resources'. That is a fancy way of saying: 'make sure that what you're doing today does not damage the environment for tomorrow'. In some definitions there's no requirement for humans to meet their own needs at the same time. As an environmentalist, I also put most of my focus on the second half: limiting the damage to our planet. But on a moral level, I cannot ignore the first half of the equation. A world full of avoidable human suffering does not meet our definition of sustainability.

A lot of the controversy about these definitions is because we assume there is an unavoidable trade-off between the first and second half. It's human well-being *or* environmental protection. That means one must be prioritised over the other, and for 'sustainability' it's the environment that wins. This trade-off existed in the past. But the central argument throughout this book is that this conflict does not have to exist in our future. There *are* ways to achieve both at the same time, which means there should

increasingly be less conflict between the definitions. So, if you still want to adopt an environment-only definition, then think of human flourishing as a nice add-on.

The world has never been sustainable because we've never achieved both halves at the same time. If we only focus on the second half, it might seem like the world has become unsustainable in the very recent past, when carbon emissions, energy use and overfishing accelerated. We think that the world *used* to be sustainable, but our environmental damage has kicked things out of balance. That's the wrong conclusion. For thousands of years – more so since the agricultural revolution, but also before then – humans haven't been environmentally sustainable. Our ancestors hunted hundreds of the largest animals to extinction, polluted the air from burning wood, crop wastes and charcoal, and cut down huge amounts of forest for energy and farmland.[1, 2, 3]

It's true that there have been periods or communities that have achieved a harmonious balance with other species and the environment around them. Many indigenous groups have managed this, as well as being protective of biodiversity and the ecosystems.[4, 5] Respect for the Earth lies at the heart of indigenous principles. As the Native American proverb goes: 'Take only what you need and leave the land as you found it.' Similarly, the ancient Kenyan proverb: 'Treat the Earth well: it was not given to you by your parents, it was loaned to you by your children.' Our understanding of sustainability starts there. The modern definitions are academic and uptight versions of these beautiful proverbs.

But communities that achieved environmental sustainability were always small, and that's because rates of child mortality were high: losing children stopped the population from growing.

A world in which half of all children die is not meeting 'the needs of the present generations' and is therefore not a sustainable one.

That's the challenge we face. We need to make sure that everyone in the world can live a good life *and* we need to reduce our environmental impacts so that future generations can flourish too. That puts us in uncharted territory. No previous generation had the knowledge, technology, political systems, or international cooperation to do both at the same time. We have the opportunity to be the first generation that achieves sustainability. Let's take it.

There is no better time to be alive than today

Having thought I was living through humanity's most tragic period, I now believe I'm living through its best. There has never been a better time to be alive. If someone had told me that eight years ago, I would have scoffed. In fact, when I heard Hans Rosling say it on-screen for the first time, I nearly stopped watching. What planet was he living on?

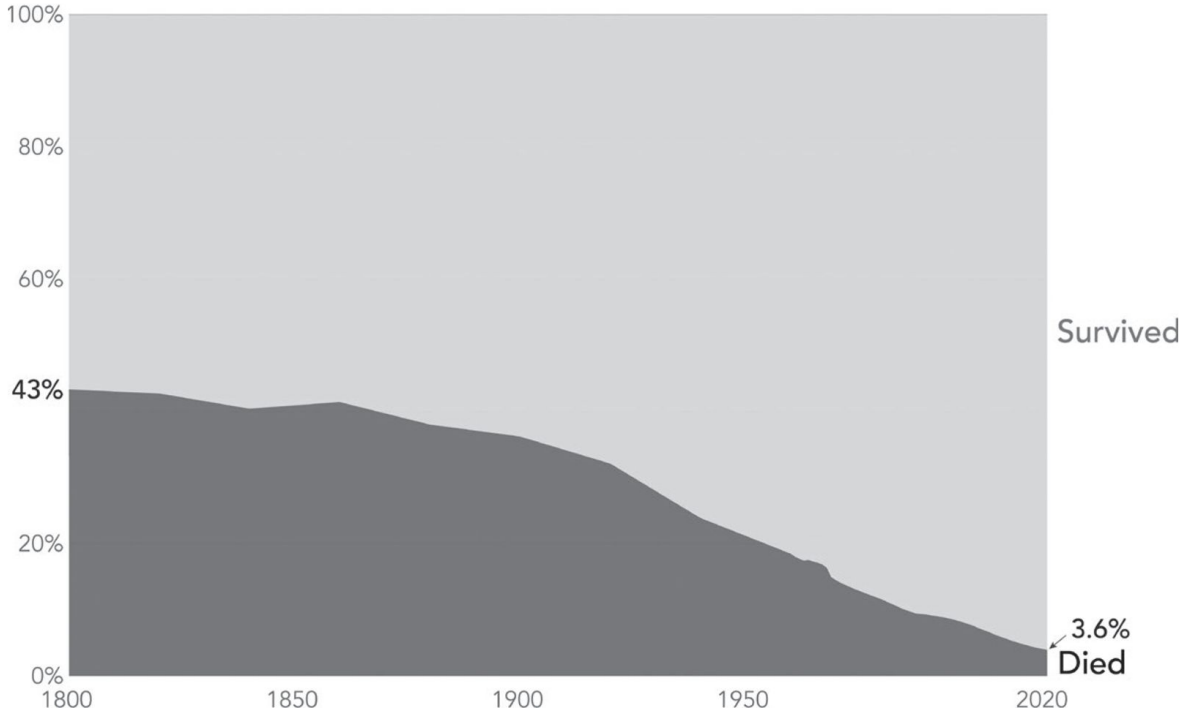
But it's true. And I hope that looking at the data and progress of seven key measures of well-being will help change your mind.

(1)
Child mortality

Stopping children from dying has been humanity's greatest achievement. The majority of us think there's a natural order to death: it's the old not the young that die. But this sequence is a very recent development. The prospect that a child would outlive its parents is not a 'natural' occurrence at all: it's something that we've had to fight hard for.

For most of human history, your odds of living to adulthood were 50–50. Around a quarter of children would die before their first birthday, and another quarter died before they reached puberty.[6] There was no exception to this. Children dying was commonplace, regardless of continent or century.[7] Even the elite couldn't buy their children a path to adulthood. The Roman emperor Marcus Aurelius had fourteen children. Nine of them died before he did. Charles Darwin lost three of his children. This rate was also found in hunter-gatherer societies. Researchers looking at mortality rates across 20 different studies in modern hunter-gatherers and archaeological records found that at least a quarter died in infancy, and half died before reaching puberty.[8]

Until the last few centuries, there was almost no way for us to stop children from dying. It wasn't until the rise of clean water, proper sanitary conditions, vaccines, better nutrition and other advances in health care that rates of child mortality started to plummet. As recently as 1800, about 43% of the world's children died before reaching their fifth birthday.[9] Today that figure is 4% – still woefully high, but more than 10-fold lower.



Stopping children from dying is a very recent achievement
The global child mortality rate, which is the share of newborns that die before reaching their 5th birthday.

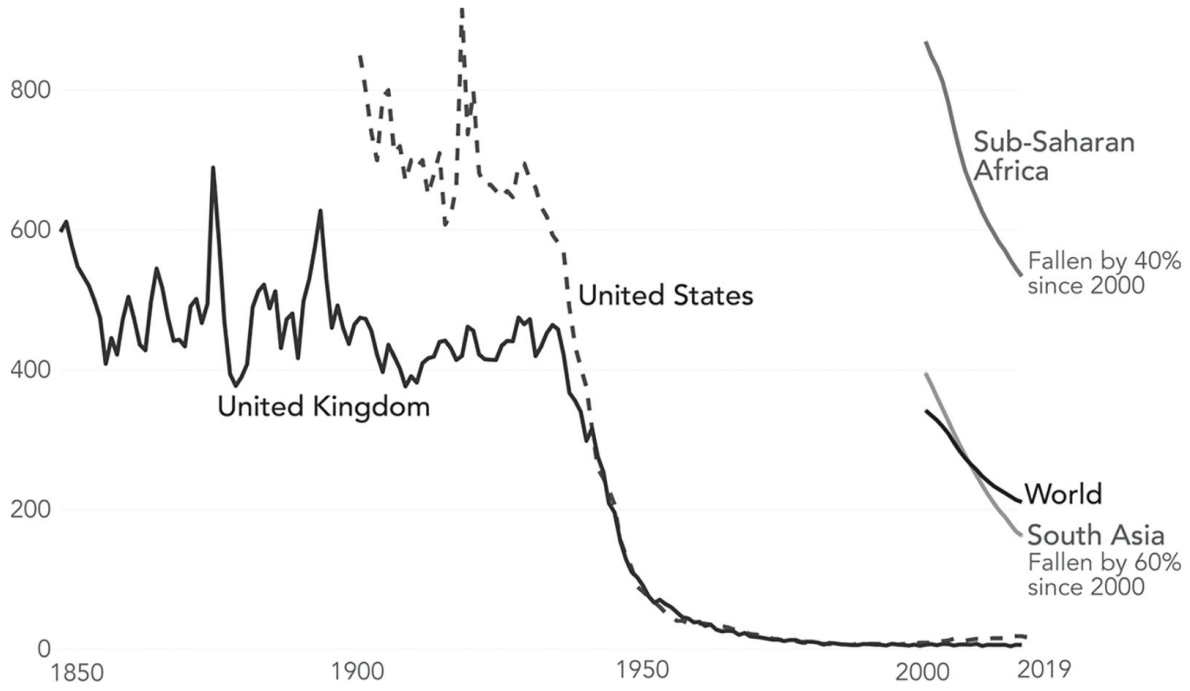
It would be wrong to think that this has only happened in rich countries. *Every* single country has made massive progress in the last fifty years. In 1950s Mali, 43% of newborns would die before reaching the age of five. Now, 10% do. India and Bangladesh have both reduced child mortality from around one in three to less than one in 30.

It's not just the *share* that is falling; the *number* of children dying is too. The year I was born – 1993 – almost 12 million children under the age of five died. Since then, this number has more than halved. We still have a lot of work to do – five million children dying every year is a tragedy – but we have achieved the unthinkable: our ancestors could never have imagined a world where the death of a child was so rare.

(2)
Mothers dying

When my mum went through a complicated birth with my brother, she was told by my great-grandmother: 'If it had been back in my day, dear, you would have just died.' In just a few generations we've made pregnancy tens – in some countries, hundreds – of times safer.[10]

My mum's odds of dying in childbirth were around 1 in 10,000. [fn1] My grandmother's odds were more than twice as high. My great-grandmother's were a staggering 30 times higher. In most countries today, the chances that a woman will die from causes related to pregnancy are very low.



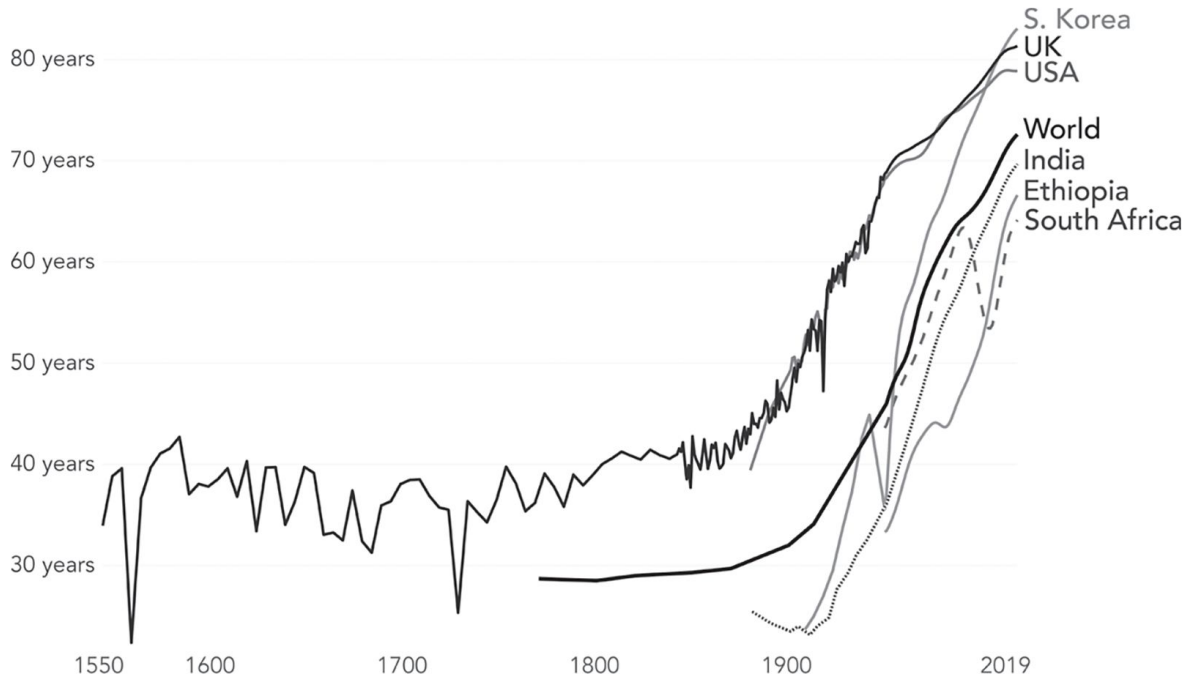
Mothers dying: maternal mortality rates have plummeted in recent centuries
The number of women who die from pregnancy-related causes per 100,000 live births.

(3)

Life expectancy

Until the 19th century, the average life expectancy at birth in the UK was between 30 and 40 years.[11] Even by the turn of the 20th century, it was just 50 years. By the middle of the century, it was 70 years. In 2019, the average life expectancy was over 80 years old. Within 200 years, life expectancy has doubled.[fn2] And this improvement is not 'just' because we've managed to reduce child mortality. It has improved at all ages.

Again, this progress has been seen across the world. Globally, average life expectancy has increased from around 30 to more than 70 since the start of the 20th century. In the poorest countries too, life expectancy has improved substantially. In Kenya, Ethiopia and Gabon, it's 67 years. The average across sub-Saharan Africa as a whole is 63 years.



People are living longer across all regions of the world
Life expectancy at birth is the average number of years a newborn would live to if age-specific death rates stayed at their current level.

(4)
Hunger and malnutrition

For most of human history, every day for our ancestors was a fight to feed the family. Crop yields were low and supply was tight. One bad season – a drought, a flood or a pest invasion – and everyone could be left starving.

Food insecurity and famine were common. It's possible that prior to the agricultural transition, many tribes and communities had ample nutrition. We just don't know. What we do know is that after the advent of farming, and as small groups grew into villages, food supplies were unpredictable. There were more mouths to feed, less scope for travelling to find supplies, and yields from the fields were often at the mercy of the seasonal weather. It seemed like there was no way of preventing famine and hunger. This all changed in the last decades of the 20th century. Despite several devastating famines, technological advances in agriculture made it much more productive and allowed people to break free from a subsistence lifestyle.

In the 1970s, around 35% of people in developing countries did not get enough calories to eat. By 2015, this had fallen by almost two-thirds to just 13%. Many still face huge problems. In 2021, around 770 million people in the world – almost one in 10 – did not get enough food.[12] But it doesn't have to be this way. The world now produces far, far more food than it needs. Many countries have come close to eradicating hunger. We need to make sure that every country can do the same.

(5)
Access to basic resources: clean water, energy, sanitation

For most of human history, we'd take water from the river, a stream or lake, and it was a lucky draw as to whether it was clean or not. Disease was rife. Children died from diarrhoeal diseases and infection – many in poor countries still do. Getting access to clean water sources, sanitation and hygiene has saved tens of millions of lives every year, if not more.

In 2020, 75% had access to a water source that was clean and safe – up from just 60% in the year 2000[13] – and 90% of the world had access to electricity.[14] Some might see electricity as a luxury – an unnecessary drain on natural resources – but it has become essential for a healthy and productive life. We need it to keep vaccines and medicines cold; to keep our hospital machines running; to cook our food and wash our clothes without spending all day doing chores; to keep our food cool and contamination-free; to power lights for children to study at night; and to keep our streets safe.

Progress is slower when it comes to sanitation and access to clean cooking fuels: just 54% have a safe toilet, and just 60% have clean fuels. We must ensure access to these resources, but regardless of what metric we're looking at, the trend is consistently upward. Every day, 300,000 people get access to electricity and a similar number get clean water, for the first time. This has been the case *every day* for a decade.

(6)
Education

I know how lucky I was to have the chance to finish school. Especially as a girl. In the Western world, more of us should appreciate how fortunate we are to be in that position. The world we are building, with better health care, technology, connectivity and groundbreaking innovations, rests on the power of education and learning.

In 1820, just 10% of adults in the world had basic reading skills.[15] This changed rapidly over the 20th century. By 1950, more adults in the world could read than couldn't. Today, we're closing in on 90%.

In his 2014 TED Talk, one question that had Hans Rosling's audience stumped was 'In all low-income countries across the world today, how many girls finish primary school?' Most people thought the answer was 20%. The correct answer was 60%. By 2020, this figure had increased to 64%. The share of boys in low-income countries that complete primary school was higher, at 69%. In most countries – even many of the poorest – it's more likely than not that a girl will finish primary school and get a basic education.[fn3]

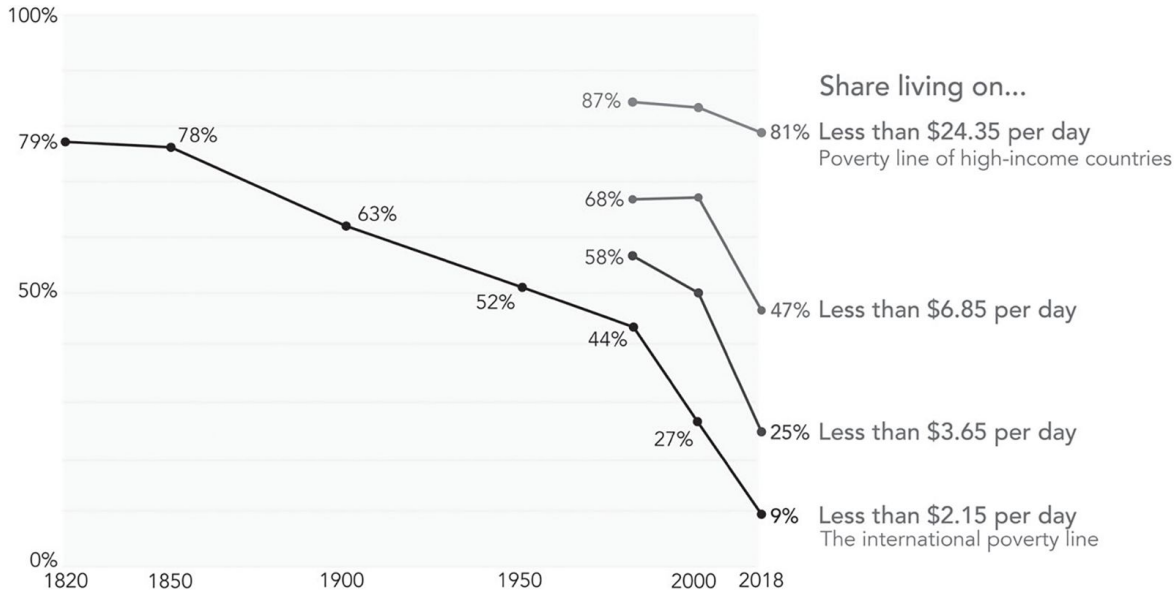
(7)
Extreme poverty

Everyone in the world living in extreme poverty today wants to escape.

The United Nations defines 'extreme poverty' by using the international poverty line of $2.15 per day. Adjusted for price differences across the world, this figure equates to what $2.15 would buy you in the United States. As the name says, this is an extremely low poverty line, used to identify those in the most destitute conditions. For most of human history, nearly everyone lived in dire poverty. In 1820, more than three-quarters of the world lived below the equivalent of this poverty line.[16] Today that figure is less than 10%.[fn4]

I've heard people argue that while the *percentage* is going down, the *total* number of people living in extreme poverty has been increasing. This isn't true. In 1990, 2 billion people lived on less than $2.15 per day. By 2019, this had more than halved to 648 million. To put this development in perspective, every day for the last 25 years there could have been a newspaper headline reading, 'The number of people in extreme poverty has fallen by 128,000 since yesterday'.[fn5]

We should set our aspirations much higher than this poverty line of $2.15. There is good news there too: more and more people are surpassing higher poverty lines – of $3.65, $6.85, or $24 per day. In the past, poverty was always the default. We can build a future where it is the exception.



Share of the world population living in poverty
Data is adjusted for price changes over time (inflation) and for price differences across countries.

Now it's time for the second half of the equation

We've just seen seven developments that have transformed the lives of billions of people. But this progress has come at a massive environmental cost. The first half of our sustainability equation has improved dramatically, but the second half has undoubtedly got worse. This brings us to the seven big environmental problems that will be tackled

in this book. To see how we can balance the environmental side of the equation too, we need to understand the progress we've already made, and how we got there. That shows us what still needs to be done if we're to realise our dream of a sustainable world. It's useful to give an overview here, to keep the bigger picture in mind as we dig into the fine detail of each problem.

(1)
Air Pollution

Air pollution is one of the world's biggest killers. Researchers estimate that it kills at least 9 million people every year. That's 450 times more than die in natural disasters in most years. But air pollution is not a modern problem: it dates back as far as the human discovery of fire. When we burn stuff, the air becomes polluted. That's true regardless of whether we're burning wood or coal, or oil in our cars. The stakes for solving air pollution are high. But we know it's possible: the air in many rich countries is the cleanest it has been for centuries or more. If we can replicate these efforts everywhere, it would save millions of lives every year.

(2)
Climate Change

Global temperatures are rising. Sea levels are rising; ice sheets are melting; and other species are struggling to adapt to a changing climate. Humans face an avalanche of problems from flooding and drought to wildfires and fatal heatwaves. Farmers are at risk of crop failures. Cities are at risk of being submerged. There's one main cause: human emissions of greenhouse gases. We've burned fossil fuels, cut down forests and raised livestock for energy and food – undoubtedly important for human progress. But we're now paying the price of severe climate change. If you only look at a chart of CO_2 emissions over time, you might believe that we're making no progress at all. But in the last few years we have, and we've done so quickly. There is hope that soon there will be no trade-off between having plentiful energy and a low-carbon footprint: we will be able to live a prosperous life without changing the climate around us.

(3)
Deforestation

Over the last 10,000 years we've cut down one-third of the world's forest, mostly to grow food on expanding farmland. Half of this was in the last century. When we cut down trees we release carbon that has been stored there for hundreds or thousands of years. But deforestation isn't just a problem for climate change. Forests are home to some of the planet's most diverse ecosystems: complex, interconnected networks of

animals, plants and bacteria that have built up over millennia. Cut them down and we destroy these beautiful habitats. While it might seem like deforestation is at its peak, it's not; but we've made a lot of progress in solving it over the last few decades, and we have a real chance of being the generation that sees the end of it.

(4)
Food

Deforestation is mostly about food, which is our next big problem. We've seen a rapid decline in hunger over the last 50 years. But growing more food has affected almost every environmental issue we face. Food production is responsible for one-quarter of the world's greenhouse gas emissions; it uses half of the world's habitable land, 70% of the world's freshwater withdrawals, and the leading driver of biodiversity loss. Growing *enough* food is not the problem – it's about growing and using this food in a smarter way. Make better decisions and we can feed 9 or 10 billion people without frying the planet at the same time.

(5)
Biodiversity Loss

It's not just farm animals that we should be concerned about. Wildlife is also in dire trouble. Biodiversity loss is driven by many of the problems covered in this book: species are affected by climate change, deforestation, habitat loss through expanding land, hunting for meat, plastic pollution and overfishing. Our conflict with other animals is nothing new – we've been clashing with them for millennia. Over the last century these extinction rates have accelerated, raising the question of whether we're in the midst of a Sixth Mass Extinction. For most of human history, it has been us versus wildlife. But there is a path forward where both can flourish.

(6)
Ocean Plastics

Plastic is the most 'modern' problem we'll look at in this book. It is both a miracle material and an environmental disaster. In fact, it's probably an environmental disaster *because* it's so magical. It's cheap, light, versatile, and brings us so many benefits, from delivering life-saving vaccines to preventing food waste. But a million tonnes of plastic pours into the ocean from our rivers every year, leaving an environmental imprint for decades or centuries to come. Many people think that the way to stop plastic pollution is to stop using plastic entirely. But this is an unlikely – and undesirable – solution. Thankfully, we have the tools we need to solve it. Many countries have implemented them already.

(7)
Overfishing

Finally, a deep dive into the ocean will look at the problem of overfishing. Newspapers and documentaries have been filled with scary headlines about the state of our oceans. The most popular claim is that they will be empty by the middle of the century. That's not true, but it doesn't mean overfishing isn't a problem: many of the world's fish stocks are depleting rapidly. Whale populations are a fraction of what they were in the past. And the world's corals – some of its most diverse ecosystems – are being bleached to death. But these are problems we can tackle – in fact, some of our most iconic and endangered fish and whale species have seen an impressive comeback over the last few decades.

Two ideas that *won't* fix our problems

Before we take off into the air and the first stop on our journey, I need to look at a few arguments that cut across all these challenges. Our collective environmental impact is quite simple when we break it down: it's the number of people multiplied by everyone's individual impact. When we put it that way, two grand solutions emerge: reduce the number of people on the planet or cut our individual impacts by intentionally shrinking the economy.

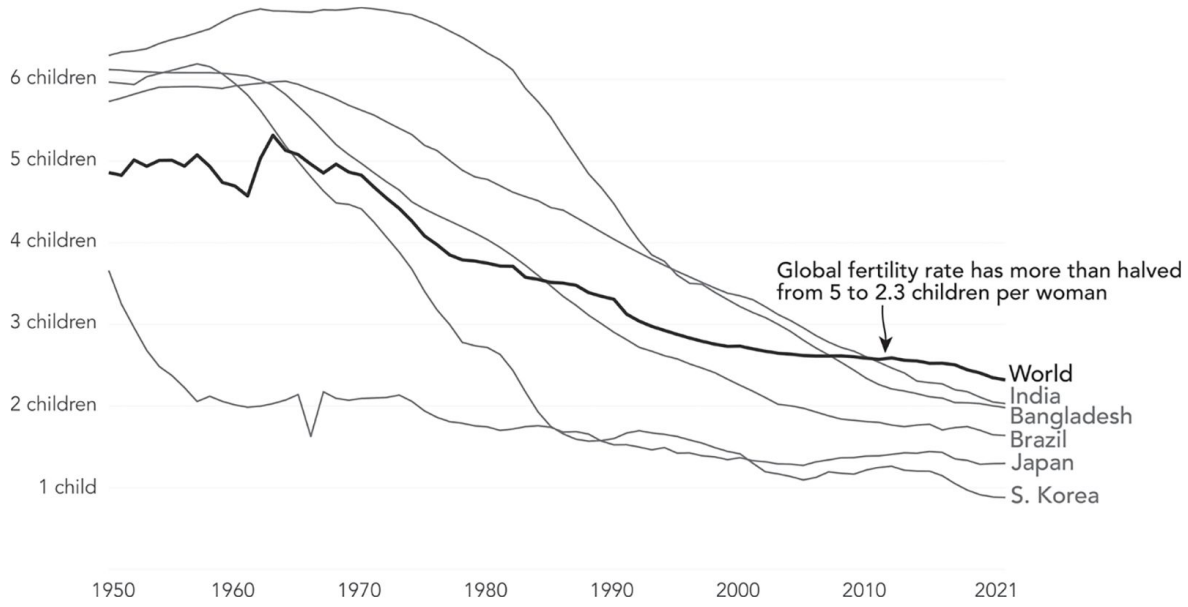
These arguments – referred to as depopulation and degrowth – are represented by very loud advocates in environmental debates. But neither of these options is viable. We will not achieve sustainability by shrinking the population or the economy. In the following chapters I'll walk us through why in much more detail. But first, here's what you need to know before we start.

(1)
Depopulation

Many people are worried that the global population is still growing rapidly. That we're seeing exponential population growth, and it's out of control. This isn't true. The global population growth rate – the change from one year to the next – peaked a long time ago. In the 1960s it was growing at more than 2% per year.[17] Since then, this rate has more than halved, to 0.8% in 2022. And it will keep falling in the decades to come. For population growth to be 'exponential' the growth rate would have to stay at 2% per year.

This is happening because women are having far fewer children than in the past. For most of human history having five or more kids was not uncommon. But this didn't drive fast population growth because so many children died young. By the 1950s and 60s, the global average was still similar – women would give birth to five children.[18]

Thankfully far more children now survived, which is why the population increased rapidly. But, since then, the global fertility rate has more than halved and is now just over two children per woman.



The number of children per woman is falling rapidly across the world
Fertility rate is measured as the average number of children per woman, assuming she was to live to end of her life-bearing years.

As a result, the world has already passed 'peak child'. According to statistics compiled by the United Nations, the number of children in the world peaked in 2017[fn6] and is now falling. Take a moment to think about what that means: there may never be more children in the world than there were in 2017. Global population growth will peak when all these children reach old age. The United Nations projects this will happen in the 2080s at 10 to 11 billion people.[19] From there, it expects the world population will start to shrink.

So, rapid population growth is behind us, the world is not facing an uncontrolled 'population explosion'. For some, this is not enough. They argue that we should actively *decrease* the number of people in the world. In *The Population Bomb*, Paul R. Ehrlich argued that the optimal global population was around 1 billion people. He still argues for this today. Here's the thing: if we were to accept for a moment that this *was* the optimal number of people (which I don't), it's not possible to reduce the population quickly enough for that to help address our environmental problems. If anyone argues that it is, they don't understand how demographic change works.

Even if some countries implemented a one-child policy and birth rates became much lower – around 1.5 as the global average – we might be talking about the population in 2100 being 7 or 8 billion, similar to our current level. To get anywhere close to 1, 2 or 3 billion people would mean *killing* billions or stopping people from having any children at all. If you think that's a viable and moral solution, then I don't know what to

tell you. Trying to 'control' population in any humane way (if there is such a thing) might reduce it a bit, but not by that much. Our sustainability solutions need to be scalable for many billions of people. If we can make them scalable for 8 billion people, we can do it for 10 billion.

The end goal that we're aiming for is to reduce our impacts per person to zero – or at least very close to zero. If we're to build a sustainable world for the future then we all have to tread with the lightest of footprints. That's really the point of this book: to work out if and how we can do that. In a world where our per capita impacts are zero (or, maybe even *negative*, meaning we restore historical environmental damage) then it doesn't matter whether we live in a world with 1, 7 or 10 billion people. Our total impact will still be zero. One half of our sustainability equation would be complete.

(2)
Degrowth

What about 'degrowth' – shrinking the economy – instead? This argument hinges on the fact that, historically, economic growth has been linked with more resource-intensive lifestyles. As we got richer, we used more energy from fossil fuels, had a higher carbon footprint, used more land and ate more meat. And it's true that in a world without technological change, we'll be stuck with fossil fuel power, petrol cars and inefficient homes. But as the chapters that follow will show, new technologies are allowing us to decouple a good and comfortable life from an environmentally destructive one. This is what makes it possible for us to be the first generation. In rich countries carbon emissions, energy use, deforestation, fertiliser use, overfishing, plastic pollution, air pollution and water pollution are all falling, *while these countries continue to get richer*.[fn7] The idea that these countries were more sustainable when they were poorer is simply not true.

There is another important reason why degrowth will not build a sustainable future. Degrowth argues that we can redistribute the world's wealth from the rich to the poor, giving everyone a good and high standard of living with the resources already at our disposal. But the maths doesn't check out.[20] The world is far too poor to give everyone a high standard of living today through redistribution alone.

We can see this with a quick thought experiment. Let's imagine that every country in the world ends up like Denmark. Almost all its population lives above the $30 poverty line that most rich countries adopt, and it is one of the most equal countries in the world.[21] That's what I want: everyone in the world to live a comfortable, poverty-free life, and in a society with low levels of inequality.

In this scenario, we're going to do a global redistribution: all the countries that are richer than Denmark are brought down to its average level of income, and all the countries that are poorer – which is 85% of the global population – are brought up to it. There are no inequalities between countries, and inequalities within countries are also

shrunk massively. Would it be possible to achieve this by just redistributing the world's money?

No: the global economy would have to be at least five times bigger than it is today. That's right: to lift everyone out of poverty, with a level of equality like Denmark, the global economy would need to increase five-fold. If everyone in the world lived on $30 per day with *zero* inequality (so the richest and poorest both get $30), the global economy would need to more than double.

A world without economic growth would remain a very poor one. I'm agnostic about growth in rich countries, but the data is clear that we need strong economic growth *globally* to end poverty, even with lots of redistribution.

Historically, countries have become rich from fossil fuels and other resources. That means many people now assume that growth equals 'bad'. But there is no reason for it to stay that way. If a country, or an individual for that matter, can lead the way in providing a cheap, low-carbon energy source that could power the world, I would be more than happy for them to get rich from it. And they could. There is a massive 'solutions vacuum' for our environmental problems. The early movers in this space can build a prosperous economy while building solutions to our problems at the same time. Countries can 'grow' by leading the way on 'good' technologies, not just exploiting polluting ones.

This leads to another argument, which is that having money gives us options. The solutions and technologies we need to fix our environmental problems have become viable only in the last few decades. Some, such as solar energy and electric vehicles, only in the last few years. Before then, these technologies did not exist or were far too expensive. They've become competitive through years of investment and development – and that has needed extra cash from governments and entrepreneurs.

For hundreds of thousands of years, burning wood was the only source of 'controllable' heat and light that our ancestors had. Then, a few centuries ago, our ancestors acquired a couple more – albeit destructive – options: whale oil and coal. But we've only had real choice in the last few years.

Economic growth is not incompatible with reducing our environmental impact. In this book I'll show that we can reduce our environmental impact and reverse our past damage while becoming better off. The big question here is whether we can decouple these impacts fast enough. The answer to that depends on what actions we take today.

We've seen how dramatically things have improved for humanity when it comes to the first half of the sustainability equation. And that neither depopulation nor degrowth, despite their many advocates, are the solution to the second half. In fact, they would make both the first *and* the second half of the equation worse. What should we do instead? It's now time to explore our seven environmental problems one by one and see what we need to do to solve them.

2

Air Pollution

Breathing clean air

‘Inside Beijing’s airpocalypse – a city made “almost uninhabitable” by pollution’

– *Guardian*, 2014[1]

For years, Beijing was near the top of the list for ‘most polluted city in the world’. It had become the poster child for global air pollution, especially in the Western media. The pollution got so bad that it was named an ‘airpocalypse’.

The city’s air quality was put in the spotlight when Beijing hosted the Summer Olympics in 2008. In the run-up to the event, the government took action and its pollution levels dropped significantly.[2, 3] Half of its cars were taken off the road, industrial plants were temporarily closed, and construction activities were put on hold. Despite these improvements, it hosted one of the most polluted Games in history. The media lamented the impacts on the athletes’ and spectators’ health. But this missed the point: the polluted air that participants were briefly exposed to was much cleaner than the daily reality for the people living there.

In 2022 Beijing hosted the Winter Olympics, which was worlds apart from the Summer Games 14 years earlier. The city’s air quality had improved rapidly in the last decade. Once ‘almost uninhabitable’, news headlines now referred to its blue skies and smog-free air.[4] It had dropped off the list of the world’s 200 most polluted cities.[6] This time, the improvement was different: it wasn’t a temporary flex for its international visitors. It was a permanent change demanded and achieved by the city’s population itself. But how?

After the world packed up and went home in 2008, Beijing’s air quality continued to get worse. By 2013, public anger boiled over. Citizens demanded proper air-quality monitoring and data. Even Chinese state media were reporting on the terrible pollution that cloaked not just Beijing, but cities across the country.[5] The Chinese government responded and in 2014 declared a ‘war on pollution’. It moved quickly, bringing in

tough regulations on industrial plants; it took old cars off the road, shut down coal stations near the city, and switched from coal to gas boilers, which produce much less pollution.[fn1]

Between 2013 and 2020, Beijing's pollution levels fell by 55%.[6] Across China as a whole, they fell by 40%. The health benefits of these changes are huge: it's estimated that the life expectancy of the average person in Beijing has increased by 4.6 years.

By the 2022 Winter Olympics, China's environmental image had transformed. The media no longer focused on the smog. Instead, it focused on the unique backdrop to the ski-jump venue: a closed and abandoned steel mill, one of the casualties of the 'war on pollution'. It stood majestically in the background of every jump, a reminder of China's new focus on clean air, and its transition from the polluting industries that took years off its citizen's lives.

China's air is still not perfect. It's still well above the World Health Organization (WHO) guidelines, and several times higher than you'd find in a city in the United States or Europe. Its work is not done. But its example offers us an important lesson in how quickly we can act when we have the tools: a demanding citizenship, the money and political will.

How we got to now

We associate air pollution with modernity and industrialisation. But it is not a modern problem. In fact, in many parts of the world, the air we now breathe is the cleanest it has been for thousands of years.

The Roman philosopher Seneca (4 BC–AD 65) was stoic about most things, but the air of ancient Rome[fn2] was filthy, and Seneca knew that it was impacting his health. As he once remarked upon leaving the city:[7, 8] 'As soon as I escaped from the oppressive atmosphere of the city, and from that awful odour of reeking kitchens which, when in use, pour forth a ruinous mess of steam and soot, I perceived at once that my health was mending.'

Even further back, in 400 BC, Hippocrates documented the ills of pollution in his book *Airs, Waters and Places*.[9] The Arab geographer Al-Mas'udi (896–956) wrote about it during his trips through the Silk Road in Central Asia.[10] Several writers from the Song Dynasty (960–1279) documented their concerns about coal-burning.

Our understanding of air pollution's impact didn't develop much until the 19th century, but now we are in a unique position where we can use modern solutions to make sure that it is soon a problem of the ancients.

Air pollution is caused by one very simple principle: burning things. When we burn stuff – whether that's wood, crops, coal or oil – we generate small unwanted particles at the same time. This is the root of the problem, and the key to solving it.

Burning wood

When I was a kid, one of my favourite things was going camping with my family. The climate in Scotland meant that the opportunities were few and far between. But when there was a clear weather window, my dad, cousins and uncles would pack up our stuff and make camp in remote woodland. We would collect wood and set it alight. I would sit there for hours, at peace with the intense heat and meditative from its warm glow. I still love an open fire.

What I once thought of as a luxury has been one of humanity's biggest silent killers. It still is. Humans started burning wood for fire at least one and a half million years ago.[11] It gave us heat, fuels for cooking and protection in the darkness. But it also gave us poor health from the pollution it created.

The small particles produced when we burn wood can get deep into our lungs and lead to a range of respiratory and cardiovascular problems, including heart disease and cancer. We know that early humans were exposed to these pollutants because we find them in their remains from hundreds of thousands of years ago. When researchers looked at the preserved teeth of hunter-gatherers from Qesem Cave in Israel from 400,000 years ago they found pollutants from charcoal in them.[12] These pollutants, they suggest, came from indoor fires for the roasting of meats.

Researchers also found evidence of air pollution in the preserved lung tissue of Egyptian mummies. When the scientist Roger Montgomerie looked at the lungs of 15 mummies – ranging from noblemen to priests – he found fragments of fine particulates and scarring of the lungs, resulting from exposure to pollution and conditions such as pneumonia.[13] Despite all the fossil fuels, cars and pollution we produce today, Montgomerie believed the levels of pollution thousands of years ago were not much different.

While the odd night around a campfire in the open probably didn't do me much damage, we now know that long exposure to the particles from wood-burning and the burning of other biomass is terrible for human health. It's particularly bad in enclosed spaces, where people huddle over a stove to cook or get warm.

But this was the only energy option for our ancestors for what might have been a million years.[fn3] Whether or not they were aware of the health impacts of what they were breathing in, the sacrifices of giving up wood-burning were severe. They needed fuels for cooking, heating, light and safety. Perhaps early death from respiratory infections, cardiovascular disease or lung cancer was worth it for a better life. As we'll see later, this is a trade-off that billions of people still face today. In the end, having a source of energy nearly always wins.

Burning coal

Coal is the dirtiest fossil fuel. Not only does it create the most pollution when we burn it, but it's also the worst for driving climate change. But moving from wood to coal was a big step-up. Per kilogram, coal gives us about twice as much energy as wood. And you don't have to cut down forests to supply it.

By the 15th and 16th centuries, many rich countries were quickly running out of forest. Three-quarters of British and French forests had been cut down.[14] Protecting what was left was becoming a priority. Many countries started burning coal in their homes for cooking and heating. Cities rose up. Households filled with smoke from coal-burning stoves. The streets filled with smoke too, as it wafted out from windows and doors. Whether inside the home or out on the streets, smog hung in the air. A silent killer, but one that seemed like an inevitable price to pay for progress.

London air was more polluted than the world's most polluted cities today

I've spent much of my life living in two cities renowned for having filthy air. A few centuries ago, one of Edinburgh's central spots – Nor' Loch – was the drainage site for the city's waste, and even the collection point for dead bodies. A nauseating stench would fill the air. This was compounded by the toxic fumes that leaked from chimneys and coal fires across the city. The city was cloaked in a dense fog, and the name 'Auld Reekie' or 'Old Smoke' was born.

If Edinburgh was the 'Old Smoke', London was the 'Big Smoke'. It's hard to capture just how polluted London was in the 18th and 19th centuries. The city was under thick smog for most of the year, and became a breeding ground for crime – coal-burning providing an invisibility cloak for thieves. It was often so bad that people couldn't travel.

The massive health costs of air pollution became obvious. Just breathing had become a ticking time bomb. In 50 years – from 1840 to 1890 – death rates from bronchitis increased 12-fold, meaning 1 in 350 people died from it.[15] If that were still the case today, 26,000 Londoners would be dying from air pollution every year.

That was nothing compared to the tragic smog that masked the city in December 1952. Air pollution levels were already improving by this point, but an unfortunate combination of cold and completely windless conditions meant that the particulates hung in the air longer than usual. The city ground to a halt. Londoners were rendered practically blind: to walk outdoors they would have to shuffle their feet around, feeling for kerbs and other obstacles. Ambulances stopped running. The pollution snuck indoors, forcing concerts and plays to be cancelled. The Great Smog of London lasted just four days but is estimated to have killed around 10,000 people and made 100,000 seriously ill with respiratory problems.

In the world's most polluted cities today, Delhi often tops the global pollution rankings, but if 18th- or 19th-century London were to enter the race it would be guaranteed to win this title, based on levels of suspended particulate matter.

That doesn't undermine the serious air pollution issues we face today. Far from it. Dirty air is still one of the world's biggest killers. I flinch when I see images of Delhi or Beijing peeking out from a thick haze. My point is that these modern levels of pollution might seem unprecedented, but they're not. That should be a relief: it's scary to face waters that seem uncharted. The fact that the level of pollution in our old cities comes as a surprise to us is good news. It means we found a solution. We managed to clean it up.

London's air was more polluted than Delhi's air today
Average concentrations of suspended particulate matter, measured in micrograms per cubic metre.

How countries tackled acid rain

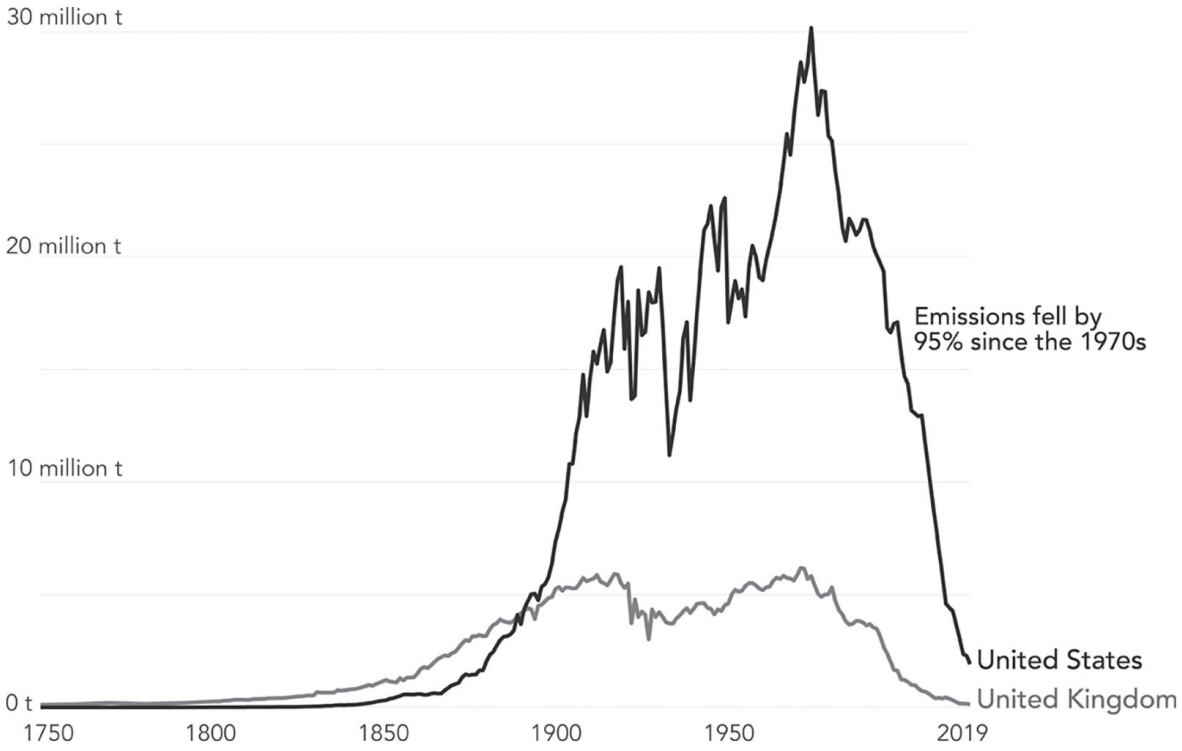
The dramatic reduction of air pollution in London is an example of a local success. But there are two other big success stories that are worth mentioning: acid rain, which needed countries to collaborate at a regional level, and the ozone layer, which required the world to work together to find a solution.

In the late 20th century, statues and monuments were dissolving. The faces of queens and kings became featureless blobs. Rivers and lakes became acidic, killing off fish. Freshwater insects were disappearing. Many forests were dying, stripped bare of their vegetation.

The culprit was acid rain, which is caused by emissions of sulphur and nitrogen oxides. In the atmosphere, these compounds react with water to form sulphuric and nitric acid. The rain, and everything it then filters into – trees, soils, rivers and lakes – become more acidic. The main sources of sulphur and nitrogen oxide are fossil fuels, industry and some forms of agriculture. Coal, for example, contains lots of sulphur.

When it's burned, it emits sulphur dioxide (SO_2), a molecule that dissolves in rainwater and makes it more acidic.

By the 1980s, acid rain had become the environmental problem of the day. What became clear is that individual countries couldn't tackle the problem on their own. It was an issue that crossed boundaries: emissions of SO_2 from the UK drifted over Scandinavia, ruining Norwegian forests, and emissions in the US blew over to Canada where they polluted freshwater lakes. After strong resistance, the United States and much of Europe brought in tight regulations. The impact was almost immediate. SO_2 emissions in the US were cut by around 95% from their peak in the 1970s.[16] In Europe, they've fallen by 84%, and in the UK, by 98%. The solution was quite simple: add a reactant to the smokestack of a coal plant, and the SO_2 can be stripped away so that it's not emitted into the atmosphere.



Sulphur dioxide (SO_2) emissions have plummeted in many countries
Measured in tonnes per year.

Acid rain has almost disappeared across North America and Europe. Many other countries are making fast progress too. To prove it, look at China. In just over a decade its SO_2 emissions have fallen by two-thirds. That's while the country's coal use more than doubled.

Acid rain is a problem we know how to solve. It has a simple technological solution. And when countries want to tackle it, with the right political will and investment, they can do it incredibly quickly.

How the world fixed the ozone layer

The effect of pollution on the ozone layer was the climate change of its day. The environmental problem that dominated the headlines. A problem that no country could tackle alone. Now it barely gets a mention.

In the 1960s, scientists were starting to understand the reactions that determined the photochemistry of the upper atmosphere. Ozone (O_3) is a gas that is present in Earth's atmosphere at multiple altitudes. You can find it at ground level, where it presents as a local air pollutant that causes respiratory problems for those who breathe it in. But the ozone we're interested in is very high in the atmosphere, around 15 to 35 kilometres above the surface, in the stratosphere.

This is the so-called 'good ozone'. It plays a crucial role in absorbing dangerous ultraviolet (UV-B) radiation from the sun. This protective layer of ozone guards humans against skin cancer, sunburn and blindness, and protects other life forms as well. We might want to get rid of ozone at ground level, but we definitely don't want to remove it in the stratosphere.

A trio of scientists that would later win the Nobel Prize – Paul Crutzen, Frank Rowland and Mario Molina – proposed that human emissions of chlorine substances could be doing exactly that: destroying ozone in the stratosphere.[17] They couldn't yet see ozone holes developing or measure this breakdown directly, but they could hypothesise from their understanding of chemistry that this might be happening. These substances – the most well known being chlorofluorocarbons (CFCs) – were being used in refrigerators, freezers, air conditioners, aerosol sprays and industry. By measuring concentrations of chlorine molecules throughout the lower atmosphere, they realised that these gases were not breaking down. Instead, they were rising through into the higher stratosphere.[18] There, UV radiation would break the chlorine atoms free, allowing them to react with ozone, and destroying it.

A scientific consensus on the decline of the ozone layer emerged relatively quickly after this hypothesis was shared in 1974, and in 1985 a major report laid out the evidence for it.[19] However, the biggest scientific game-changer was the discovery of the ozone hole over Antarctica. When we emit CFCs they tend to spread across the upper atmosphere evenly – including to spots in the world without direct emissions. CFCs are transported over Antarctica and cold temperatures are a key catalyst for these reactions, so ozone depletion is particularly bad at the poles.

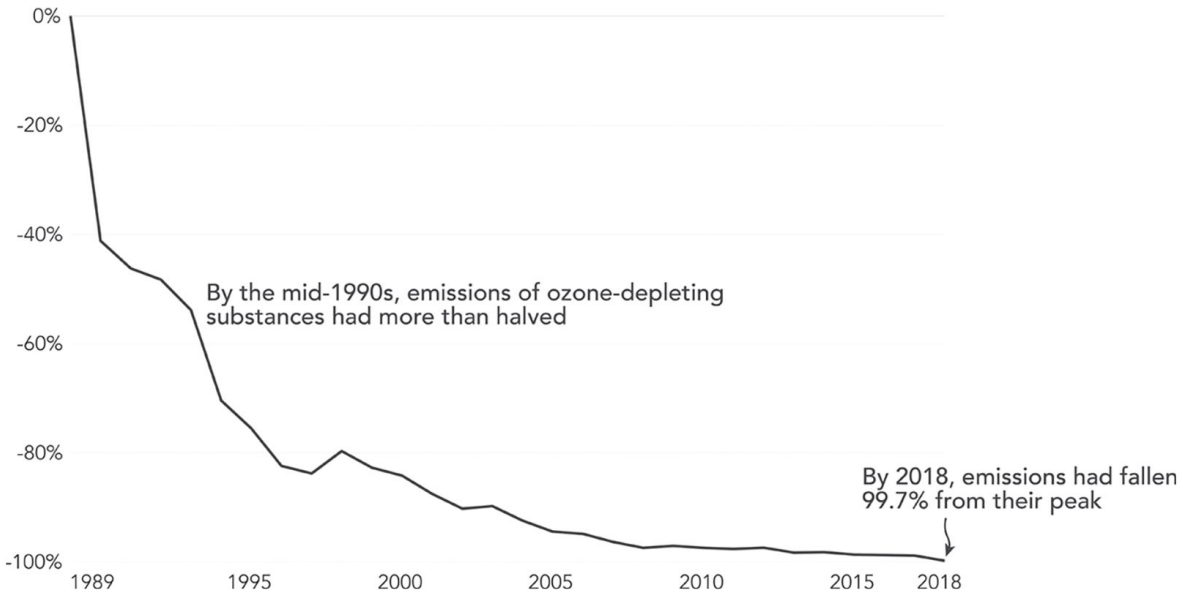
Until this point, Crutzen, Rowland and Molina had faced strong resistance and denial from industrial and political players.[20] The chairman of DuPont – the largest global manufacturer of CFCs – said the theory was: 'a science fiction tale … a load of rubbish … utter nonsense'. The leading producers formed the Alliance for Responsible CFC to coordinate their efforts and launched intense PR campaigns discrediting the theory of ozone depletion. Anne Gorsuch, the US's first female head of the Environmental

Protection Agency, dismissed ozone depletion as an environmental scare.[21] But the visual imagery of a growing ozone hole was hard to ignore: it finally put pressure on governmental and industrial actors to take action.

Forty-three countries signed the Montreal Protocol in 1987, agreeing to phase out ozone-depleting substances from 1989 onwards. The first countries to take action were mostly richer ones that were the main industrial producers – the US, Canada, Japan, most of Europe and New Zealand. Their aim was to halve global production by 1999 before working towards a total phase-out later.[22, 23]

Regulations became tighter as more evidence of the problem emerged. The deadline to phase out the production of ozone-depleting gases was brought forward. By the turn of the millennium, 174 parties (which are mostly countries and a few independent states) had signed the protocol. In 2009, it became the first international convention – of any kind, not just environmental – to achieve universal ratification from every country in the world.

The success of this international effort has been stunning. The phase-out that followed the first protocol in 1989 was rapid. Within a year, the use of ozone-depleting substances fell 25% below its 1986 levels. Within a decade the levels had fallen by almost 80%. This was far beyond the initial target of a 50% reduction. As of today, they have fallen by 99.7%.



International action on ozone depletion reduced emissions by more than 99%
The world adopted the Montreal Protocol in 1987 to reduce ozone-depleting substances. Shown is the reduction in global emissions compared to 1989.

The concentrations of ozone in the stratosphere more than halved through the 1980s and these levels stabilised in the 1990s. It will still take the ozone layer a long time to recover and global concentrations of ozone probably won't get back to their 1960 levels until the middle of the 21st century.[24] It might be the end of the century before

ozone levels in Antarctica get back to where they once were. But as long as we stick to our phase-out of ozone-depleting substances, the hole will continue to shrink. We've taken action, and now all we need to do is wait.

Tackling climate change and some of the other problems in this book will be more difficult, but there are still important lessons to learn from both the acid rain and the ozone success stories. Humans can solve real global problems. Every country has the opportunity to be involved. And we can take action quickly when we're up against it. It serves us well to remind ourselves that we are capable of cooperating on such global problems.

As you go through the following chapters, you should keep these lessons in mind, too. You might be sceptical. I certainly was. But what might at first seem like unmovable barriers are not destined to stay that way. There are many more Crutzens, Rowlands and Molinas working tirelessly in the shadows.

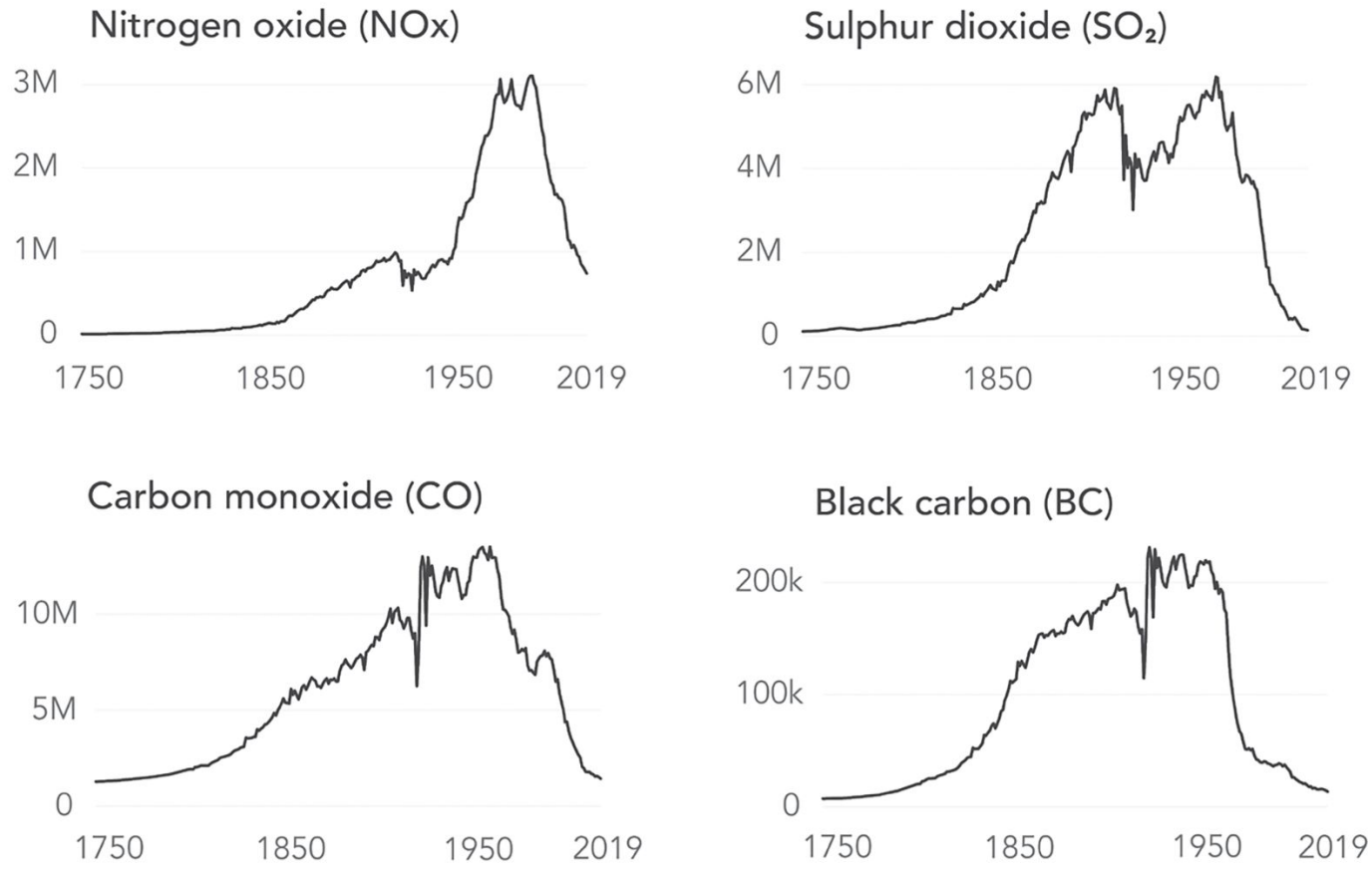
Where we are today

Many of us are breathing in the cleanest air in centuries

The air I breathed as a child was much cleaner than my parents ever experienced in their youth, and much, much cleaner than my grandparents enjoyed. We're breathing air that is cleaner than it has been for centuries. But it's a success story that we rarely tell.

It's not just emissions of SO_2 that have fallen in the UK. Emissions of local air pollutants are just a fraction of what they were. Nitrous oxides are down 76% from their peak. Black carbon is down 94%, volatile organic compounds down 73% and carbon monoxide down 90%.

The UK is no outlier. It's the same story across most of the world's rich countries. Reductions in the US, Canada, France and Germany, have been just as impressive. This success is largely the result of successful environmental regulation. The UK implemented its first Clean Air Act in 1956, following London's Great Smog. Decade by decade, these regulations were made tighter. In response, industries had to develop low-pollution technologies. We learned how to strip the sulphur out of coal-burning. We banned leaded petrol. We learned how to produce cars and trucks that emit just a fraction of the pollution they once did. The US implemented its Clean Air Act in 1970, with similarly impressive results.[25]



The rise and fall of air pollutants in the United Kingdom
This pattern – the increase, peak then rapid fall of emissions – is consistent across most rich countries. Emissions are measured in tonnes per year.

Environmental action is often framed as at odds with the economy. It's either climate action or economic growth. Pollution versus the market. This is just wrong. Countries have slashed air pollution while growing their economies at the same time. Lower pollution, better health *and* a stronger economy? That sounds like the perfect sales pitch to me.

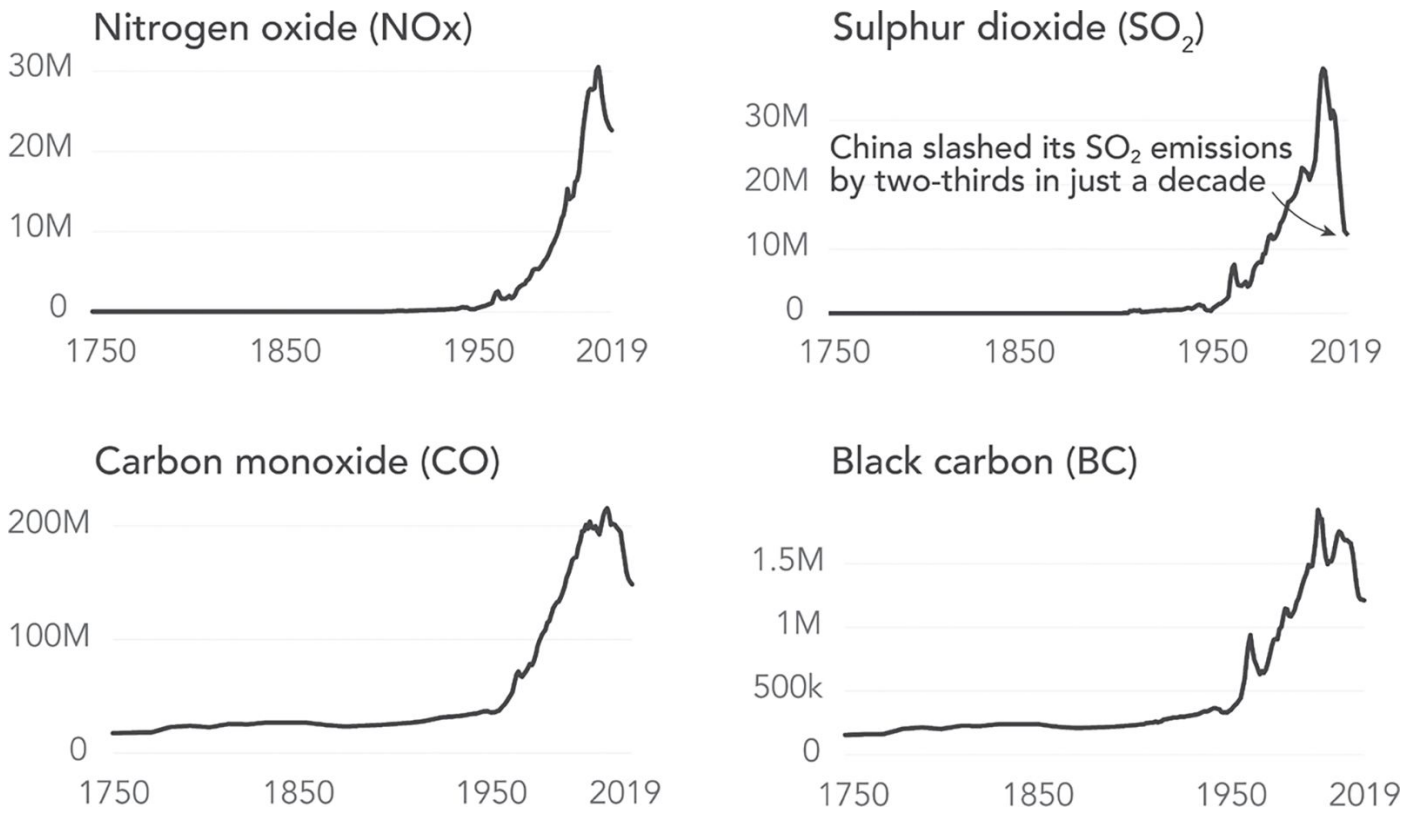
It often gets worse before it gets better: air pollution is also falling in many growing economies

The path that countries follow is a predictable one. Pollution first rises as a country starts to move out of poverty. At this stage, access to energy is the priority. It burns coal, oil, gas without tight restrictions on how clean it needs to be. There are no demands for top-of-the-range power plants with anti-pollution controls, or new car engines with particle filters. Pollution levels continue to rise as more people get electricity, cars, and can afford to heat or cool their homes. The country enters an industrial boom. People have more money and life is getting better. The pollution isn't pleasant, but the trade-off seems worth it.

But, eventually, the country reaches a tipping point in its pathway to prosperity. Once life is comfortable, our concerns turn to the environment around us. Our priorities shift, and we no longer want to tolerate dirty air. Governments have to shift too; they are forced to take action and reduce levels of air pollution. The curve of air pollution reaches its peak and starts to decline.[26]

This journey is often called the 'Environmental Kuznets Curve':[fn4] plot an environmental metric against income and it forms an upside-down 'U' (it's low when we're poor; it rises to reach its peak at middle incomes; then falls again as we get richer). There are lots of environmental metrics where this Kuznets Curve doesn't hold true. But it works for air pollution, which means we can tell what stage of economic development a country is in just by drawing a curve of how polluted its air is. India, for example, is just approaching its turning point. It's on the brink of peak pollution. As seen earlier, China is further ahead and has now passed the peak.

It took countries like the UK and the US two centuries to go through the rise and fall of air pollution. With new technologies, countries are going through this transition four times as quickly. Better yet, some of the poorest countries might be able to skip the curve entirely.



China has now passed 'peak air pollution'
Air pollution is now falling quickly in many upper-middle-income countries. Emissions are measured in tonnes per year.

Millions of people die from air pollution every year

Air pollution might be falling in many countries, but it's still one of the world's biggest killers. It increases our risk of respiratory disease, stroke, cardiovascular disease and lung cancer.

And it's the little particles we can barely see that are especially bad for our health. Scientists often refer to them as '$PM_{2.5}$' – particulate matter that is smaller than 2.5 micrometres in diameter. Almost invisible. The problem is that these tiny particles can sneak deep into our lungs and respiratory system. Visit the beach and you will find annoying bits of sand in your shoes for days. You won't find any hidden boulders in there, but the smallest grains get into the smallest cracks. Particles in the air are no different.

In 2020, nine-year-old Ella Adoo-Kissi-Debrah became the first person in the world to have 'air pollution' on her death certificate. She died of asthma, and a London Coroner's Court concluded that air pollution played a large role. This outcome is rare. Air pollution kills a lot of people, but it's not cited as a cause of death. Instead, researchers estimate premature deaths from measurements of pollutants in the air, and our understanding of how this increases our risk of deadly diseases. Researchers don't agree on the exact number. But they do agree that it's tragically high – in the order of millions. The World Health Organization estimates that air pollution kills 7 million people every year: 4.2 million from *outdoor* air pollution, and 3.8 million from *indoor* air pollution from burning wood and charcoal. The world's other big health institute, the Institute for Health Metrics and Evaluation (IHME), gives a similar number: 6.7 million. Some scientists think this number could be even bigger: some of the most recent and widely cited studies estimate that at least 9 million people die every year from the air they breathe.[27, 28]

To put these numbers into context, this is similar to the death toll from smoking: around 8 million.[29] It's six or seven times higher than the number of people that die in road accidents: 1.3 million. Hundreds of times more than the number that die from terrorism or war each year. Air pollution is the silent killer that doesn't get enough headlines. It doesn't shock us like images of a flood or a hurricane, but it kills around 500 times more people a year than all 'natural' disasters combined, in most years.[fn5]

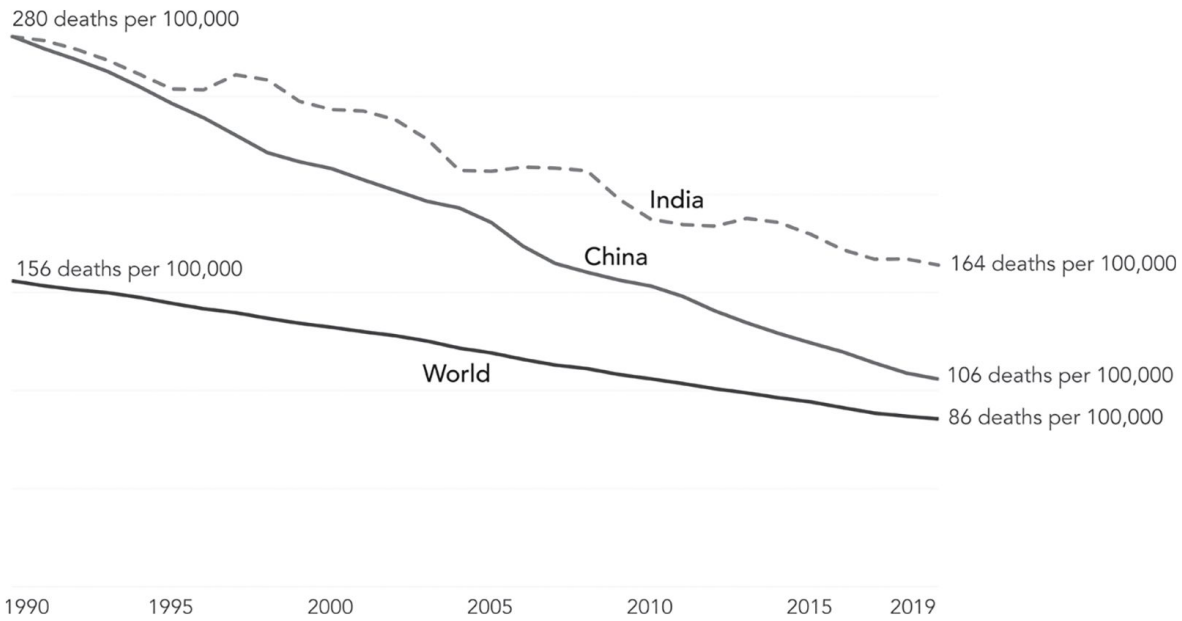
But death *rates* from air pollution are falling

This is a bleak picture. But as with so many examples in this book, it is not the whole picture. While the number of deaths from air pollution is still horrifically high, the data does contain hope. We could be at the peak of the human tragedy that is air pollution. It's possible – in fact, it's likely – that we're approaching 'peak pollution deaths'. That sounds grim, but it also means that the worst is behind us.

Why do I think we're approaching the peak? The total number of deaths from air pollution globally has been about the same for decades. The death toll hasn't changed

much despite there being many more people in the world. And, especially, older people who are at much higher risk of dying from strokes, cardiovascular disease and cancers. This means that the death *rate* from air pollution – or the risk for the average person – has been declining, and not just a little: death *rates* have halved since 1990 by some estimates.[30]

If global population growth slows down, and air pollution continues to improve, the world will soon pass the peak of air pollution deaths. The downward slope could be much steeper than the upward one. A rollout of clean technologies could see pollution deaths plunge in a matter of decades.



Death rates from air pollution are falling, even in the most polluted countries
Death rates from indoor and outdoor air pollution, measured as the number of premature deaths per 100,000 people.

How do we achieve clean air?

To understand what we need to do to stop air pollution, we first need to understand where it's coming from.

Delhi's average concentration of tiny particulates – those smaller than 2.5 micrometres – is twenty times higher than the WHO guidelines. In winter, things get even worse. The winds drop, and the pollution settles on the city. During these months, it's not uncommon for levels to reach more than 100 times the WHO limit.

In January 2016, the local government needed a quick fix. It decided to take half of Delhi's cars off the road, implementing the 'odd-even' rule: if your number plate ended in an odd number then you could only drive it on 'odd' dates, and if it ended in an even number, the opposite. If it wasn't 'your' day to drive then you'd have to use public transport or catch a ride with someone who had the right number plate. Ignoring the rule resulted in a fine.

You'd think this would have a dramatic effect, but researchers estimate that the odd-even rule in 2016 only led to a 5% drop in Delhi's pollution. It tried again in November 2019, with a little more success: a drop of around 13%.

How could such a dramatic change make so little difference? The answer is obvious if we step back to look at *where* Delhi's pollution is coming from. It's not coming from its cars. In fact, only around 23% of Delhi's winter $PM_{2.5}$ pollution was coming from transport, and *cars* were just 4%, with most of the rest coming from trucks.[31] But trucks, buses and motorcycles were not included in the scheme. And, actually, not all cars were either. Women drivers were exempt. So were cars running on cleaner fuels, taxis, and those carrying VIPs such as government officials, judges and embassy members. In other words, the rule applied to non-VIP males driving a private petrol or diesel car.

There were benefits to the programme. Congestion got a lot better, for a start. But it would have been clear to anyone that had studied the numbers that this was not going to bring Delhi's pollution under control. To do that, the sources of pollution that trump cars would have been a better place to start. That includes winter crop-burning, when farmers prepare their fields for the new wheat season by burning the leftover stubble from their rice harvest; industrial fumes in the city; dust from surrounding areas; diesel generators for energy; and the burning of coal and wood in homes.[32]

Globally our emissions come from a handful of sources. The first is burning wood or charcoal for energy or burning crops in the field. This is one of the biggest sources at lower incomes, and a big contributor to indoor *and* outdoor pollution. Then we have emissions from agriculture, with the ammonia and nitrogen gases that come from manure and fertilisers. The next is burning fossil fuels for electricity. Then emissions from industry – the fumes leaking out of chemical plants, metal manufacturers and textile factories. Finally, we have transport – the cars we drive, but also the trucks, ships and planes that carry goods around the world.

To get air pollution close to zero everywhere, we need to knock these sources off one by one.

How to get air pollution close to zero everywhere

The solution to air pollution – as we saw earlier – follows just one basic principle: stop burning stuff. We need to find a way of producing energy without burning things. Or, if we do, we need to capture the particles safely and make sure they don't make it out into the atmosphere. Many countries are not far away from this step. The world's poorest are lagging behind, but they could already get pretty far by burning *different* things for energy.

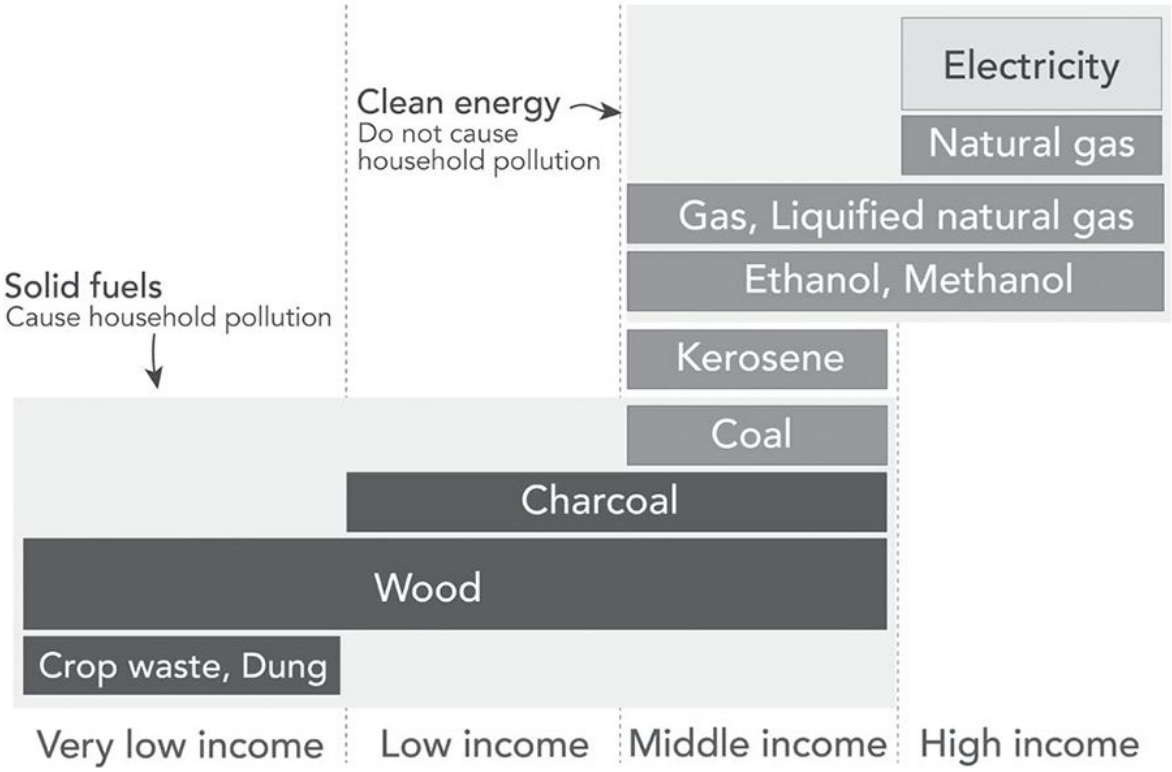
(1)

Give everyone access to clean cooking fuels

Not everything we burn creates the same amount of pollution. Wood is worse than coal; coal is worse than kerosene; kerosene is worse than gas.

This process of moving from one form of energy to another is called climbing the 'energy ladder'. The world's poorest still rely on wood as their main (possibly only) source of energy. This puts them at the bottom of the ladder. Once they get a bit richer, they might start to burn charcoal, then a bit later, coal. These solid fuels are still terribly polluting, and toxic for those inhaling the emissions every day. What's shocking is that this is the reality for around 40% of the world's population – more than three billion people.

No one in the world should be on this rung of the energy ladder. Everyone should have access to clean fuels for cooking and heating. The fact that billions of people don't means this should be one of the environmental movement's top priorities. Our first step towards clean air is a tried-and-tested one: reduce poverty and make sure no one is using old, traditional fuels.



The 'Energy Ladder'
The dominant energy source for cooking and heating, by level of income.

(2)

End winter crop-burning

Crop-burning is a seasonal contributor to local air pollution in India.[33, 34] October and November are the changeover months for farmers, when they harvest their rice and get ready to plant wheat. The planting window is short – the first two weeks of November – which means they need to quickly get rid of the straw from the rice crop that has been left behind in the field. The easy thing to do is burn it. Easy for the farmer, but costly for the country. All the farmers do this at the same time, and the surrounding cities are filled with pollution.

There are some possible solutions. The waste residue could be gathered up to be used for animal feed or other materials. Or farmers could be encouraged to plant a different rotation of crops. There are also some technological solutions. A tractor-like machine called the Happy Seeder can cut and lift the rice straw, sow the wheat underneath, then put the straw back on top as organic manure. The Indian government has tried to support the Happy Seeder by offering subsidies for farmers to buy one. And studies have shown that these types of technologies can be profitable for the farmer.[35] The problem is that it's an expensive upfront investment, and an ongoing cost for the farmer to maintain, for a piece of kit that's only used for 15 days a year.

To reach the scale that's needed to put a dent in crop-burning, subsidies from the Indian government would need to be substantial. Still, it would be a massive benefit economically and environmentally. When weighing up the price of taking action, we tend to compare it to the alternative of investing nothing at all. But that's wrong. There are societal costs to not taking action that we forget to factor in. We might think that spending hundreds of millions of dollars is expensive. But that's because we ignore the alternative: the costs of not fixing the problem.

There is no single estimate of how much air pollution costs us in monetary terms; it depends on what 'price' we put on poor health and early death. But most studies come up with a similar order of magnitude: trillions of dollars are lost globally every year from ill health, sick days, loss of productivity, crop losses and other 'hidden' impacts.[36] In a 2022 report by the World Bank, this figure was $8.1 trillion, which was equal to 6% of global GDP.[37] In India, the cost of air pollution in 2019 was estimated at $350 billion: that's 10% of its GDP. We can look away and pretend these societal costs don't exist, but they'll keep racking up a bill until we solve it.

(3)
Remove the sulphur from fossil fuels

Coal will eventually be a fuel of the past, but it's still going to take some time for the world to move away from it completely. In the meantime, people will continue to die from the pollution it creates, so we should do what we can to limit this.

The sulphuric haze that hangs over Delhi and Mumbai doesn't have to be there. We already have a fix for it: capturing the sulphur dioxide that comes out of coal power

plants. Power plants need to add a ‘scrubber’ to the smokestack. For example, add limestone and the sulphur dioxide in the gas reacts to form a solid that you can capture.

Scrubbers can remove at least 90% of sulphur dioxide, hence the nosedive in pollution in many countries over the last 50 years. A power plant with these technologies is more expensive than one without them. That’s why rich countries all have them, and poor countries don’t. But just as we saw with China, each will reach its tipping point. When it does, the solutions are ready and waiting. We can just scrub the sulphur away.

(4)
Which is the cleanest car to drive?

When most of us think about air pollution in our cities, we picture bumper-to-bumper cars idling in traffic. News stories about air pollution nearly always cut to B-roll footage of fumes coming out of car exhausts. So most of us know that the pollution from our cars is bad for our health.

In the UK, this attention was ramped up in 2015 when ‘Dieselgate’ (also called ‘Emissionsgate’) hit the headlines. Many countries put strict policies on how much pollution vehicles can generate, so they have to meet certain air-quality standards to be sold on the market. In 2015, it was revealed that one of the world’s leading car companies, Volkswagen, had been cheating. They had programmed the engine’s pollution controls in many of their cars to only run when the cars were being tested. During the test, these controls kicked in and they passed. When the cars were let loose on the road, the controls stopped working. Their emissions were well over the legal limit. This scandal not only put a temporary dent in Volkswagen’s reputation, but it also put the limelight on the emissions spewing out of our cars.

Some governments tried to push consumers towards diesel cars. The rationale was that diesel cars emitted less CO_2 per kilometre than petrol cars. Moving from petrol to diesel would be good for the climate. But this didn’t quite go to plan, and many of the governments eventually made a U-turn. This was partly triggered by the Dieselgate scandal, but also because it emerged that diesel cars emitted quite a lot more of the local pollutants that get lodged in our lungs than petrol cars. The dilemma was to decide what matters more: climate change or local air pollution that damages our health. Then it was discovered that diesel cars don’t in fact emit much less CO_2 than petrol cars. Diesel cars need to be fitted with technologies to reduce their emissions of local pollutants, and that comes at an energy cost. That added cost takes away a lot of the climate benefits. Some studies suggest that diesel cars are worse for both climate and local air pollution.[38]

Diesel cars are few and far between in the US, so American consumers have escaped the petrol versus diesel dilemma. But what is the right decision for consumers elsewhere? When it comes to diesel versus petrol, the difference often isn’t huge. What

plays a bigger role is how old the car is. Modern petrol and diesel cars are much cleaner than their older cousins. Emissions standards have become stricter and filtering technologies much better. But, as we'll see in the next chapter, the debate on petrol versus diesel is quickly becoming outdated. Fossil fuel-powered cars are on their way out. Electric cars and car-free living are making their breakthrough. We should ditch the old technologies soon, and make that switch as quickly as possible. It will save many thousands of lives every year.

(5)

Drive less; cycle, walk and take public transport

We can debate which type of car causes the least pollution, but this misses the solution that trumps them all: not driving at all. If it's doable for you, ditching the car for a bike or a walk is one of the best ways individuals can reduce air pollution (and climate change). The congestion and pollution benefits for the city become crystal clear any time you see a line of cyclists roll past a queue of idling cars, fumes spewing out the back of the tailpipe.

This is both an individual and societal responsibility. Many of us have the option to leave the car at home when our destination is within cycling or walking distance. There are safe routes for us to use. We are healthy enough to do so. It's personal choice that stops us. After walking and cycling, the next best thing is to go for public transport.

But some don't have this option. Work is too far from home. There are no cycle lanes, and sometimes no pavements to walk on. Public transport systems are old. Buses and trains are late, unreliable and only come every few hours (if they come at all). The lack of infrastructure forces people into their cars.

We should be more ambitious about how we imagine our cities, towns and transport systems in 2040 or 2050. They could be built around pedestrians and cyclists, not cars. In my dream world, there would be no need to *own* a car, especially if it does nothing 23 hours a day. We could create networks of driverless, low-carbon Ubers that serve the city. When you do need a ride, press a button on an app, and a clean, autonomous vehicle will swing by to pick you up. If governments and planners think about this carefully, this could even be a form of public transport. The health and economic benefits would be massive.

(6)

Ditch fossil fuels for renewables and nuclear

Cleaning up our coal power stations and putting filtration technologies in our cars has got us pretty far. These measures can help us achieve pollution levels that are just a fraction of what they were in the past.

But they are not enough. Even in the richest countries, most of us are still breathing air that shortens our lives. Our children are breathing air that might affect their concentration and learning potential. Just because things aren't as bad as they were in the past doesn't mean we have to accept the status quo. We deserve better. If we're to stamp out air pollution completely we need to stop burning fossil fuels.

The good news is that we need to do this anyway if we're to tackle climate change. That means we can fix two big problems at the same time. In fact, people demanding clean air from their governments might be an important way to accelerate climate action. When Beijing or Delhi is hidden under a cloak of haze, people can't ignore it.

When we ditch fossil fuels, what energy sources should we shift to? On this, I'm more agnostic than most. In the environmental community, there is an intense rivalry between two camps: pro-nuclear and pro-renewables. The fights between these tribes get surprisingly fierce. To me, this rivalry is frustrating and counterproductive.

Nuclear energy and renewable sources, like solar, hydropower and wind, are all low-carbon. The reason they don't emit *zero* CO_2 is that we still need energy and materials to build the panels and turbines in the first place. But compared to fossil fuels they emit very little. Switching from fossil fuels to any of these sources is such an obvious win for the climate. And switching to nuclear or renewables would stop deaths from air pollution, so it's a big win for global health too.

One of the biggest misconceptions is that nuclear power is unsafe. In fact, it's one of the safest sources of energy. Over the last 60 years there have been only two major nuclear accidents: Chernobyl in Ukraine in 1986, and Fukushima in Japan in 2011. When we think about nuclear power, it is these two terrible incidents that come to mind. When I polled my friends about how many people had died in them, the most popular guess was hundreds of thousands. The numbers are actually much smaller.[39]

When we combine the direct deaths from the Chernobyl explosion, and the potential deaths from cancer cases caused by the radiation, the accident is likely to have caused up to 400 deaths.[40, 41] Every one of those deaths is tragic, but they're much fewer than most imagine, especially given the fact that this was the worst nuclear disaster in history and is unlikely to be repeated. The Chernobyl reactors were an old and unsafe design, and the secrecy of the Soviet Union at the time meant the response to the disaster was slow.

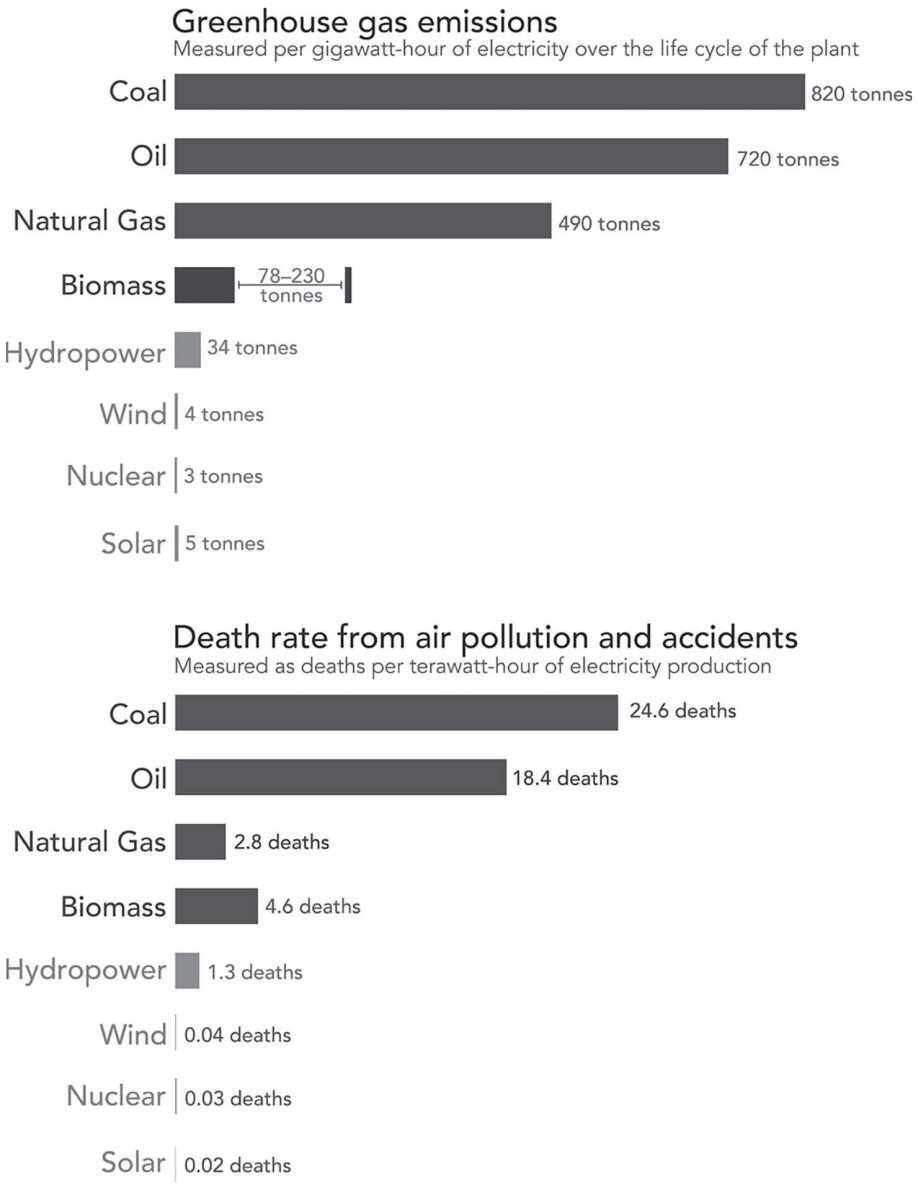
In 2011, the Fukushima nuclear plant in Japan was hit by a tsunami after the country's largest recorded earthquake. Remarkably, no one died directly from the incident. Several years later, the government announced that one man died from lung cancer which might be linked to the disaster. Overall, that is quite remarkable: a nuclear power plant was hit by a tsunami and there was only one possible death. However, the government does attribute around 2,700 premature deaths to the stress and disruption of evacuation from Fukushima in the years that followed.

When the deaths from Chernobyl and Fukushima are combined, it's estimated that a few thousand people have died from nuclear power over its history.

Does that make it safer or more dangerous than other sources of power? Death rates – how many people have died per unit of electricity production – from nuclear, solar and wind are all very low.[42] And there is not much difference between them. Hydropower is also pretty safe, though its one major incident – the 1975 Banqiao Dam Failure in China, which killed 171,000 – pushes its death rate up quite a bit.

Look at the chart below and see how the alternatives compare to fossil fuels. Air pollution from coal kills thousands of times as many people per unit of electricity production. Oil kills thousands of times more than nuclear and renewables.

Those who squabble about whether nuclear death rates are a little bit higher than solar, or a little bit lower, or whether solar is more deadly than wind are completely missing the point. Separating these is like splitting hairs. The big headline is that all of them kill far, far fewer people than any fossil fuel. Millions die from fossil fuels every year, with estimates ranging from 3.6 to 8.7 million – 1 to 2.5 million come from electricity, and most of it from coal.[43] Nuclear and renewables are hundreds, if not thousands, of times safer. And, importantly, they all emit very little CO_2, so are much safer for our climate too.



Renewables and nuclear energy are much safer and better for the climate than fossil fuels
Fossil fuels kill millions every year from air pollution, and also emit far more greenhouse gases per unit of electricity.

When it comes to saving lives, it does not matter what low-carbon source we transition to. We just need to get off fossil fuels, in any way we can. We need to keep our existing nuclear plants in operation. Build some more in countries where this is affordable and they have technological expertise. Put solar panels on roofs. Put solar panels and wind turbines on deserted land.

If we want to squeeze out these final sources of air pollution we need to transition to low-carbon energy, and shift our cars to electric. Until recently, this transition seemed impossible because batteries, solar panels and electric cars were far too expensive. This is changing, and it's changing fast.

Things to stress less about

Every day I come across motivated and thoughtful people trying to do their best for the environment. They think about the environmental impact of almost every decision they make. Or they home in on some things that they *think* will make a huge difference. What's heart-breaking is that this energy and stress is often wasted: what they're doing makes almost no difference, and, as we'll see later, occasionally makes things worse.

I said I would be clear about which things we should stress less about. But in this chapter, I won't be listing things to stress less about. Because there are two problems I think people should stress a little *more* about. Air pollution is one of them (the other is biodiversity loss). We worry a lot about climate change, and the fact that it could kill many people in the future. But air pollution is *already* killing millions every year and has done so for a long time. Cutting out fossil fuels now would have an immediate impact. It would save lives, and people living in highly polluted cities like Delhi, Lahore or Dhaka would instantly see the difference. They could breathe again. Reducing air pollution is one of the most impactful ways that we can stop people from dying. That's something we should be thinking a lot *more* about.

Are there things that individuals – beyond walking, cycling, using public transport and electric cars – should be doing more of? The first obvious one is speaking up. Demanding clean air so that governments make it a priority. At the beginning of the chapter, we saw the power of speaking up in Beijing. The Chinese government took note and was forced into action. We already have most of the tools and knowledge we need to reduce air pollution. What's missing is money on the table and the political will to act. That's something we can influence.

The second is making sure that we resist the temptation to return to behaviours that *seem* environmentally friendly but are not. As I write, the UK is seeing a surge in popularity for open wood fires and stoves. These seem like an eco-friendly way to heat your home – it's what we used to do before we started burning fossil fuels – and feel more 'natural' and 'primitive'. But burning wood is what many of the world's poorest are trying to move away from. It creates large amounts of pollution inside your house, and also contributes to pollution outdoors. It's much worse than gas or electricity. Burning these solid fuels was once a massive problem that we solved. Let's resist the temptation to roll back this progress: it might *feel* like the eco-friendly thing to do, but the data tells us that it's not.

3

Climate Change

Turning down the thermostat

‘Scientists say temperatures could rise by 6°C by 2100 and call for action ahead of UN meeting in Paris’

– *Independent*, 2015[1]

A world that was 6°C warmer than it is today would be devastating. And remember, 6°C is just the average. Some parts of the world would get *much* warmer, especially the poles. Crops would fail. Many people would be malnourished. Forests would be stripped back into savannahs. Island nations would be completely submerged. Many cities will have disappeared due to sea-level rise. Climate refugees will be on the move. ‘Normal’ temperatures in many parts of the world would be unbearable. Even the richest, most temperate nations would see devastating floods most winters, and baking summers. We would be at very high risk of setting off warming feedback loops – the melted ice would reflect less sunlight, the melted permafrost might unlock methane from the bottom of the ocean, and dying forests wouldn’t be able to regrow to suck carbon out of the atmosphere. A 6°C warmer world might be short-lived – it could quickly spiral into 8°C, 10°C or more. It would be a massive humanitarian disaster.

Only a few years ago I thought this was where we were headed. Forget 1.5°C or 2°C – we were destined for 4, 5 or 6°C and there was nothing we could do about it. Most people still think that this is the path we’re following. Thankfully, it’s not.

In 2015, I went to Paris for the big, famous climate conference, COP21. Representatives and policymakers from every country came together to hash out a new climate deal. The previous goal of the international agreement was to keep the global average temperature rise below 2°C by the end of the century. So I couldn’t believe it when there were rumours that a target of 1.5°C was being discussed. Were they crazy? At that point, I had already given up on the prospects of 2°C. It was so far out of our reach. The notion that we could keep the rise below 1.5°C seemed delusional. And yet the target made it into the final agreement. Mostly as an aspiration, but it was in there

nonetheless. The world pledged to 'limit global warming to "well below" 2°C above pre-industrial levels and also, if possible, "pursue" efforts to cap warming at 1.5°C'.

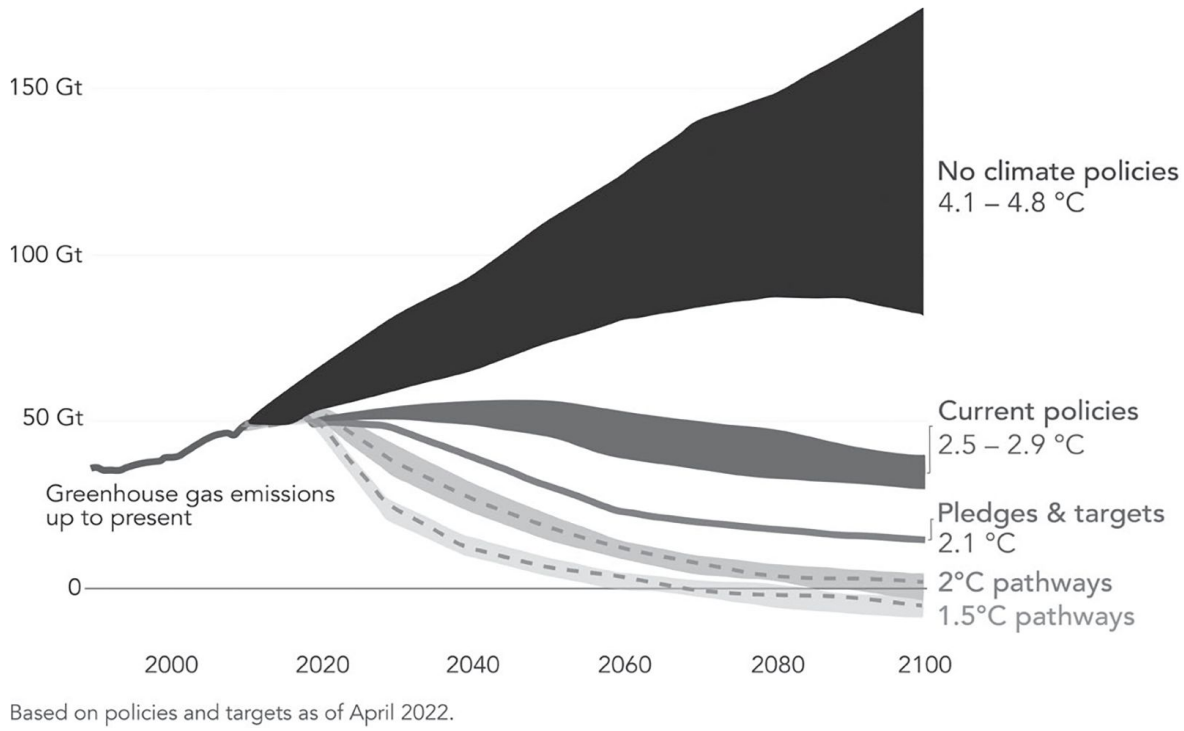
My perspective on 1.5°C hasn't shifted much since then. Without a major, unexpected technological breakthrough, we will go past this target. Nearly all the climate scientists I know agree: they obviously want to cap warming at 1.5°C, but very few think it will happen. This doesn't stop them fighting for it, though; they know that every 0.1°C matters, and is worth working for. But my perspective on 2°C *has* changed. I'm now cautiously optimistic that we can get close to it. It's more likely than not that we will pass 2°C, but perhaps not by much. And there is still a reasonable chance – if we really step up to the challenge – that we can stay below it.

My perspective flipped quickly after studying the data, not newspaper headlines. I didn't focus on where we are today, but on the *pace* that things have moved at in the last few years, and what this means for the future. One organisation – the Climate Action Tracker – follows every country's climate policies, and its pledges and targets. It combines them all to map out what will happen to the global climate. At Our World in Data I sketch out these future climate trajectories, and update them every year. Every time they get closer and closer to the pathways we would need to follow to stay below 2°C.

If we stick with the climate policies that countries currently have in place, we're heading towards a world of 2.5 to 2.9°C warming.[2] Let me be clear: this is terrible and we have to avoid it. But countries have pledged to go much further. They've committed to making their policies much more ambitious. If each country was to follow through on their climate pledges, we'd come out at 2.1°C by 2100.

What's most promising is how these pathways have shifted over time. In a world *without* climate policies, we'd be heading towards 4 or 5°C, at least. This is the path that most people *still* think we're on. That would be a scary world indeed. Thankfully, over time, countries have stepped up their commitments. As we saw with the example of the ozone layer, incremental increases in ambition can make a huge difference.

The other big change is that moving to a low-carbon, sustainable economy is not seen as the sacrifice it used to be. Fossil fuels were far cheaper than renewables. Electric vehicles cost a fortune. But now low-carbon technologies are becoming cost-competitive. It now makes financial sense to take the climate-friendly path. Leaders have become more optimistic about how the landscape is changing. We are still some distance from a 2°C pathway. We need to step up our efforts – and quickly. But as it becomes more and more realistic, I'm confident we can keep moving closer to it.



How much warmer will the world get?
Projected warming by 2100 relative to pre-industrial temperatures based on different scenarios of climate policies.

When I was in my early teens I thought most of us were going to die from climate change. I tried to convince my classmates of this too. For my English oral exam I held up a map of all of the cities and coastlines that were going to sink by the end of the century. I showed projected satellite images of the wildfires that would ravage the globe. In trying to light flames of interest, I simply added fire to my own anxieties.

By the time I reached Edinburgh University, I was being flooded with images every day. Some from my university lectures, which, given the fact I'd chosen a degree in earth sciences, was expected. But, more importantly, my obsession for environmental sciences was growing in tandem with the uptick in the frequency of reporting. The more determined I became to stay informed, the quicker the stories came at me, often accompanied by streams of recorded videos. I didn't have to imagine the pain of the victims, I could see and hear it too. As a responsible citizen, I wanted to stay informed. I had to know what the latest disaster was. To switch off from them seemed like a betrayal to the lives that were lost.

With reports of disasters coming at me faster every day, it seemed that things must be getting worse. Climate change was driving an intensification of disasters, and more people were dying than ever before.

Or so I thought. The problem was that I mistook the increase in the frequency of reporting as an increase in the frequency of disasters. I mistook an increase in the intensity of my second-hand suffering for an increase in the intensity of global suffering. In reality I had no idea what was happening. Were disasters getting worse? Were there more this year than last? Were there more people dying than ever before?

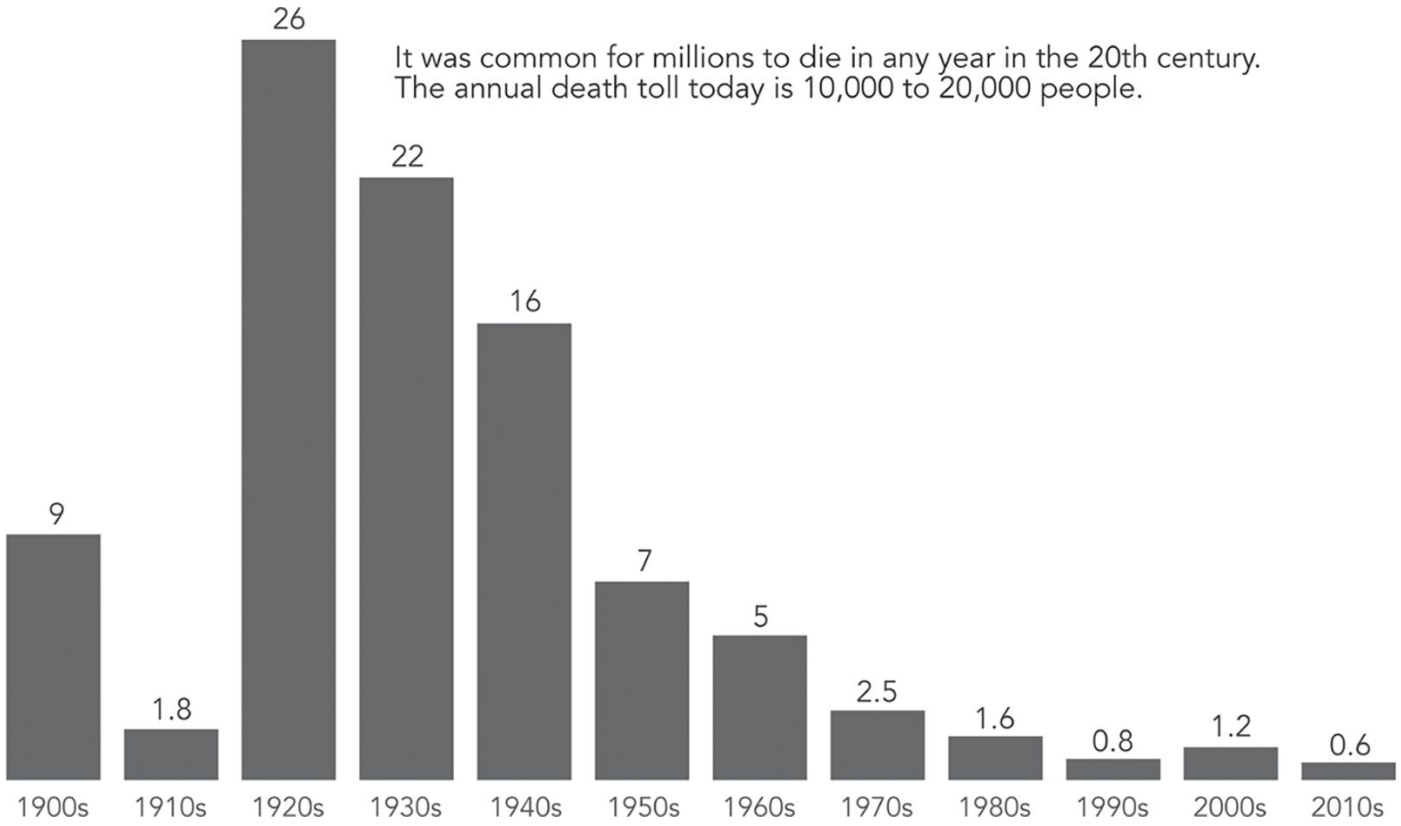
After Hans Rosling taught me that extreme poverty and child mortality were falling and education and life expectancy were rising, I went looking for other areas where my preconceptions might be wrong. I started with data on 'natural' disasters. I would have bet a lot of money that more people were dying from disasters today than a century ago. I was completely wrong. Death rates from disasters have actually *fallen* since the first half of the 20th century. And not just by a little bit. They have fallen roughly 10-fold.[3, 4]

It's at this point that I should make one thing clear: none of the above means that climate change is not happening. The decline in deaths from disasters does not mean that disasters are getting weaker or less common. Deniers often misuse this data to downplay the existence or risks of climate change. But that's not what the data shows us at all.

In the past it was common for disasters to claim millions of lives a year. The 1920s, 30s and 40s were particularly bad. There were a few large earthquakes which claimed many lives: China, Japan, Pakistan, Turkey and Italy were all hit by a series of earthquakes that cost tens of thousands of lives. The most lethal – the 1920 earthquake that struck the Gansu province in China – is estimated to have killed 180,000 people. But it was drought and floods which were the most deadly. China endured a number of large floods and droughts through the 1920s and 30s, which often led to widespread famine and killed millions at a time.

Today the annual death toll is much smaller, usually between 10,000 and 20,000. Sometimes there are particularly devastating years where the toll is much higher – like 2010, when the annual death toll was over 300,000 with most deaths resulting from the Haitian earthquake.

When I zoomed out and saw these trends, I felt stupid. I also felt cheated. I had been duped by an education system that was supposed to teach me about the world. I was a diligent student. I won medals for coming top for everything from earth materials to sedimentology, atmospheric science to oceanography. I could create complex diagrams of seismic faults, I could recite the chemical formulas of pages of minerals from memory, but if you'd asked me to draw a graph of what was happening to deaths from disasters, I'd have sketched it upside down.



Far fewer people are dying from natural disasters than in the past
Death rates from 'natural' disasters, measured as the number of deaths per decade per 100,000 people.
Deaths have fallen – not because disasters have become less frequent or severe, but because our infrastructure, monitoring and response systems have become much more resilient to them.

I wasn't alone in my ignorance. In the 2017 Gapminder Misconception Study, the public, across 14 countries, were asked 12 key questions, one of which was:

> How did the number of deaths per year from natural disasters change over the last hundred years?
>
> A: More than doubled
> B: Remained more or less the same
> C: Decreased to less than half

Just 10% got the right answer: C. The most popular answer, 48% of the vote, was A.

My fear is that this disconnect has only got worse since then. Climate change gets more attention, and rightly so. But reporting has become more frictionless. Some media outlets even see the frequency of stories as their key performance metric. *'With a piece of environmental journalism published every three hours, the* Guardian *is a leading voice in the fight to save the planet'* reads a large banner plastered across the newspaper's website.[5] In other words, the *Guardian* wants to fire as many crushing stories as possible, as quickly as it can. The faster it does this, the more committed it is to 'saving the planet'. It's an anxiety-inducing feed, and one that inevitably leads us to the conclusion that things are getting worse and worse.

The falling death rates shouldn't downplay the risks of climate change. Instead, it shows us that humans are capable of solving problems. A century ago, floods and droughts would lead to severe famines that killed millions.[6] Food insecurity is certainly still a major problem – we'll look at this in Chapter 5 – but severe famines are almost a thing of the past. Our infrastructure is now built to withstand earthquakes. We can predict and track incoming hurricanes. We can evacuate, before it's too late. When disaster does strike, we can respond quickly. At home, we set up emergency shelters and rebuild communities. Abroad, we facilitate international support networks. We send in the world's best experts and ship packages of essential goods.

Building resilience, and predicting and responding to disasters costs money. Our success in reducing their impacts comes from an increase in knowledge and scientific understanding. Meteorologists can model storm tracks. Engineers work with seismologists to design buildings that can withstand extreme forces. Agricultural innovations mean that our food systems can weather and bounce back from shocks. But the success also comes from being a lot richer. These sophisticated networks and infrastructure need money. There's no point in designing quake-proof buildings if no one can afford them. No point in planning escape routes if there are no roads to drive on, or vehicles to drive in. No point in designing new farming techniques if farmers cannot afford the seeds and fertilisers. Fewer people die from disasters today because the world is richer.

But not everyone is richer, and this is the biggest risk of climate change. Also, it's not inevitable that deaths from disasters will keep going down. There is a real chance that climate change will reverse this trend. But not if we can slow climate change and stop it in its tracks.

Now we're going to look at what we can do to tackle climate change. For this to make sense, we have to accept two things: climate change is happening, and human emissions of greenhouse gases are responsible. The existence of climate change is not a question that I'm going to argue here – I don't have time or space, and many others have done so already. Second, *we* don't have time. By 'we' I mean all of us, collectively. The time for debating whether climate change is or isn't happening is over. We need to move past it to the question of what we're going to do about it.

How we got to now

From forests to fossil fuels

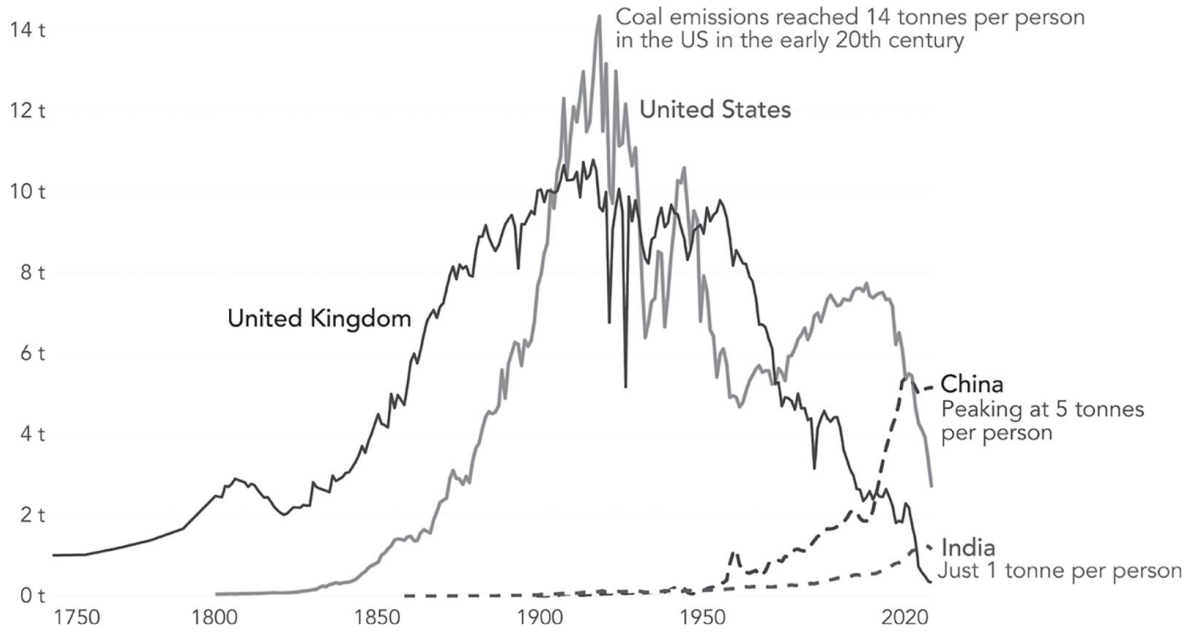
Carbon emissions started rising rapidly after the Industrial Revolution. But humans have been tinkering with the balance of gases in the atmosphere for tens of thousands of years. Our carbon dioxide emissions come from two main sources: burning fossil fuels and changing the use of land. When we cut down trees we release biological carbon

into the atmosphere. As we'll see in the next chapter, deforestation is far from a recent phenomenon. Humans have been reshaping the world's landscapes for thousands of years, and releasing carbon at the same time.

If we look at estimates for how much carbon we have released over the last 10,000 years through deforestation and the conversion of grasslands into farmland, it amounts to around 1,400 billion tonnes of CO_2.[7] So, our ancestors were slowly tweaking the Earth's thermostat for millennia, even before we started to dig fossil fuels out of the ground.

Until the 1700s, people could only really get energy from three main sources: their livestock, wood from forests and human power. But these sources don't scale very well: we don't have unlimited forests, and there's only so much a human can do. Human development was hindered by not having a scalable source of energy. Then we discovered coal.

In the UK – the birthplace of the Industrial Revolution – coal consumption slowly rose through the 18th century into the early 19th.[8] Then it really picked up speed. Other countries across Europe and the US got involved. By 1900, emissions in the UK had hit 10 tonnes per person.[9] In the US, as much as 14 tonnes. Compare that to just five tonnes in China, and around one tonne in India today. It's not hard to see why many growing economies get mad when the rich world tells them to stop burning coal.



Per capita coal emissions are a fraction of rich countries in the past
Per capita emissions are measured in tonnes of carbon dioxide (CO_2) per person.

China and India are seen as big emitters today, but per capita emissions are just a fraction of emissions in the UK and US in the past.

By the middle of the 20th century, the world had unlocked the power of oil, and then natural gas. We could not only generate electricity, we could also scale up transport and

transition to cleaner ways to heat our homes.

The global population was growing rapidly, and people were getting richer. Fossil fuels meant progress. People in the 1950s weren't thinking 'let's screw over the generations that come after us by locking us into an energy system built on coal and oil'. Fossil fuels were the route to a better life.

Historically, the richer you were, the more CO_2 you would emit, and it was mostly rich countries that were responsible for the world's carbon emissions. That changed in the second half of the 20th century when booming economies started to emerge. The rise of China, India, Indonesia, Malaysia, Thailand and South Africa has been a human triumph. It has alleviated massive amounts of poverty and suffering. But it has been powered by fossil fuels and added hundreds of billions of tonnes of CO_2 to the atmosphere. At the same time, many richer countries have started to reduce their emissions, while getting even richer at the same time. With low- and middle-income countries coming up, and rich countries coming down, the world's carbon emissions per capita have started to converge.

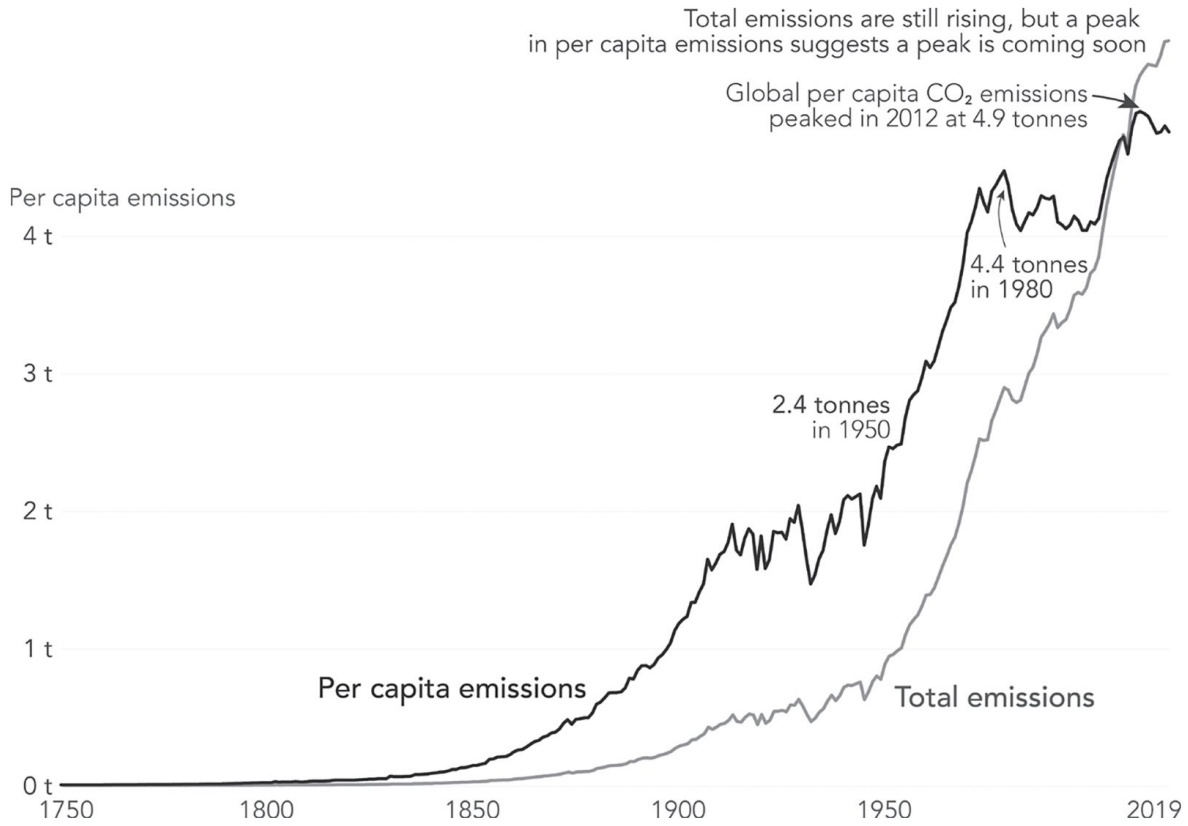
Where we are today

Total emissions are still rising, but emissions per person have peaked

The world has already passed the peak of *per capita* emissions. It happened a decade ago. Most people are unaware of this.

In 2012, the world topped out at 4.9 tonnes per person.[10] Since then, per capita emissions have been slowly falling. Nowhere near fast enough, but falling nonetheless. This is a signal that the peak in our total (not per capita) CO_2 emissions is coming. This is the case with any metric in a world with an increasing population. Per capita measures will peak first, then it's a tug-of-war over whether our impacts per person will fall more quickly than the population is growing.

We are very close. Emissions increased rapidly in the 1960s and 70s, then again in the 1990s and early 2000s. But in recent years this growth has slowed down a lot. Emissions barely increased at all from 2018 to 2019. And they actually fell in 2020 as a result of the Covid-19 pandemic. I'm optimistic we can peak global emissions in the 2020s.



Global per capita CO_2 emissions have peaked; total emissions will peak soon too

Carbon dioxide emissions from fossil fuels and industry. Land-use change isn't included.

Who emits the most greenhouse gases?

If we want to peak then reduce our emissions, we need to know where they're coming from. Who's responsible? It seems like a straightforward question, but there is no simple answer. It's not doing the sums that's the problem – I have all of the numbers to hand. The problem is agreeing on what 'responsibility' actually means. There are so many metrics we can use to compare countries, and people never agree on which are best.

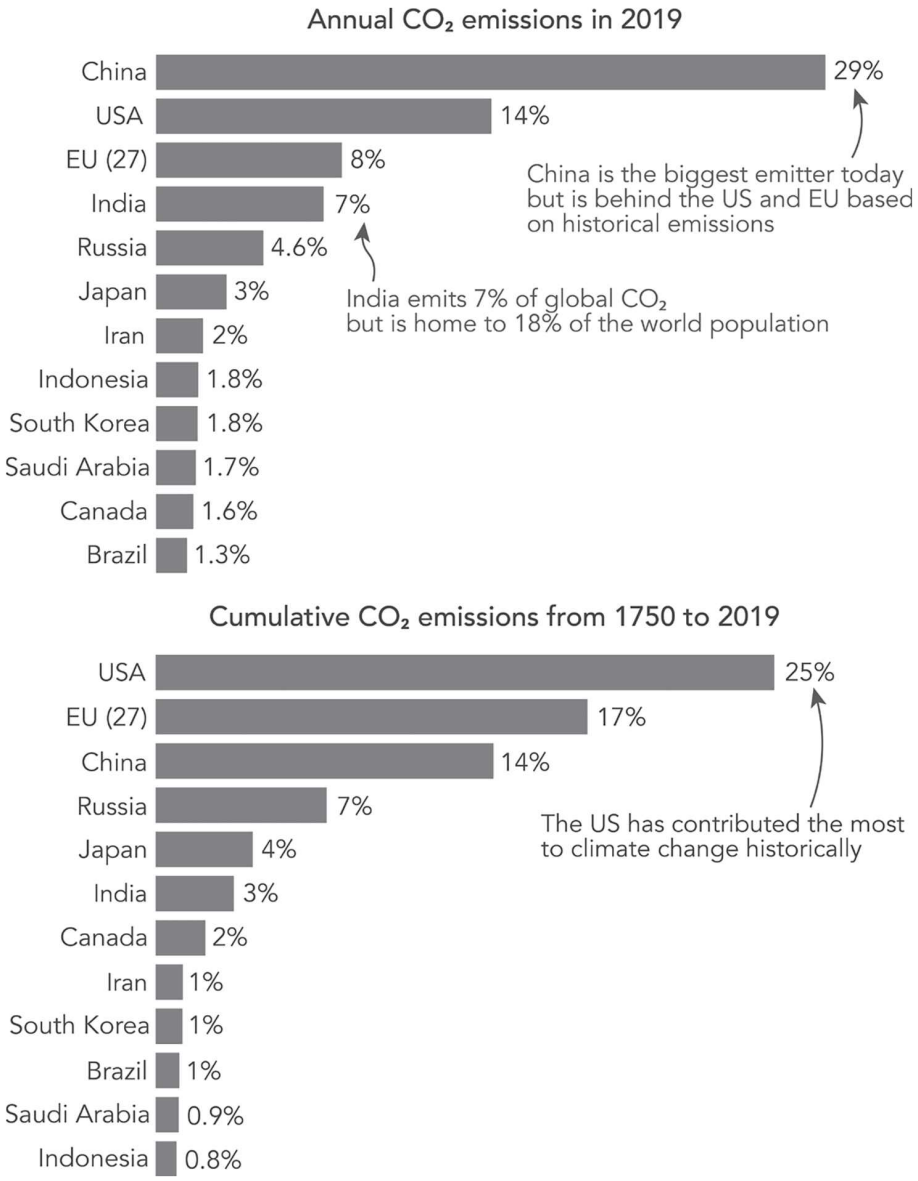
Are we talking about how much each country emits per year or per capita? What about a country's historical responsibility – should we tally up all its emissions over time? Then there is the thorny issue of trade: if the UK buys something that was manufactured in China, should it be China or the UK that adds those emissions to its account? In the end, there is no single 'right' answer.

It's good to get some perspective on these numbers, so let's look at how different countries or regions stack up.[fn1] China tops the emissions list. This is not surprising because it's home to the most people. It emits around 29% of the world's emissions. The US is in second place at 14%. The European Union (which tends to participate in climate negotiations as a group) is next at 8%, followed by India at 7%, and then Russia at 5%.

We can already see the inequalities. India is responsible for 7% of emissions but is home to 18% of the world population. The US contributes 14% of emissions but is home to just 4% of people. It is almost a direct mirror image of the entire continent of Africa, which is home to 17% of the world's population but emits just 4%. The disparities get even more extreme when we zoom into particular countries and compare their emissions per person.

The picture is also skewed when we look at each country's historical responsibility. To do this we add up all of a country's emissions since 1750. The US is way out in front, having contributed 25% of the world's emissions. The EU comes in second at 17%. China slips down the list to third place, having contributed only half as much as the US. India is even further down, having emitted just 3%.

These perspectives can be useful. But when we turn climate change into a blame game, there is no end to it. People are not really fighting about the numbers. They're fighting about what numbers they should be using in the first place. If they don't agree on that – which they often don't – the fight goes nowhere useful. This battle has plagued international climate agreements for decades. The US and EU blame China and India, who then pick another (very reasonable) metric and fire it back.



Which countries have contributed the most to climate change?
Carbon dioxide emissions from fossil fuels and industry. Land-use change isn't included.

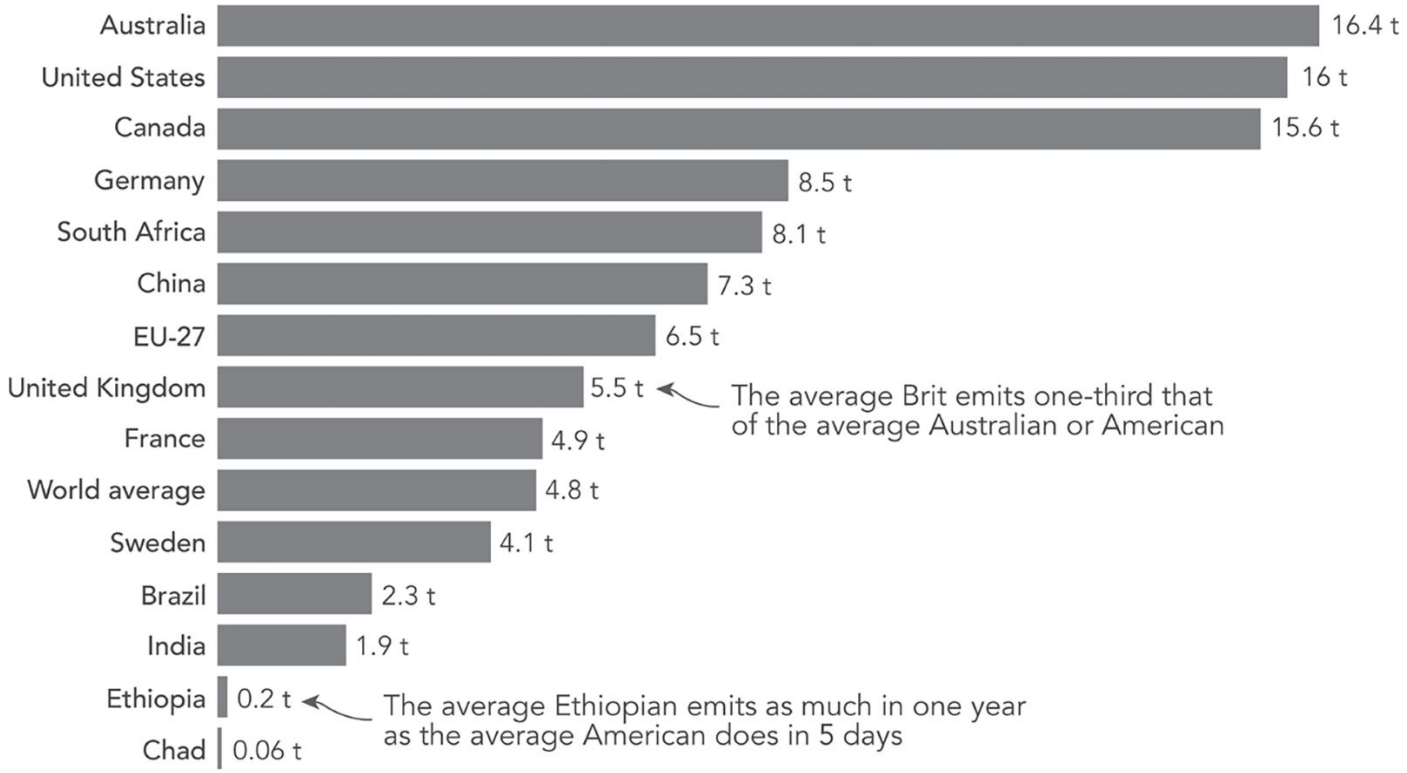
Richer people emit more, but that's not the whole story

Some countries in sub-Saharan Africa contribute almost nothing to the world's emissions. The average person in Chad emits just 0.06 tonnes of CO_2 per year. In an entire year they emit the same amount as the average American does in just a day and a half. If you don't have access to fossil fuels, electricity, a car or industry, then your carbon footprint is going to be extremely low.

As we get richer we gain access to these things, and our emissions increase. But that's not the full story. We see large differences in emissions *among* rich countries. Culture, transport infrastructure and our choices of energy sources matter a lot. Living standards in Sweden are just as good as they are in the US, if not higher. Yet the average Swede emits just one-quarter of the emissions of the average American, and half as

much as the average German. And some middle-income countries – such as China and South Africa – have now overtaken many richer countries across Europe in per capita emissions. And this is not just because rich countries have exported their emissions elsewhere.

Sweden and France, with lots of nuclear power and hydropower, have very low-carbon electricity grids. They don't have the massive transport emissions of the US. Living well does not need to come at a high cost for the climate.



There are large differences in CO_2 emissions per person, even among rich countries

Carbon dioxide emissions from fossil fuels and industry, measured in tonnes per year. Land-use change isn't included.

More sustainable than my grandma: many countries have already reduced their emissions

One of the simple things that bring me the most joy in life is getting an email from my grandma. My gran is in her mid-eighties, and can almost work an iPad. By 'work' I mean do the basics of looking at a photograph, and sending an email. She doesn't have an iPhone, a laptop or a smartwatch. My grandpa rejects all modern technology, except television. Their life is very similar to how it was a few decades ago.

This has created something of a divide between the generations on climate change. Many see the lifestyles of youngsters as the problem. We spend all day on energy-guzzling gadgets. We flock to dense cities with no gardens or green space. We buy lots of stuff and don't bother to repair it. We never ration food, and waste too much of it.

Yet my carbon footprint is less than half that of my grandparents' when they were my age. When my grandparents were in their twenties, the average person in the UK emitted 11 tonnes of CO_2 per year. We now emit less than 5 tonnes. The gap between me and my parents is equally wide. From the 1950s to the 1990s, emissions in the UK changed very little. It's only since then – in my lifetime – that emissions have plummeted.

This seems hard to believe. How can my lifestyle today be more sustainable than in the 1950s? I won't pretend that I am as frugal as my grandparents. I'm more wasteful. I turn the heating on more readily. I spend many more hours powering gadgets from the electricity grid. Still, I use much less energy and emit much less carbon.

Technology has made that possible. In 1900, nearly all of the UK's energy came from coal, and by 1950 it was still supplying over 90%. Now coal supplies less than 2% of our electricity, and the government has pledged to phase it out completely by 2025. Coal is now almost dead in its birthplace, where it all began. It has been replaced with other sources of energy: gas, then nuclear, and now a transition to wind, solar and other renewable sources.

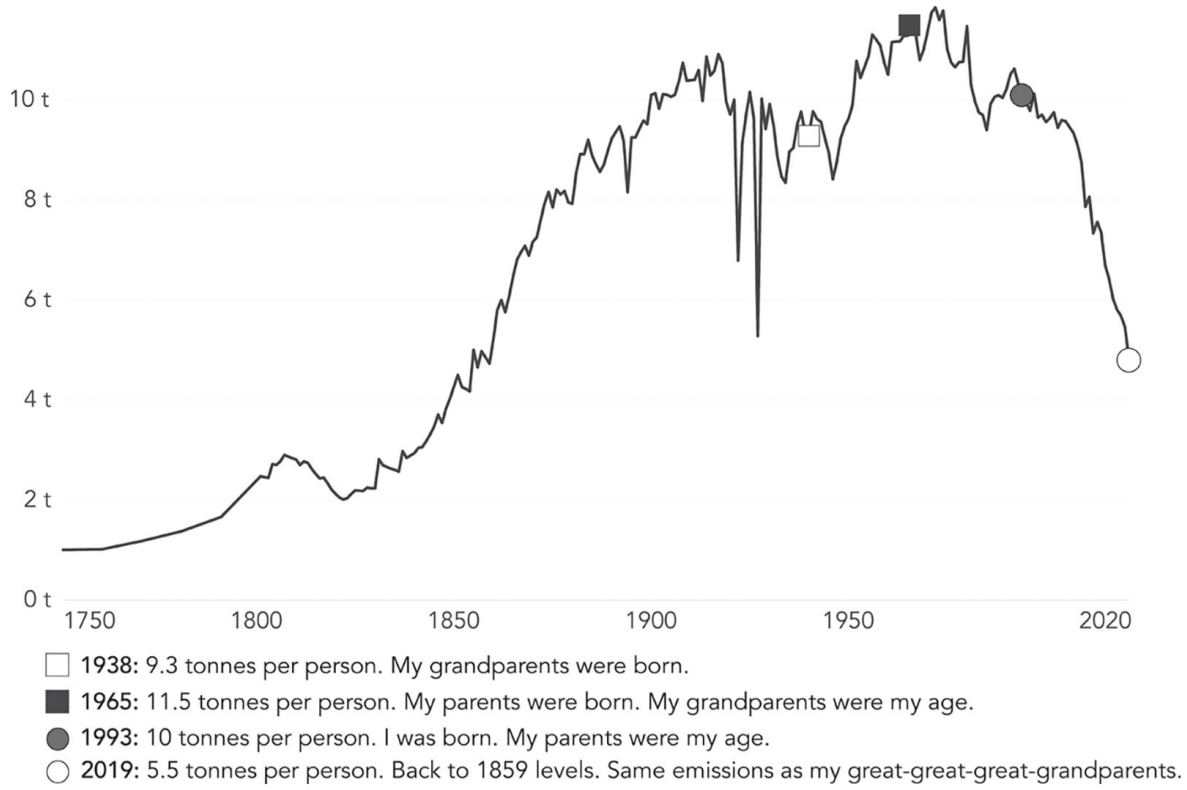
That means that for every unit of energy we consume, we emit much less CO_2. But that's not the only change. We also use much less energy overall. Per capita energy use has fallen by around 25% since the 1960s. Year after year, more efficient gadgets have come into our lives. First, it was improvements in the energy ratings of white goods, then it was the trend of replacing inefficient light bulbs. Then it was double-glazed windows and home insulation to stop heat leaking out into the street. When I was a kid our family television – we 'only' had one – was a massive box that seemed to be two metres deep. The screen was so small you had to sit really close to see anything. Our car was a gas guzzler. Not a gas guzzler like we see with SUVs today. My parents would never have bought one of those. No, our car was second-hand and it was a 'banger'. It was inefficient: you could hear the engine roar, and feel it overheating. The miles per gallon were terrible.

These massive strides in technology mean that we use much less energy than we did in the past, despite *appearing* to lead much more extravagant energy-intensive lifestyles. The notion that we need to be frugal to live a low-carbon life is simply wrong. In the UK we now emit about the same as someone in the 1850s. I emit the same as my great-great-great-grandparents. And I have a much, much higher standard of living.

Like the UK, emissions are falling quickly across most rich countries. Per capita emissions in the US and Germany have fallen by a third since the 1970s. They've more than halved in France, and fallen by almost two-thirds in Sweden.

And yet very few people know that emissions are falling. Recently one of my climate scientist peers – Jonathan Foley – polled his followers on Twitter.[11] He asked what had happened to emissions in the US over the last 15 years. Had they:

a. Increased by more than 20%
b. Increased by 10%
c. Stayed the same
d. Fallen by 20%



My carbon footprint is half that of my grandparents
Per capita CO_2 emissions in the UK, measured as the average tonnes per person.

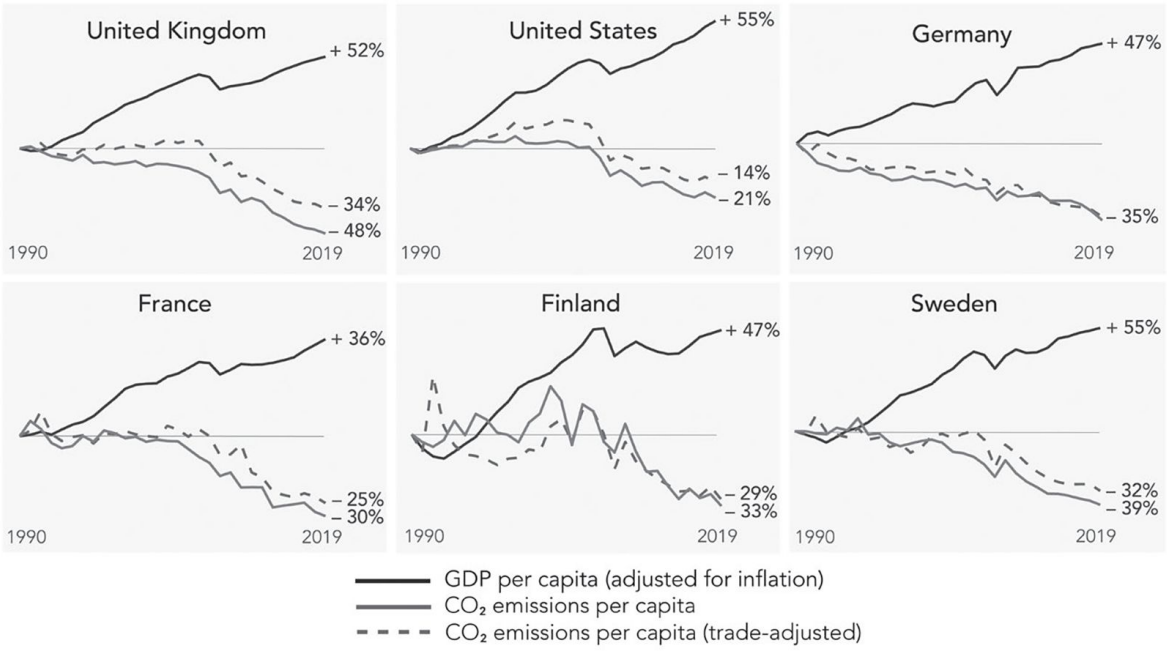
Thousands of people answered. Two-thirds of people picked (a) or (b). Just 19% picked the correct answer (d). No wonder people think we're screwed.

Many countries have grown their economies while reducing their emissions – and not because they're sending their emissions overseas

When I mention that emissions in rich countries are falling, the common response I get is that they 'aren't really reducing their emissions, they're just sending them overseas'. Since CO_2 emissions are usually counted based on the country that they're *produced* in, maybe rich countries are doing some devious accounting to make themselves look good. If they get China, India, Indonesia or Bangladesh to produce their stuff for them, then they don't have to include these emissions in their reports. That would make rich countries look good, but would actually achieve nothing for the climate. The climate doesn't care whether CO_2 is emitted in the UK or in China. It only cares about the total amount.

This ‘offshoring’ of emissions is an important concern. But, thankfully, it is not the whole story. Researchers can use trade data across the world to adjust for the carbon that is emitted in the production of goods that are exported or imported.[12, 13] When we account for all these traded goods we get what are called ‘consumption-based emissions’: for the UK, these not only reflect the emissions produced within the UK’s borders but also those involved in all of the goods it imports from overseas.

In the UK, GDP per capita has increased by around 50% since 1990.[fn2] Domestic emissions have halved. Consumption-based emissions – those that adjust for ‘offshoring’ – have fallen by a third. It’s not true that the UK has sent all its emissions overseas. The reductions in emissions are real – whether they are counted domestically or internationally. It’s the same across most rich countries. In Germany, *both* domestic and consumption-based emissions have fallen by a third. GDP per capita has increased by 50%. In France, consumption-based emissions have fallen by a quarter, GDP per capita increased by a third. In the US, since 2005, emissions have fallen by a quarter both domestically and when we adjust for offshoring.



Many countries have decoupled economic growth from CO_2 emissions

Shown is the change in gross domestic product (GDP) and CO_2 emissions per capita between 1990 and 2019.

CO_2 emissions are shown as production-based domestic emissions, and separately as emissions which adjust for international trade and offshoring.

This is a narrative that rarely makes it into the headlines. Economic growth and emissions reductions are often framed as being incompatible. But countries are proving that they can be. This doesn’t mean that rich countries are making reductions anywhere close to fast enough. They can, and should, be making them much faster. But it shows us

that reducing emissions *is* possible. And it does not have to mean tanking the economy at the same time.

Low-carbon technologies are getting cheaper and cheaper

I have a habit of underestimating how quickly things can change. Most of us have been too pessimistic about renewable energy in the past, even the experts. Part of the reason I thought that 2°C was so far out of reach was that I couldn't see how low-carbon energy could grow quickly enough. Historically, energy transitions have been very slow. The scientist Vaclav Smil has shown this many times in his work.[14, 15, 16] Remaking energy systems and shifting from one source to another, whether it was from wood to coal or coal to oil, happened over many decades, if not longer. And coal, oil and gas were just so much cheaper than solar or wind, especially with large fossil fuel subsidies.

Let's go back to 2009. You're the prime minister of a low-income country, and you want to build a new power plant. One-quarter of the population does not have access to electricity at all. Many of those that do can only afford to consume very small amounts. Hundreds of millions live in energy poverty. It's your job, as the leader, to improve the lives of the people in your country.

You have to decide which type of power plant to install. Obviously, cost is a big factor. We're going to compare electricity sources based on a metric called the 'levelized costs of energy' (LCOE). You can think about LCOE as the answer to the question: what would be the minimum price that my customers would need to pay so that the power plant would break even over its lifetime? This includes the cost of building the plant itself, as well as the running costs for the fuel and operations.

Here are your options, and how much each will cost *per unit* of electricity:[17, 18]

a. Solar photovoltaic (PV): $359
b. Solar thermal: $168
c. Onshore wind: $135
d. Nuclear: $123
e. Coal: $111
f. Gas: $83

What are you going to pick? If you're worried about climate change, you'd want to pick solar, wind or nuclear. But solar is more than three times the cost of coal. For a given budget, you would supply three times less electricity. In a country where one-quarter do not have any electricity at all, and many more can afford very little, you'd therefore be denying people affordable energy. It certainly wouldn't be a popular choice with the public. This is the decision that most countries faced, and they, unsurprisingly, chose coal or gas. No wonder, then, that getting countries to act on climate change has been so hard.

In just 10 years this has changed completely. It's now 2019, and you have to make the same decision. Here are the prices now:

a. Nuclear: $155
b. Solar thermal: $141
c. Coal: $109
d. Gas: $56
e. Onshore wind: $41
f. Solar photovoltaic: $40

In just a decade, solar photovoltaic and wind energy have gone from the most to the least expensive. The price of electricity from solar has declined by 89%, and the price of onshore wind has declined by 70%. They are now cheaper than coal. Leaders no longer have to make the difficult choice between climate action and providing energy for their people. The low-carbon choice has suddenly become the economic one. It's staggering how quickly this change has happened.

Why did the cost of solar and wind fall so quickly? The price of fossil fuels and nuclear depends on the price of the fuel – the coal, oil, gas or uranium – and the cost of operating the plant itself. Renewable energy is different. Sunlight and wind is free. Instead, the cost comes from the parts of the technology itself – the electronic components and solar modules. In the 1960s, solar power could never have made it to the mainstream. My colleague, Max Roser, estimated that one solar panel in 1956 would have cost at least $596,800 in today's prices. Despite being wildly expensive, the solar panel didn't die out, because we needed it in outer space. In the 1950s, it was being used as the electricity source for satellites. Year by year, the technology developed. By the 1970s, it made it down from space and onto land. But still only in expensive settings where there was no electricity grid to tap into: lighthouses, remote crossings and the refrigeration of vaccines.

Over the last few decades, the price of solar (and wind) has become cheaper as we've used more of it. This is what we call a 'learning curve'. As we deploy and scale technologies, we learn how to make them more efficient. Technologies can get wrapped up in a virtuous cycle: more solar panels are deployed, the prices fall, demand for them increases, so we deploy more, and so on. The 'learning curve' for solar panels has been 20%: this means that every time the installed capacity of solar PV doubles, the price falls by around 20%.[fn3] Onshore and offshore wind have followed a similar path to solar.

This is not just the case for sources of renewable energy. To manage the intermittency of renewables, and unlock technologies such as electric vehicles, we need batteries. Large, cheap batteries. We've seen exactly the same thing happen there. In the last three decades, the price of lithium-ion batteries has fallen by more than 98%.[19, 20] Only in

the last few years have they become remotely affordable for electric vehicles. More on this later.

What haven't followed a learning curve are fossil fuels, like coal. It's hard to make coal plants much more efficient than they are. The amount of energy you get out of a lump of coal, and the amount of heat energy that's wasted, is difficult to change. And the price of coal power is tied to the cost of the fuel itself. This cost goes up and down, but there is a fixed cost to how expensive it is to dig it out of the ground. In other words, new low-carbon technologies will get cheaper and cheaper. Fossil fuels will not.

These very recent developments have been absolutely critical. They have opened up new low-carbon and cheap pathways for countries to follow. They mean poorer countries do not have to follow the fossil fuel-heavy and unsustainable trajectories that rich countries did. They can leapfrog the centuries-long journey that we've taken. And they don't have to sacrifice human well-being or access to energy. In fact, by adopting these technologies they can ensure that even more people have access to affordable energy.

How do we tackle climate change?

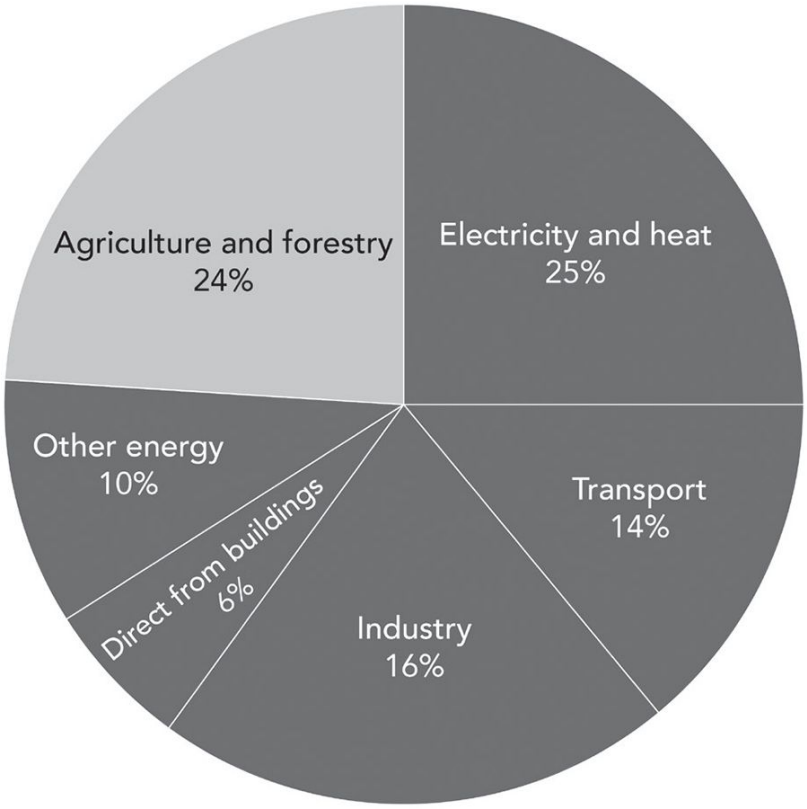
When it comes to climate action, things are starting to move in the right direction. We've been laying the bedrock for what needs to change. We now need to start building on top of it. And we need to do it quickly.

So far, 127 countries have committed to reaching net-zero emissions.[fn4] This is no small feat. It will force us to redesign and reshape our energy systems. To change how and what we eat. How we live, how we move, and how we build. But this change must go forward. It can't be a step backwards.

Solutions that involve cutting energy use to very low levels are no good. People need energy to live a good and healthy life. They need it for health care, for education, to power washing machines and kitchen appliances so they have time to work, play and learn. They will also need it to adapt to climate change.

What must we do to reduce our emissions? How do we get to net zero? Unfortunately there's no silver bullet. To see how big the challenges are, we have to look at where our emissions come from. If we break it down into two categories, we can see the energy system and industry is responsible for around three-quarters of greenhouse gas emissions. Our food system is responsible for the other quarter.[21, 22, 23]

Zooming in on individual sectors more closely reveals that energy for producing stuff is responsible for around one-quarter of emissions.[24, 25] Moving us – and stuff – around accounts for one-sixth. Energy in our homes and offices is the same. Then there are some emissions from industry that are really hard to tackle: cement and chemicals that form the basis of many of the things around us.



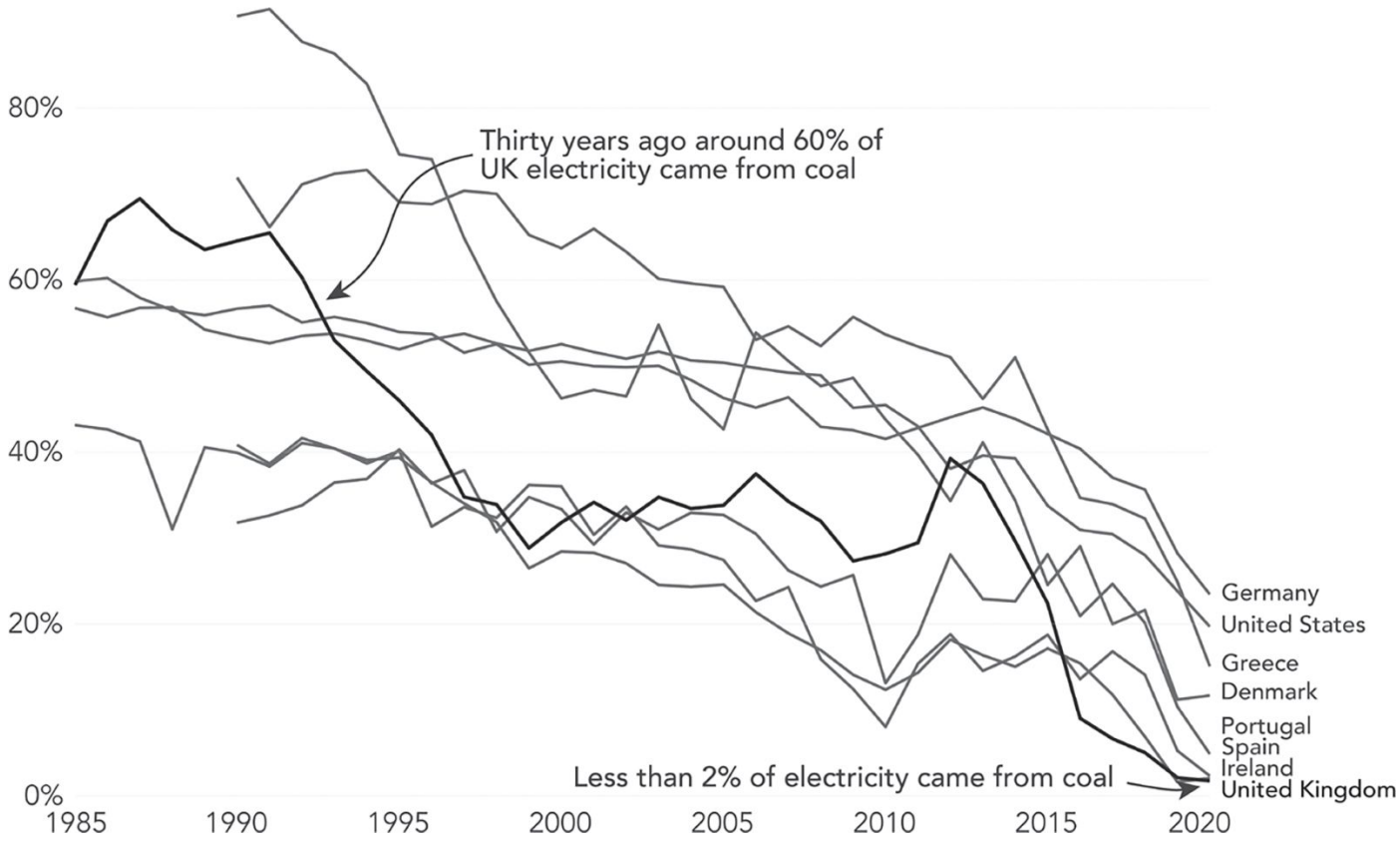
Where do our greenhouse gas emissions come from?
Around one-quarter of the world's emissions come from food systems.
Three-quarters come from energy and industry.

We can't solve climate change without addressing each of these slices of the pie. How do we do that?

Energy

As we've seen, we need to get off fossil fuels, and renewable sources and nuclear are great options. They emit very little CO_2 or air pollution, and are far, far safer. The battle needs to be low-carbon sources versus fossil fuels, not nuclear energy versus renewables. We are wasting energy on the nuclear argument.

We have already seen how quickly coal died in the UK. It's dying in other countries too. Thirty years ago the UK was getting nearly two-thirds of its electricity from coal. This is now less than 2%. The US was getting 55%; this is now less than 20%. Denmark was getting nearly 90%; this is now 10%. Energy systems across the world have transformed.



Coal is now dying across the world
Share of electricity production that comes from coal.

To take its place, renewable energy has grown at an astounding pace. And not just for the rich. Some unexpected countries are showing the rest of us how it's done. In 2014, Uruguay was getting just 5% of its electricity from wind. Now it's closing in on 50%. At that point, Chile had no solar power. Now it has 13%. Many more countries will follow in their footsteps. The continued plummeting costs of renewable energy technologies and batteries will soon make these choices the default.

A switch to these sources, alongside batteries and energy storage, is how we decarbonise our *electricity* systems. But we also need to decarbonise other uses of energy, such as transport, heating and industry. This is harder to do. There's no sustainable liquid fuel that can just take the place of petrol or diesel. So the mantra to fix these energy sources is: 'electrify everything'. If we can electrify our cars, industry and heating then we can just build more and more nuclear and renewable energy to power them.

That sounds simple: just build lots of solar, wind and other renewables. But aren't there other things we should be concerned about? Do we have enough land? Do we have enough minerals to build them?

Climate sceptics love to tell you that our landscapes will become littered with solar panels. They do this to 'prove' how land-hungry and unsustainable our so-called green technologies are. But when we crunch the numbers, the results are surprising: a move to

renewables (and especially to nuclear) wouldn't mean using more land. In fact, we might even use less.

When comparing the land use of energy sources, we need to think about more than just the space used by the plant itself – the area that the coal plant or solar panel physically takes up. We also need to include the land used to mine the materials, extract the fuels, handle the waste at the end. A large assessment by the United Nations Economic Commission for Europe estimated the land needed by each source to produce *one unit* of electricity, when we consider all of these steps of the supply chain.[26]

The most land-efficient source of electricity was nuclear: per unit of electricity, it needs 50 times less land than coal, and 18 to 27 times less than solar PV on the ground.[27] Gas was the second most land-efficient.

The land efficiency of solar depends on what minerals we use: when panels are made from silicon and placed on the ground rather than a roof, land use is marginally higher than coal. But if we use a cadmium panel, it needs less land than coal. Of course, that's not our only option with solar PV, which we can also put on roofs. Then, the only land use is for mining. In that case, solar PV is almost as good as gas and is much better than coal.

We can also integrate solar and wind with existing uses of land, such as farming. There is evidence that 'agrivoltaic' systems could be great examples of shared land. Recent studies show that, under certain conditions, the yield of agrivoltaic crops can even increase compared with conventional crops, because of better water balance and evapotranspiration, as well as reduced temperatures. The same is true of wind: many farmers are already making extra money by allowing turbines to be dotted across their farmland. The impact on the farm is usually minimal.

The conclusion is that a move to clean energy technologies will not need much more land than we currently use for fossil fuels. If we use some nuclear, utilise roofs for solar panels and share land we're already using, we might even need less.

We've looked at how the land efficiency of different sources stacks up. But it's worth considering whether the land use of energy is a big deal in the first place. Are we talking about 5%, 10%, maybe even 50% of land? I estimate that we currently use around 0.2% of the world's ice-free land for electricity production – most of it for the mining of fossil fuels. (That's small, considering we use 50% of the world's ice-free land for farming.) In a world with low-carbon electricity, we could reduce this number. If the world moved to 100% nuclear, we'd need just 0.01% of the world's land. If we used solar panels on roofs, it'd be 0.02% to 0.06%.

Soon, the world will need much more electricity: we want people in lower-income countries to use more, and we'll need more to charge our electric cars and run our heating. That's still not a massive problem for land use: we could double or triple the numbers above and they'd still be small. Much less than 1% of global land.

One final concern is whether we'll have enough minerals to build the solar panels, wind turbines and batteries we'll need. These technologies need a range of different materials – lithium, cobalt, copper, silver, nickel – and we're often told that the amount of mining will be immense, or that these minerals will run out.

Those that say low-carbon energy will use too many materials should take a look at how much we currently mine for fossil fuels. The world extracts around 15 *billion* tonnes of coal, oil and gas every year. The International Energy Agency projects that the world will need around 28 to 40 *million* tonnes of minerals for low-carbon technologies in 2040, at the height of the energy transition.[28] That's 100 to 1,000 times lower than fossil fuels. Of course, rocks are not made of pure minerals; the minerals are often in much lower concentrations, so the total amount of rock we'll have to move will be higher. But the same is true for fossil fuel mining: to get those 15 billion tonnes of fuel, we dig a lot more stuff out of the earth. Put simply: moving to low-carbon technologies will mean less mining, not more.

Studies also show that we will have enough lithium, nickel, and other minerals.[29] We won't run out. This is especially true when we consider the potential of recycling: many of the minerals we'll use in panels, turbines and batteries can be refurbished into new products. In this way we could set up a circular economy where we continually reuse these materials without increasing demand for more.

We do need to be careful about *where* we get these minerals from, and how they are extracted. Some deposits lie under areas that we want to protect for ecological reasons, or because they overlap with indigenous lands. We need to make sure we utilise deposits elsewhere, and that they are extracted in fair and safe working conditions. The era of fossil fuels has been one that has exploited both people and planet. Let's make sure that the low-carbon world we're building does neither.

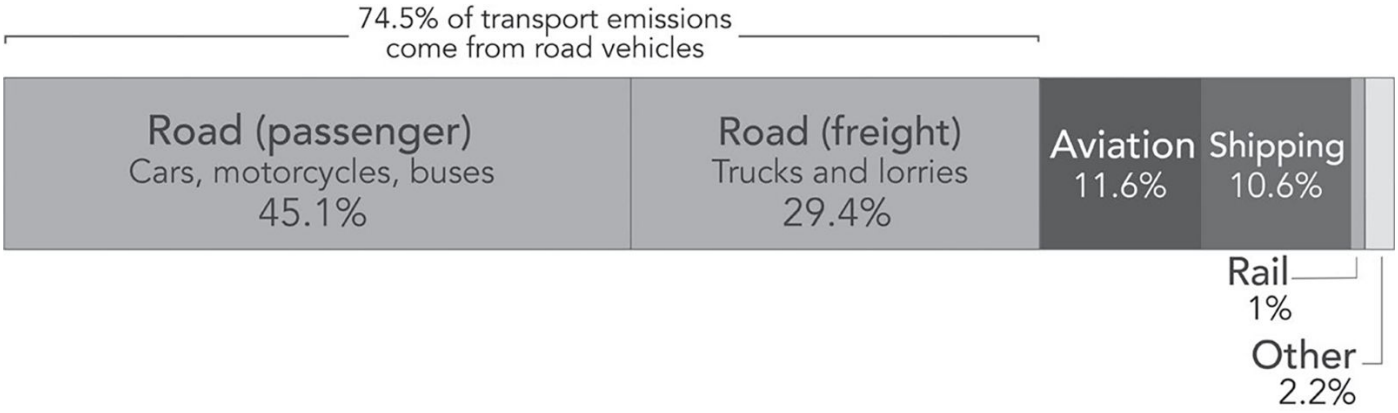
Transport

Being able to cross the country in a matter of hours is a modern luxury. Being able to cross the *world* in mere hours is a modern miracle.

The exciting world of travel will open its doors to billions in the next few decades. Many have just recently gained access to basic energy services – electricity and cleaner fuels to cook with. The next stop on their energy journey is being able to afford a motorbike, maybe even a car. They will then take their very first flight. In rich countries we despair of the side effects of transport: the carbon emissions, the air pollution, the traffic. But despite its troubles, transport has the potential to unlock the connectivity, experiences and perspectives of billions. That is the balance we need to strike.

Around one-sixth of the world's greenhouse gas emissions come from transport. As people across the world get richer, emissions from transport will rise. How, then, do we build a future where we can keep the doors to travel open while reducing emissions?

The bulk of our transport emissions come from roads. Road vehicles are responsible for 74% of the world's transport emissions.[30, 31]



Cars, planes and trains: where do our transport CO_2 emissions come from?

The average car today is more than twice as carbon-efficient as the average in 1975.[32] These improvements are impressive and have been important in keeping some of our emissions in check. But transport emissions are still rising because we're travelling further, and there is a limit to how efficient cars running on fossil fuels can get. We're not going to decarbonise our transport using petrol and diesel.

Some suggest that we use biofuels instead. Again, this is not going to cut it. Studies have shown that biofuels can often emit *more* CO_2 than petrol, especially when we take into account land use.[33, 34] As the following chapters will show, putting cereals that people could eat into cars is not a good solution. If we're going to seriously reduce our emissions from road transport we can't run them on oil, or food. We need to run them on electricity.

Switch to electric vehicles – they really are more climate-friendly

My brother – the least environmentally minded member of our family – was the first to buy an electric car. It wasn't the low-carbon footprint that won him over, it was the beauty of driving one. That's important: if we want to get everyone on board with shifting to a low-carbon life, we have to make it cool. People need to feel like it's making their life better.

But is this decision *really* better for the environment, or are electric vehicles a green scam? Lots of people think they emit just as much CO_2 as petrol cars – if not more – once we consider the production of the battery, and the electricity to power it. Let's run through the numbers and see.

My brother was faced with the choice of buying a new electric vehicle (EV) or a new petrol one. When he first bought the EV, it had emitted more carbon because it takes more energy to manufacture the battery than it does to produce a combustion engine. So,

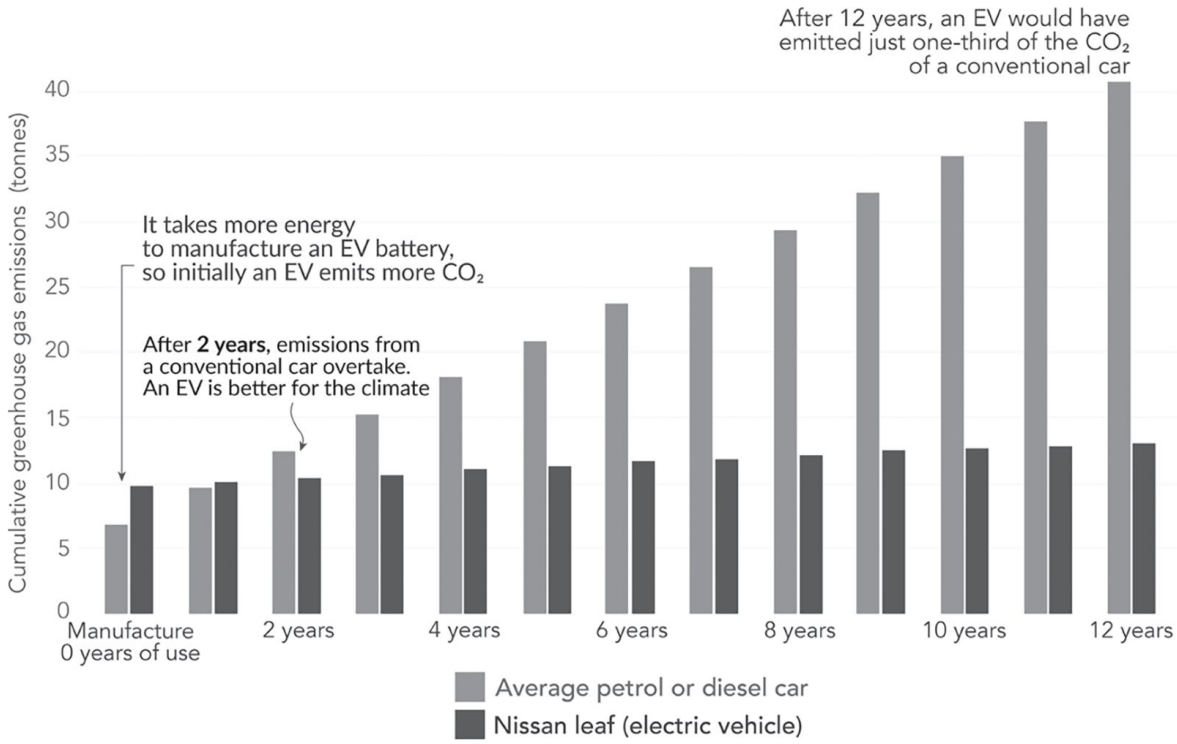
the *production* of an electric vehicle does actually emit more carbon than a petrol car. But once we start driving them, the tables quickly turn.

Driving an EV emits much less carbon than petrol or diesel. How much less depends on how clean our electricity is. In the UK we get more than half of our electricity from low-carbon sources, and we're now basically coal-free (this will still be true if the UK does open a new coal mine, because this coal will not be used for electricity production). If you're running one in France, Sweden or Brazil, the benefits would be even greater. If you're running one in coal-hungry China or India, they're less. But even in these countries, an EV is still better than a petrol one.

The lower emissions of driving an EV means that an electric car quickly 'pays back' its debt. In the UK, this payback time is less than two years.[35] So, within two years your EV is already better for the environment. Within ten years it has emitted just one-third of the CO_2 of a petrol car.

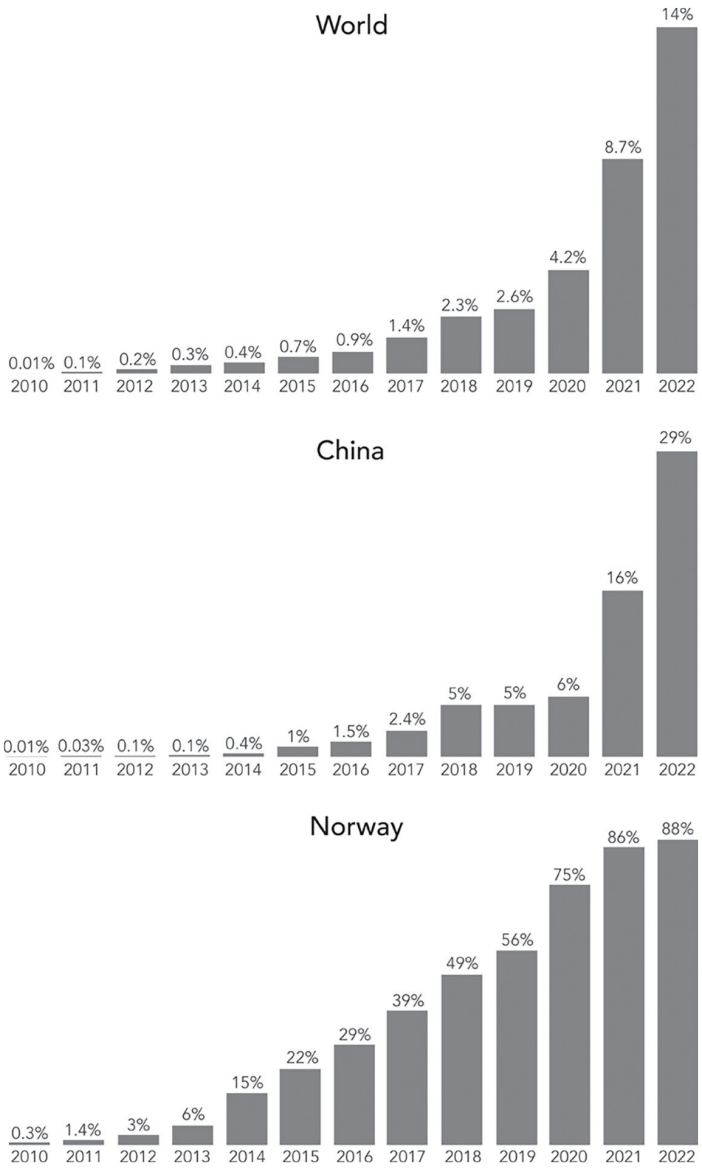
If anything, this is a pessimistic outlook: the carbon emissions of EVs could fall even more. They are a fairly new technology, so there is plenty of room for improvement. We also know that our electricity grids – our EV juice – will get cleaner and cleaner.

But was my brother's new car more climate-friendly than my parents' decision to keep their existing petrol car running? Over four years, the emissions of running an existing petrol car are higher than a new electric one. So, my brother wins.



Electric vehicles are better for the climate
Based on running an average car in the UK. Manufacturing an electric vehicle emits more greenhouse gases, but this pays back in 2 years.

In 2022, 14% of cars sold globally were electric.[36] That might seem small, but the change over time is what's really staggering. Two years before it was just 4%. In 2019, just over 2%. EV sales are exploding. They now dominate the car market in some countries. In Norway, 88% of car sales in 2022 were electric. In Sweden, 54%. In the UK, it was 23%. The US has been lagging behind, with just 8% of new cars being electric (although Joe Biden's new climate deal could change this quickly). In China in 2022, nearly two-thirds (29%) of new sales were electric. This is a massive leap from 2020, when it was just 6%.



The share of new cars that are electric
Sales of new internal combustion engine cars peaked in 2017.

The price of lithium-ion batteries has fallen by more than 98% over the last three decades. This has opened up the world of electric transport. The battery you'd find in a Tesla car today costs around $12,000. A Nissan Leaf battery is around $6,000. But go

back to the 1990s, and these batteries would have cost between $500,000 and a million dollars.[37] There was no such thing as an 'affordable' electric car.

This growth in electric vehicles means that the world has already passed peak petrol car. Sales of new petrol cars in the world peaked in 2017.[38] Since people tend to run their cars for a decade or so, it will be a few more years before we pass the peak of petrol cars on the road at any one time – 'peak fleet' – but that momentous occasion is also coming.

Affordability will be the key driving force of our transport revolution. But the cost of these technologies might not come down fast enough for us to meet our climate targets. We'll have to combine it with political action. Many countries are doing this already by banning the sales of new petrol and diesel cars. In the UK, this happens in 2030. More and more countries are committing to phasing them out by 2030, or 2040 at the latest. China and the US both have a target date of 2035. Lower-income countries are also taking a hard line: Ghana and Kenya have committed to 2040. This combination of plummeting prices and political action will get us far. The petrol car will disappear much more quickly than people might once have imagined.

But there is one thing that will trump EVs in our efforts to drive down our transport emissions, and that's not having a car at all. I live in London, where having one would be more hassle than it's worth. I can hop on the Underground and cross the city much faster than the queued cars, emitting very little carbon in the process.

The rest of my family can't do this: they live in a small town where the public transport is not great. It's even harder for my extended family who live in a tiny village in the countryside, where the nearest shop is miles away. People often picture eco-friendly living as rural. Living on your farm in the countryside is the green thing to do. Living in the packed energy-guzzling city is what's wrecking the planet. In reality, it's the opposite. There are clear environmental benefits to cities: we can build efficient, connected networks for travel.[39] When we look at the travel emissions across towns and cities we find a clear pattern: people in denser cities emit less.[40]

Part of bringing down our transport emissions will involve rethinking our living spaces. Many European cities are making good progress here. Cars no longer take centre stage, pedestrians and cyclists do. Cities not only become calmer, less polluted places to live, they also function much more efficiently. There's nothing less efficient than having roads filled with cars bumper-to-bumper. A well-designed combination of cycle lanes, pedestrian walkways and high-speed public transport can transform the feel and efficiency of cities. It slashes our emissions and gives us cleaner air too.

The big dilemma of the 2000s and 2010s was whether to get a diesel car or a petrol one. The big dilemma of the 2020s and beyond is to get an electric car or no car at all.

Long-distance transport will need innovation

Things get tricky when we're looking at trucks, lorries and long-distance travel. The problem with batteries is that they're heavy. The heavier your vehicle, the more energy batteries need to store. That makes them even heavier too. The balancing act can be made to work at the scale of cars. But trucks and planes are just too big.

We might edge closer to a solution as electric transport and battery technologies improve. There has already been progress in short-distance hauling.[41] We've sent electric planes into the air successfully. But these planes are small: a far cry from the jumbo jets that carry us across the world. Whether these solutions will scale to the level we need – and whether this can happen fast enough – is an open question.

In the meantime, we need to try out other options. Solar-powered flight – where we harvest solar energy during the flight so that we need less battery storage – could be one way forward. Another developing technology is hydrogen power. Hydrogen fuel is produced by splitting water molecules (H_2O) into hydrogen gas (H_2) and oxygen.[fn5] Hydrogen in this form is ideal: it's stored energy in a gaseous form. It holds on to this energy until we burn it, just like we do with petrol or diesel. Except it's much better than them because it can store and release three times as much energy per unit.

Hydrogen could be a game changer. Its big sticking point is that it takes energy to split water molecules. If we're producing this energy in the form of electricity from low-carbon sources then it could be a low-carbon fuel. If we're relying on fossil fuels, this obviously comes at a climate cost. For hydrogen to be a fuel of the future we need to improve its efficiency, but we also need to ramp up the amount of low-carbon electricity we're producing.

You might wonder why I'm not talking about cutting out flying completely. 'Flygskam' or 'flight shame' was born as an environmental movement in Sweden in 2018. But people have been talking about flying less for as long as I can remember. It's a very reasonable position to take: most people in the world have never flown. It's a luxury of the few. Some people had got used to hopping on a plane to attend a one-hour meeting. If the coronavirus pandemic taught us anything, it's that most of these meetings can be done just as well online. It's perfectly sensible that those who do fly should cut back. But aviation has given the world too much to cut it out completely. It has offered people the opportunity to migrate from one country to another. It lets them return home to visit their families. It has provided jobs. Driven innovations in new technologies. It has made our societies more diverse and multicultural and has allowed us to experience the beauty of other countries. These are experiences I want everyone in the world to have access to.

We don't *have* to fly across the world to connect with others. We can find other ways to travel, and we can get a long way by connecting online. But to make flying an act of shame is a step backwards. If we want to make flying only an occasional experience for people, it needs to be one that they appreciate. It shouldn't be one that they spend the next year trying to make amends for.

Food

Anyone that trusted the Netflix documentary *Cowspiracy* would believe that cutting out meat will stop the climate crisis. The film claims that more than half of the world's greenhouse gas emissions come from livestock. This is nonsense. The actual number is just under a fifth.[42]

Changing what we eat is not going to solve climate change. We need to stop burning fossil fuels to do that. But only fixing our energy systems, and ignoring food, will not get us there either. Researchers have looked at how much greenhouse gas emissions our food systems will emit over the next few decades if we keep eating as we are. The news is not good. We would blow right past our 1.5°C and 2°C targets.

Between 2020 and 2100 food production would emit around 1,360 billion tonnes of greenhouse gases.[43] To have a good chance of keeping global warming below 1.5°C, we can only emit around 500 billion tonnes.[44] And that budget is not just for food, it's for everything: food, electricity, transport, industry, the whole lot. Food on its own would emit almost three times as much as our 1.5°C budget would allow. It would eat up all of our budget for 2°C. The numbers are clear: to stand a chance of tackling climate change, we can't ignore food.

The good news is that we *can* get there. While we have a plateful of options, most boil down to a few key changes in what we eat (and *don't* eat), and how productive we are at making our food. The next two chapters will look at food in more detail.

For now, let's look at the things we need to do to cut the climate impact of our food. Every day another evil food emerges in the media: don't eat x; don't eat y; if you eat z you should feel guilty about it. If we were to cut out every food that makes it into the headlines, there would be nothing left to eat. Thankfully the list of things that really make a difference is short. Here are the five big things we need to focus on.

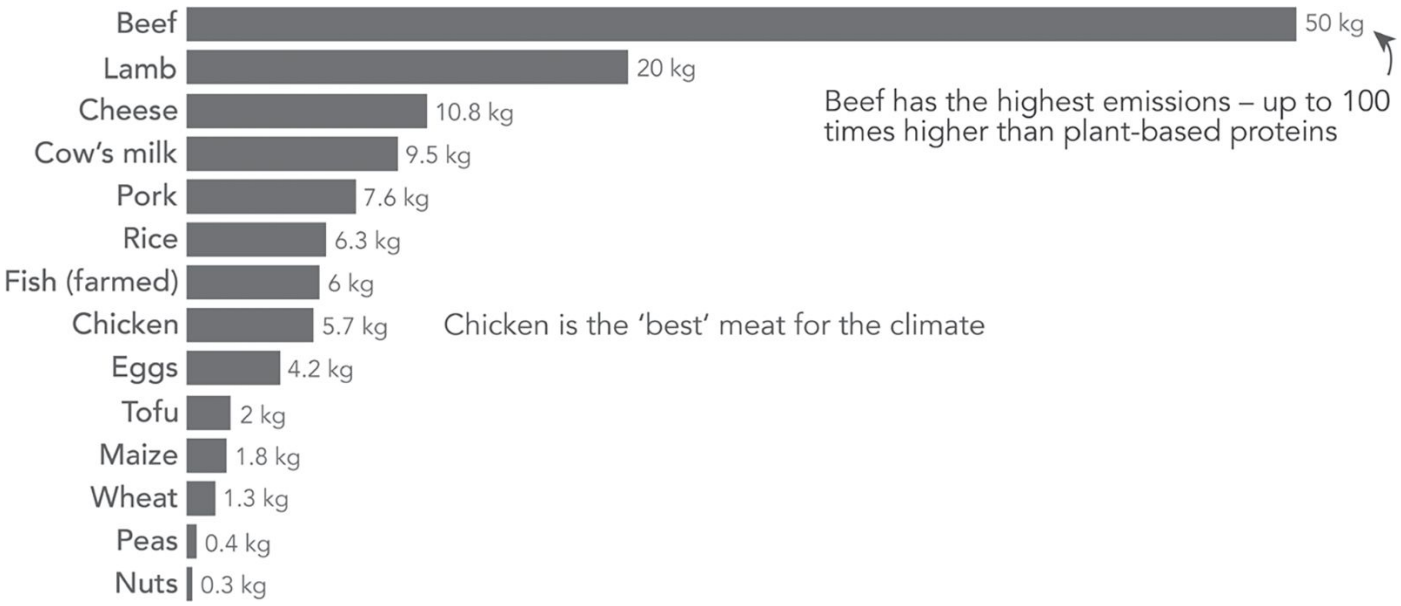
(1)
Eat less meat and dairy, especially beef

This one will make the biggest difference. It's one of the most effective things you can do to cut your carbon footprint. When we look at the impact of different foods, a hierarchy emerges. At the very top of this list – way ahead of everything else – is beef. Producing 100 grams of protein from beef emits around 50 kilograms of carbon dioxide equivalents.[45] Then we have lamb, at around 20 kilograms. Then dairy, then pork, followed by chicken. You will notice here a clear ranking of animal foods: from the biggest animal (cows) to the smallest (chickens, then fish). Chapter 5 will look at why.

Most plant-based foods – soy, peas, beans, lentils, cereals, nuts – lie at the bottom of the list. They have a much lower carbon footprint than animal-based products. The takeaway from this is simple: if we want to reduce our carbon footprint, we should eat a more plant-based diet. This doesn't mean we have to go vegan. And people in the world

that can only afford a few kilograms of meat a year don't need to cut it out either. What it does mean is that those of us eating 50 or more kilograms a year could have a large impact by eating less. Even substituting chicken for beef – choosing the chicken burger rather than the beefburger – would go a long way.

Researchers estimate that if everyone were to adopt a more plant-based diet we could halve our emissions from food production. This plant-rich diet doesn't cut out meat and dairy completely.[46] It includes the equivalent of one slice of bacon, four thin slices of chicken and a glass of milk per day. You could also have an egg and a fish fillet every few days. This is much less than most people in rich countries eat. But it's more than many people in poorer countries do.



Plant-based foods are better for the climate
Measured in kilograms of carbon dioxide equivalents (CO_2e) per 100 grams of protein.

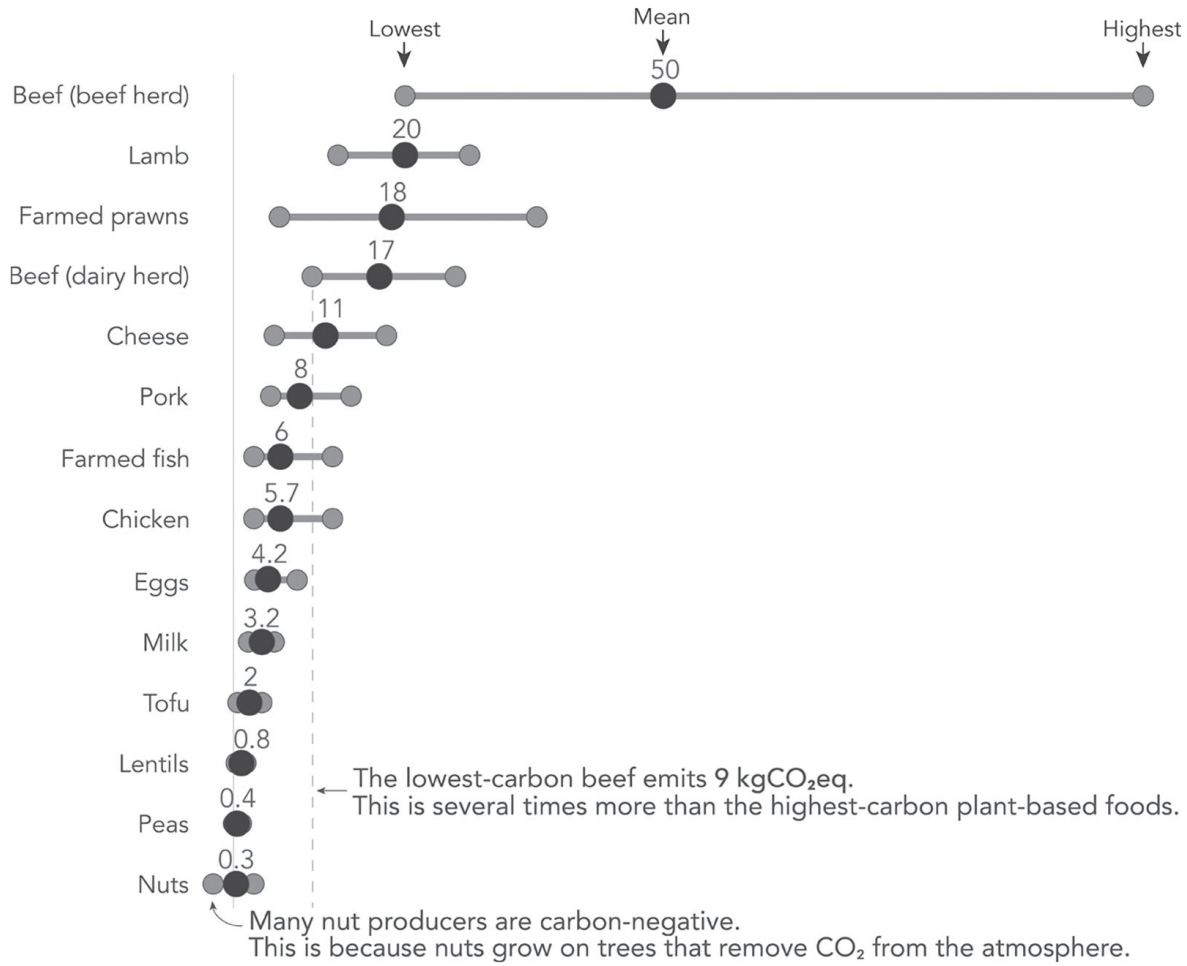
(2)
Adopt the best and most efficient farming practices we can

The numbers above are global averages from studies spanning thousands of farms across the world. But farming practices vary a lot. Beef from an efficient producer in New Zealand or the United States might not have the same carbon footprint as the producer in Brazil who had to cut down some of the Amazon rainforest.

That's an argument I hear a lot when I say that eating less meat – especially beef – is the most effective way to cut your carbon footprint. People will argue that the beef they consume – from their local farm in the UK – has a *much* lower carbon footprint than the global average. It probably does emit less, but it's still going to be much higher than plant-based alternatives.

When we look beyond the global average to the distribution of carbon footprints for each food – from the most sustainable producers to the least sustainable – the overall

message doesn't change. The *worst* plant-based foods still have a lower carbon footprint than the *best* beef or lamb. Eating less beef and lamb is still the most effective way to cut your footprint, but these differences within a given food product do matter. People will continue to eat some beef, lamb, dairy and pork, so we should source it from the most efficient and carbon-friendly producers.



The lowest-carbon meat emits more than the highest-carbon plant protein
Measured in kilograms of carbon dioxide equivalents (CO_2e) per 100 grams of protein. Emissions are measured in kilograms of carbon dioxide equivalents per 100 grams of protein. This is based on data from 39,000 commercially viable farms in 119 countries.

(3)
Reduce overconsumption

The world produces enough food to feed everyone, twice over. More on this in Chapter 5. Unfortunately, massive inequalities exist. One in 10 people don't get enough calories. Four in ten get too much and are overweight. It's a conversation we often shy away from, but it should be obvious that if we were to reduce the overconsumption of food we would need to produce less in the first place.

(4)
Reduce food waste

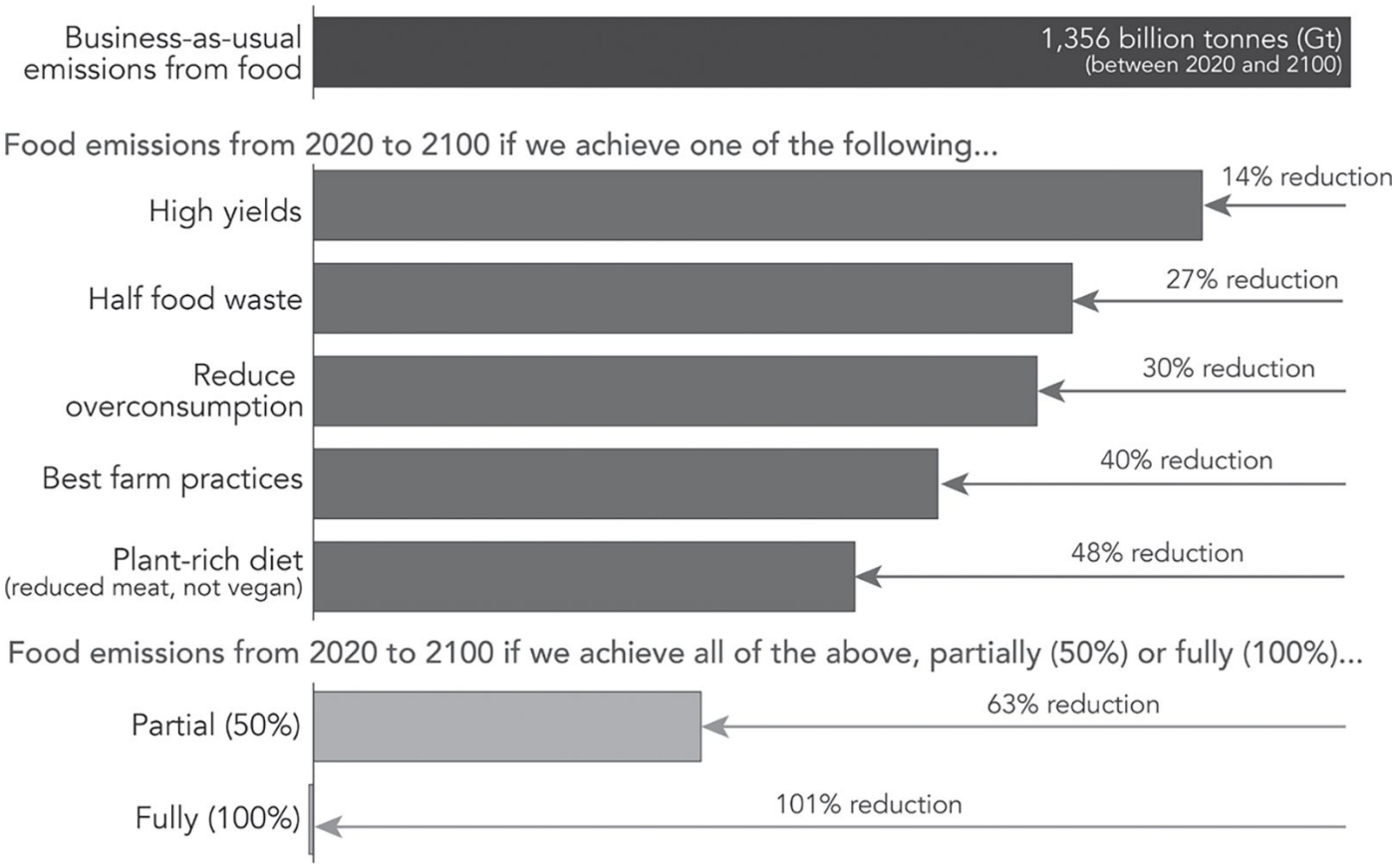
We need to stop food from rotting on its way from the farm to the shops and prevent it from going in the bin when it reaches us. We probably won't cut it out completely, but it's possible for us to reduce food waste by at least half.

(5)
Close yield gaps across the world

Over the last century the world has achieved what seemed impossible: massive increases in crop yields. In many countries they have tripled, quadrupled, or more. It means we can grow much more food without using more land and cutting down forests. But some countries have lagged behind. If we can close these yield gaps across the world, we can spare a lot of forest from being cut down.

Do these five things listed here and we can build a low-carbon food system. In the chart we can see the impact of doing any one of these things on its own. They could get us far. If we manage to do *all* of them, we could reduce our net emissions from food to zero. It's not that we would emit nothing – we would still have some emissions from fertilisers, and small amounts of livestock – but this could be offset by all the land we would free up, the forests that would grow back, and wild grasslands that would be restored. Even if we manage to achieve just half of the target for each (for example, only reducing food waste by a quarter instead of a half, or overeating by only half as much as we do today) we could cut emissions by two-thirds. This would free up lots of space in our carbon budget and buy us some time to get our emissions from energy and other sectors to zero.

When it comes to food, there are a few interventions that matter much less than we think. Eating locally produced food doesn't make a big difference. Nor does eating organic food. In fact, in both cases, those choices could actually *increase* our emissions if we're growing foods that are better suited for other climates or conditions. The plastic packaging of our food also doesn't matter much for our carbon footprint. I'll explain all three of these misconceptions in Chapter 5.



How do we reduce greenhouse gas emissions from food?
Shown are estimates of emissions from our food systems between 2020 and 2100 based on a business-as-usual scenario, and five options to reduce them.

Building stuff

When I was a kid, my dad would travel to China for work. This was in the early 2000s. He recently went back – after more than a decade – and couldn't believe how much had changed. Behind every row of houses, another was being constructed.

The pace of this development has been staggering. It's a transformation that has needed a lot of construction materials. Cement, steel, iron. There is an often repeated claim – that China uses more cement in three years than the US did in the entire 20th century. This is true. I know because I recalculated the numbers myself to check.

China is not the only country that is developing rapidly. People are quickly shifting from rural areas to cities. This is a positive step for human development, but it comes with challenges in how we build cities in a sustainable way. Around 5% of our CO_2 emissions from fossil fuels and industry comes from cement production. That might not seem like much, but over the coming decades, billions of people will make the move to towns and cities, so this will grow.

When it comes to energy, we already have a lot of the solutions we need. Decarbonising how we *make stuff* is going to be trickier. Making cement needs energy, which is not a barrier in itself: if we can make our energy from low-carbon sources, this

wouldn't be a problem. The real issue with cement is that the chemical processes involved in its manufacture also produce CO_2.[fn6] Tweaks to the process might be able to reduce these emissions a bit, but they won't get us close to producing zero-carbon cement.[47]

What we're going to have to do is capture the CO_2 and do something else with it.[48] We could store it underground, to make sure it doesn't escape into the atmosphere. We might be able to inject the CO_2 back into the process, to become part of the reaction and then the cement itself. We'd end up with cement that has CO_2 permanently 'locked' into it. There are lots of companies working on promising solutions to this tricky problem.

Why don't we just ditch the cement and make everything from other materials? The first problem is about cost and scale. Developing economies are growing quickly and need a ready supply of cheap materials to build with. For countries such as China, cement has been perfect. It's hard to produce massive volumes of wood quickly. It's also more expensive. Not to mention impossible without a huge change in how we use the world's land. Many countries would have to chop down their primary, natural forests and grow timber plantations instead. Over the very long-term this *might* save some carbon through the repeated process of growing forest, cutting it down, then regrowing it, but it could also come at a huge cost to biodiversity. As we'll see in the next chapter, timber plantations are among the largest drivers of deforestation globally. At local scales, sustainable projects might be manageable, but at the scale and pace that we need materials, it is no global solution.

The reality is that we need low-carbon innovations for materials such as cement and steel. Since cities are rising up across the world, the sooner we do, the better.

Put a price on carbon

The final thing we need to do to decarbonise our economy is not specific to any one sector. It's an intervention that underpins everything else.

I've asked many economists what we need to do to tackle climate change. Every single one has given me the same answer: put a price on carbon. It is, perhaps, the *only* thing that economists agree on.

What do we mean by putting a price on carbon? It means implementing a carbon tax on everything we buy based on how much greenhouse gases were emitted to produce it. Using carbon-intensive fuels like coal, oil and gas would result in higher tax. Using low-carbon fuels such as nuclear, solar or wind would attract very little tax, and would be much cheaper in comparison.

The argument for having this tax is that the current price we pay for things is not an accurate reflection of what they actually cost. We pay a price for burning fossil fuels that isn't reflected in the market: it has a cost in the form of climate change (which we and future generations will have to pay for), and other impacts such as air pollution

which already kills millions every year. The purpose of a carbon tax is to even this playing field, to rebalance the market so that we start paying our dues.[49]

A carbon tax would change the decisions that consumers make. The energy-guzzling SUV would be considerably more expensive next to a clean, electric Nissan Leaf. The beef would be expensive next to the popular plant-based Impossible Burger. It would push everyone towards low-carbon choices. It would also change the incentives of companies that make stuff. Their high-carbon items would be priced out of the market. They would end up in a rat race with their competitors to lower their prices. To lower their prices, they would need to cut their carbon footprint.

A carbon price could be incredibly effective. The strongest climate deniers would still end up making more sustainable choices. They wouldn't do it for the planet; they would do it for their wallets. Even leaders like Donald Trump would choose solar and wind energy over coal. The key to decarbonising our economy is to make it as pain-free as possible. It needs to be easy and products cheap.

One concern I have – and many others do too – is that putting a price on carbon would hit the poorest people the hardest. If you were to double the price of petrol tomorrow, the rich guy with five Lamborghinis might feel a bit of a pinch. But he'll be all right. He might have to sell one of his five cars or fly first class rather than by private jet. He'll get over it. But the parents living on the breadline might already struggle to heat their home and drive their kids to school. They cannot afford to buy an electric car. Carbon pricing policies need to include support for poorer households to make up for the increased cost of energy. This could be done by directing the tax revenues towards poorer households. This revenue could be used in other positive ways: to invest in developments in low-carbon technologies, for innovations in clean energy and meat, to build sustainable cities, stop deforestation or restore forests that have been cut down.

It should be the richest – those who emit the most carbon – that pay the most. Any carbon pricing scheme needs to be designed so that they do.

How do we adapt to climate change?

The very poorest countries in the world have contributed next to nothing to the climate problem. Not even 0.01% of the world's emissions so far. Yet they are the ones that will experience climate change most harshly and will have the fewest resources to adapt. Unbearable heat is tolerable when you can keep the air conditioning running all day. Crops can be managed when you can afford irrigation. You can protect against floods when you can invest in defence infrastructure and repair the damage when the water subsides. When you are living hand to mouth, a bad crop season could be the last one for you and your family. That is the cruelty of climate change.

We need to find ways to adapt to the changes that are coming and are already here. Some will argue that focusing on adaptation is a distraction to reducing emissions.

That's not true. There is no doubt about it: we must rapidly reduce the world's greenhouse gas emissions. But regardless of how quickly we reduce our emissions, some climate change is inevitable. Even if we did miraculously manage to keep temperatures to 1.5°C, we would still need to adapt to a world that's hotter than it is today. For many people across the world, ignoring it is not an option.

The latest Intergovernmental Panel on Climate Change report on impacts and adaptation to climate change is 3,675 pages long.[50] Even if we can't get into the nitty-gritty here of how each and every country needs to adapt to climate change, there are a few basic principles that are universal.

(1)
Pull people out of poverty

This is the most important thing we need to do to adapt to climate change. Being poor makes you incredibly vulnerable to the impacts of climate change. In fact, being poor makes you vulnerable to almost *any* crisis. When you live close to the poverty line, you are just one shock away from being pushed below it. If you already live under the poverty line, you live with the constant stress that the smallest shock could be the last straw. It's a truly terrible position to be in, but it is the reality for billions.

Even though deaths from natural disasters have fallen by roughly 90% over the course of the 20th century, we expect that the frequency and intensity of disasters will get worse with climate change. As we've seen, fewer people die from natural disasters because we've figured out how to protect ourselves against them. Much of that resilience has come from poverty alleviation. We can now predict extreme weather events ahead of time, but it is only with good network connections that we can spread the word across countries so that people can prepare, with houses and infrastructure that can withstand floods and hurricanes.

(2)
Improve the resilience of our crops to drought, floods and a warming world

For me, the most worrying aspect of climate change is the impact it could have on food security. Crops are often adapted to particular climatic conditions. When these conditions change, our crop response does too; we might get higher yields, we will often get lower yields; in some cases crops might fail. Here we have a lot of potential to develop crops that are either more resilient to these changes or better suited to the new climate we're creating. We know we can do this because we've done it in the past. We can improve yields using nutrients, pesticides and irrigation; but we can also develop seed varieties that are resistant to disease and pests.

Genetic breeding gets a bad reputation in environmental circles, but it has been absolutely crucial to increasing crop yields across the world, and could play a much

bigger role if we're to develop agriculture that works well in a changing climate. Not only would it allow farmers to achieve good, stable yields, it could even mean we'd need to use fewer fertilisers and pesticides too. What's most frustrating about the opposition to genetic engineering is that, once again, it often hurts the poorest the most. The ones who will be most vulnerable to a potential crash in yields and food supply. To stand in the way of solutions that might help to alleviate this damage is an injustice.

(3)
Adapt our living conditions to deal with sweltering heat

Extreme temperatures will become increasingly common. We will need a range of measures, from very basic public health advice on how to stay cool, to increased capacity of health care facilities to deal with those who are suffering. Again I have to loop back to my first point about poverty alleviation: those who will be most vulnerable are those that cannot afford shelter or air conditioning, or have no option but to go out to work in the extreme heat. In the 21st century, everyone should have access to air conditioning when they need it. This is a controversial statement in environmental discussions because that will require more energy. But I stand by it. We want to build a comfortable future for everyone, and baking in extreme heat cannot be part of it.

One of the big sticking points of international climate agreements has been how to finance adaptation efforts. The countries that have contributed to climate change the least and have the fewest resources are the ones that have to adapt the most. Rich countries should contribute financially to adaptation. They have committed to doing so, but are coming up short in their delivery. This needs to change, and it needs to change quickly.

Things to stress less about

The reputation of being a climate data person is hard to shake. Doctors at a party get asked about everyone's potential life-ending illnesses. I get asked 'Is this really bad for the environment?' or 'What's worse: this or that?' These questions often go *really* deep – right down to the behaviours that emit just grams of CO_2.

I'm happy to answer them, not least because I've geeked out on all the relevant numbers. The book *How Bad are Bananas? The Carbon Footprint of Everything* by Mike Berners-Lee was the bible I used to carry everywhere with me.[51] I was desperate to understand and optimise every tiny detail of my carbon footprint. I wanted to know if I should use the hand dryer or a paper towel. (The answer is paper towel if you're just using one sheet, but hand dryer if you go for two.) Is it more climate-friendly to read a book or watch TV? (It's definitely reading a book.) Should I use the dishwasher or the sink? (Unless you use cold water, or hot water very sparingly, the dishwasher wins.)

These comparisons are fun and nerdy. But sometimes they can do more harm than good. I can justify spending a lot of time on them because it's my job. But people shouldn't be stressed out by every tiny decision they make. It can get overwhelming. Tackling climate change feels like a massive sacrifice that has taken over our lives. That would be okay if all of these actions were really making a difference, but they're not. It's misplaced effort and stress, sometimes even at the cost of the few actions that really *will* matter. There is a concept called 'moral licensing': it explains the psychological trick we play on ourselves where we justify one behaviour because we've made a sacrifice somewhere else. So, we go for the steak because we'll recycle the plastic wrapper it comes in. Or, we'll drive rather than cycle across town because we used the 'eco-friendly' setting on the washing machine.

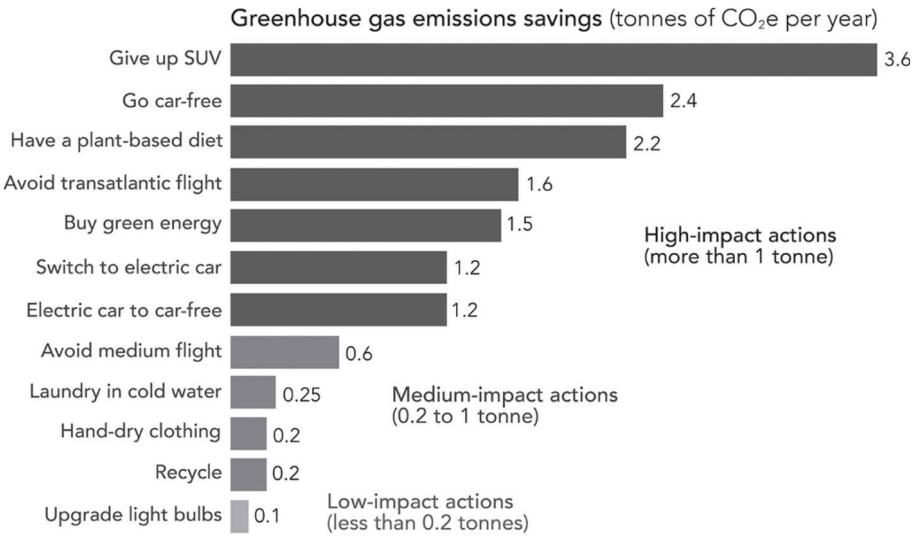
When we ask people what they think are the most effective things they can do to reduce their carbon footprint, they often mention the stuff that has the smallest impact.[52] Recycling, using more efficient light bulbs, not leaving their television on standby or hanging their washing out to dry. They often miss the big stuff: eating less meat, switching to an electric car, taking one less flight, insulating their home or investing in low-carbon energy.[53]

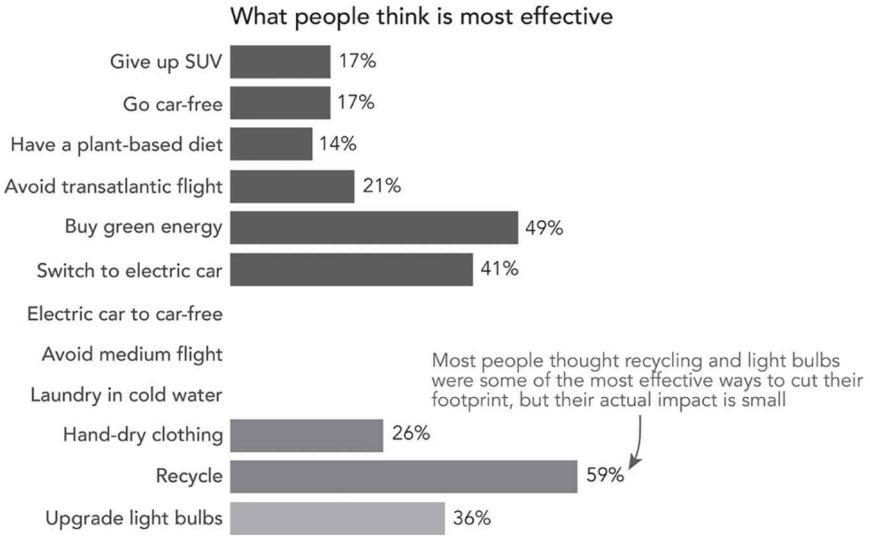
That's why understanding the numbers is important. Not so we can stress about how much CO_2 we're emitting by watching Netflix, but by helping people understand the handful of behaviour changes that *really* make a difference.

So, what should we all stress less about when it comes to climate change?

In no particular order, here is a list of common things that people *think* make a big difference, but usually have a small impact on their carbon footprint. Sure, continue doing them if you want to (I do some), but don't stress and definitely don't do them instead of the big things that really do matter.

- ➤ Recycling your plastic bottles (see Chapter 7)
- ➤ Replacing old light bulbs with energy-efficient ones
- ➤ You don't have to stop watching TV, streaming movies or using the internet
- ➤ How you read: whether it's Kindle, paper or audiobook, it doesn't matter
- ➤ Washing your dishes in the dishwasher, it doesn't matter much
- ➤ Eating local food (see Chapter 5)
- ➤ Eating organic food (this can be *worse* for your carbon footprint – see Chapter 5)
- ➤ Leaving your television or computer on standby, it doesn't matter much
- ➤ Leaving your phone charger plugged in, it doesn't matter much
- ➤ Plastic or paper bag – your plastic bag actually has a lower carbon footprint, but it doesn't matter much [fn7]





What we think is effective in cutting our carbon footprint often isn't
Actions such as giving up a car, eating a more plant-based diet, reducing flights or switching to an electric car are most effective in cutting our personal carbon footprint.

But surveys across 21,000 adults in 30 countries showed that people think actions such as recycling and upgrading light bulbs were among the top 3 most effective.

4

Deforestation

Seeing the wood for the trees

‘The Amazon rainforest – the lungs which produce 20% of our planet’s oxygen – is on fire’

– President Emmanuel Macron, 2019[1]

The Amazon rainforest is often called the ‘lungs of the Earth’. Emmanuel Macron is not the only one to claim that it produces 20% of the Earth’s oxygen. Leonardo DiCaprio, Kamala Harris and Cristiano Ronaldo are just a handful of others that have made similar claims.[2, 3] Former NASA astronaut, Scott Kelly, even tweeted this statistic out, followed by ‘we need O_2 to breathe!’[4]

What they’re implying is that the disappearance of the Amazon is a threat to the planet’s oxygen supply. As we hear about the loss of the Amazon rainforest, these claims become scary. An article in the *New York Times* stated that ‘if enough rain forest is lost and can’t be restored, the area will become savanna, which doesn’t store as much carbon, meaning a reduction in the planet’s “lung capacity”’.[5] Now, there are very real concerns about a ‘tipping point’ with the Amazon. But it’s not a concern about oxygen. The Amazon doesn’t provide 20% of the world’s oxygen. On balance, it contributes almost none of it.

The Amazon does produce huge amounts of oxygen. During photosynthesis, it sucks up carbon dioxide and emits O_2. The estimate of 20% is too high, though: it is closer to 6 to 9%.[6, 7] However, these numbers are beside the point: the Amazon produces a lot of oxygen, but it consumes a lot too. During the night, when there’s no sun around for photosynthesis, trees convert sugars into energy, using oxygen to power the process. Bacteria on the forest floor also consume oxygen when they’re decomposing organic matter that has landed there from the canopies above. The amount of oxygen the Amazon *consumes* is almost exactly the same as the amount it produces. These cancel each other out, so it provides almost none of the oxygen in the atmosphere.

It's not just the Amazon. None of the world's forests or vegetation give much to our oxygen supply. As the geologist Shanan Peters calculated: 'if every living thing other than humans burned up, oxygen levels would fall from 20.9% to 20.4%'.[8] It would also take millions of years to deplete the globe's oxygen supply by any notable amount. The oxygen in our atmosphere came from phytoplankton in the oceans, millions of years ago. Before then, Earth's atmosphere had none; microorganisms lived anaerobically – meaning they didn't need oxygen – or were 'extremophiles' living in intense environments, fuelled by elements such as sulphur. Around 2.5 million years ago, the Earth had its 'Great Oxidation Event' where cyanobacteria – the first organisms to photosynthesise – started to convert CO_2 into O_2. That's where most of our oxygen comes from, and it's very hard to significantly change this balance.

This shouldn't stop us from taking action. The Amazon – and other tropical rainforests – is home to some of the most biodiverse ecosystems on the planet. They are under threat. Deforestation is also terrible for the climate, because when we cut trees down, we can release the carbon that was locked up for hundreds or thousands of years. The reality is bad enough, and should give us plenty of motivation to act. We don't need to resort to misleading headlines to gain attention, because when the truth comes out, they erode the public's trust in scientists and belief in the reasons that we actually should care.

In fact, there are reasons to be cautiously optimistic that we can bring deforestation to an end. The headlines that often accompany the '20% of the world's oxygen' figure also claim that Amazon deforestation is at a historic high. This is also not true: Amazonian deforestation rates peaked in the late 1990s and have fallen since then.

How we got to now

Today's rich countries lost their forests long ago

The threat of running out of forest was real for many countries. A thousand years ago half of France was covered in forest. By the 19th century, it covered just 13% of the country. In the centuries from 1000 to 1300, the French population doubled from 8 to 16 million people. This period was one of peace – without wars to fight, the population could increase without interruption. A country with more people needs more food, more energy and more materials for construction. This meant cutting down trees to heat homes and make space for farmland. This period was described by some as the 'great adventure of the French countryside'. Half of the country's forests were chopped down.

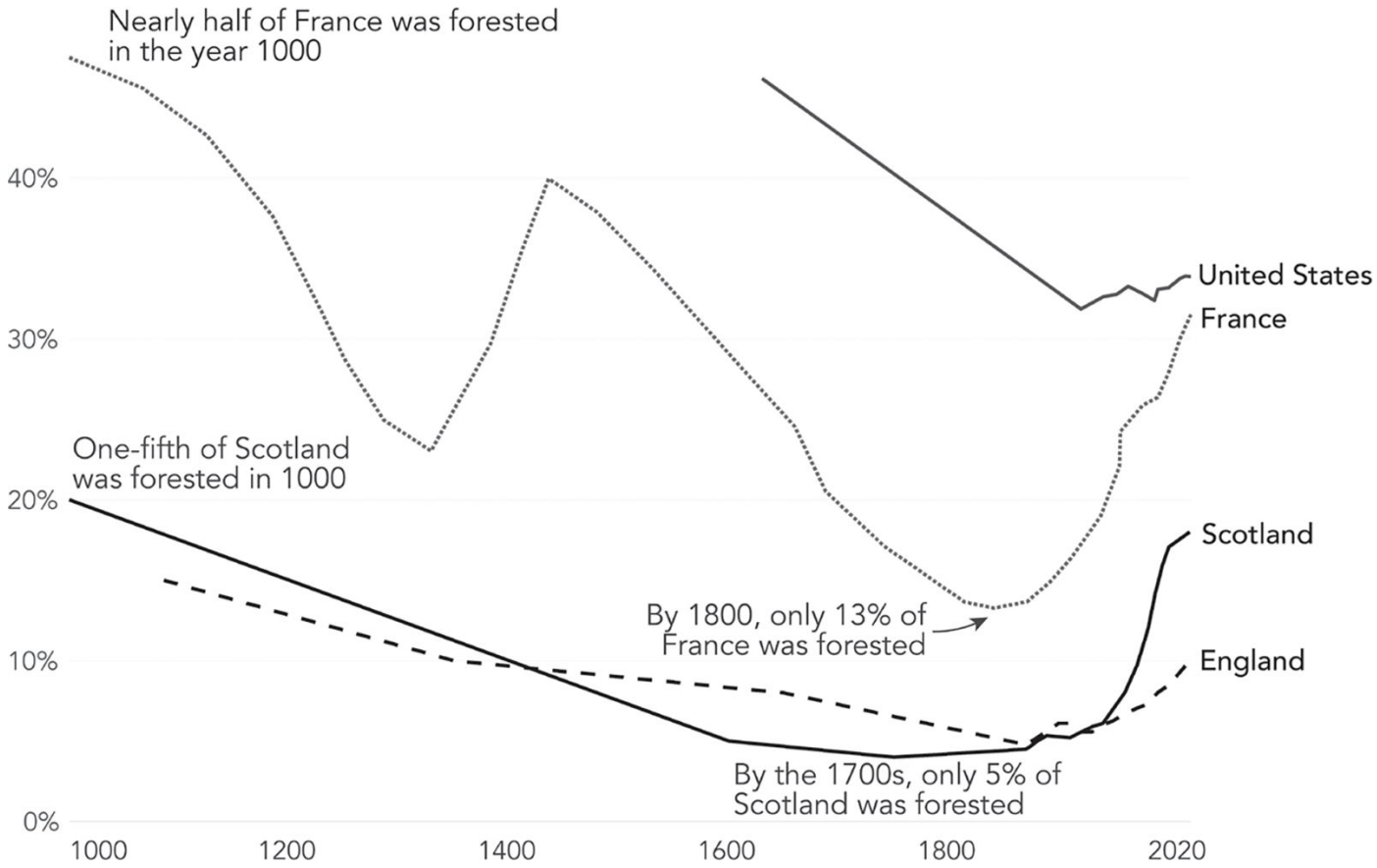
But then Europe was hit by the Black Death. This plague was caused by a bacterium that was spread by fleas, but also from person to person through droplets and aerosols. It was incredibly deadly. As much as half of the continent was killed. France was hit badly and its population shrunk from 16 million to around 10 million. Having fewer people meant that France needed less food, energy and resources. It abandoned

farmlands and the forests returned. Forest cover almost doubled again over the course of the 14th and 15th centuries. This regrowth of natural landscapes was common across Europe after the Black Death. When researchers look at pollen samples from restored forests and grasslands, they can see a large drop in plant material of cereals and a return of other plant life.[9]

This forest comeback was only temporary. It took several centuries, but the French population eventually returned to its pre-plague levels, and then some. France became a global power. Demand for land, energy and wood surged. They needed ships for expeditions to build their dominance. Running out of wood was a key concern. In the 1600s, Louis XIV cried out that 'France will perish for lack of timber!'

The population also had to be well fed. Crop yields were only a fraction of what they are today, and the only option to grow more food was to turn forests into farms. The government actively encouraged this: in the 1700s, you would get a tax exemption for 15 years after clearing the land. Finally, the demand for fuelwood also increased. Urban centres were booming across France. People needed wood to heat homes and power industries. Hectare after hectare of forest disappeared.

Just across the English Channel, the same was happening in Britain. A thousand years ago 20% of Scotland was forested, and 15% of England.[10, 11] By the 19th century, this had been slashed to less than 5% in both regions.[12, 13] Trees were tumbling across the Atlantic too. Nearly half of the US was forested in the 17th century, but two centuries later this had shrunk to around 30%.[14]



The disappearance and comeback of forests in rich countries
The share of each country that was forested.

If you were living in 18th-century France or Britain, you might have assumed that this decline would continue. But just when it seemed like these forests might disappear entirely, countries turned the tide.

This turnaround was not like the blip after the Black Death. This time the forests were coming back while the population was still growing. There are a number of reasons why. One was the beginning of the transition to productive farming. The intensification of agriculture meant that crop yields started to increase (albeit slowly). Countries switched to more productive crops – France ditched rye for potatoes, which can feed a lot more people per hectare. And policies changed: rather than incentivising people to cut down forests, governments brought in strict policies on deforestation and persuaded rural populations to abandon unproductive farmland.

Finally, the coal boom had begun. In Paris, in 1815, the average person used 1.8 m^3 of fuelwood per year. By the 1860s this had fallen to 0.45 m^3, and by 1900 it was down to 0.2 m^3. Wood was on its way out, and coal was the new fashion.

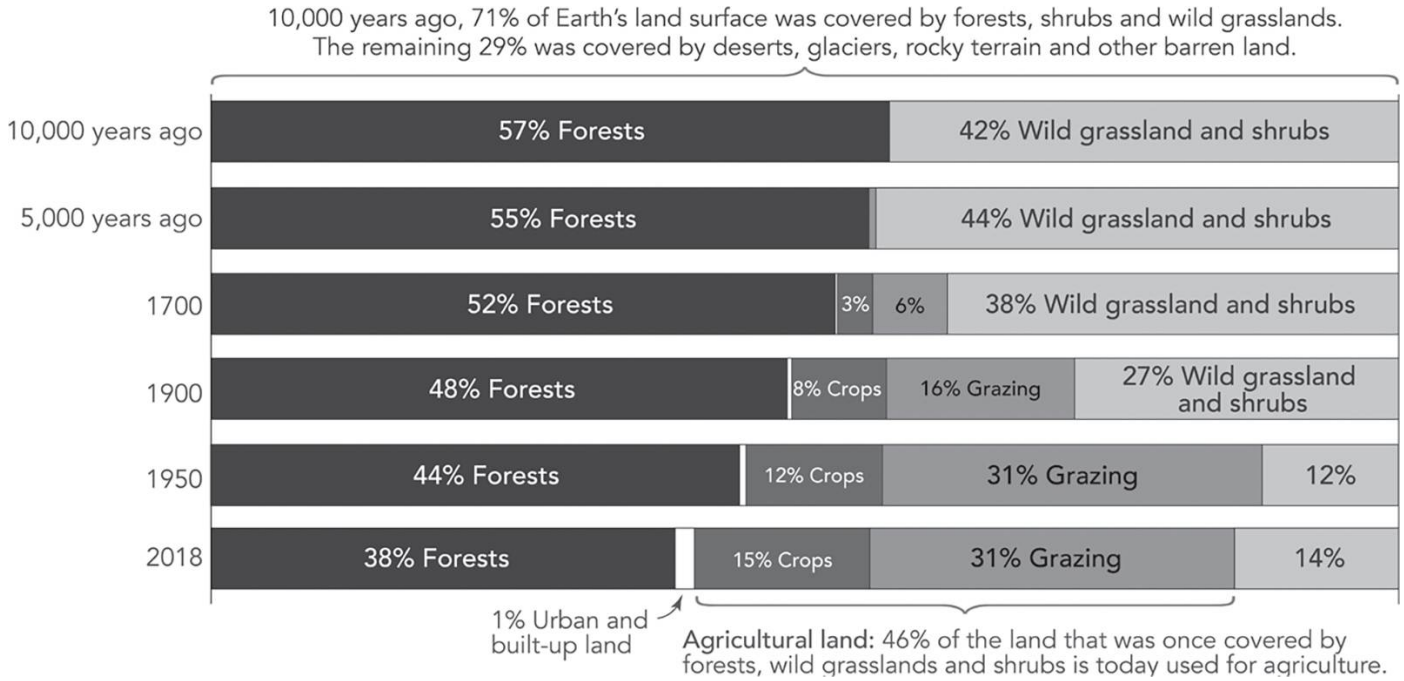
These changes meant that rich countries managed to decouple population – and economic – growth from deforestation. This trajectory is a consistent pattern that we still see across the world today. It follows a country's journey from less to more industrialised. Deforestation and development are tightly linked when a country is poor,

but this relationship eventually breaks down. Once countries get rich enough, forests stage their comeback.

The world has lost one-third of its forest since the last ice age

Let's not sugar-coat the truth, though. Things might be improving in many countries today, but the cost of deforestation globally has been huge.

The world has lost one-third of its forest since the end of the last ice age around 10,000 years ago.[15, 16] That's an area twice the size of the United States. Half of this forest was lost before 1900. Still, the world has lost an astounding amount of forest over the last century too. Nearly all of this has come from the expansion of agriculture. The area of crop and grazing lands has almost doubled. We now use much more of our land for farming than we have left in forests. Agriculture has been the driving force for deforestation for a long time, and still is today. Nowhere is this pattern more evident than in Brazil.



Humanity cut down one-third of the world's forest to make room for agriculture
Agriculture has always been the biggest driver of deforestation. This is still true today.

The former Brazilian president, Jair Bolsonaro, often created a smokescreen with his promises on tackling deforestation. At the 2021 international climate conference in Glasgow – COP26 – the Bolsonaro government pledged to end illegal deforestation by 2028, two years earlier than previously agreed.

As other countries put pen to paper, the world rejoiced. Brazil is where most of the world's forests are being lost. End deforestation there, and we can end it everywhere. On that stage, Bolsonaro sounded like a man committed to ending deforestation in the Amazon. Just a few months on, it was clear that the world shouldn't have been fooled.

INPE – Brazil's Space Agency – published the latest deforestation results. Rates in 2021 were the highest in 15 years.[17] This damning and important figure hit the headlines. It did in 2022 too. It was easy to imagine that global deforestation rates were at their highest level ever, getting worse and worse.

But zoom out and we see that this is not the full picture. No doubt about it, the world has cut down a lot of forest. And we're still losing it at an alarming rate. The 2020 UN Forestry Report estimates that in the decade from 2010 to 2020, 110 million hectares was deforested. An area twice the size of Spain. The world did regrow around 50 million hectares of forest, so the net loss of forest was around half as much.

But the data also suggests that global deforestation has fallen from its peak in the 1980s.

The UN has assessed the state of global forests for more than half a century. Its 2020 stocktake suggests that deforestation rates have fallen by around 26% since the 1990s. Earlier reports suggest that rates were even higher in the 1980s.

Now, deforestation numbers are not without their controversy. Researchers don't even agree on the simple question of what a 'forest' is. There are various methods of measuring deforestation; none are perfect. One newer method is using remote sensing and satellites. In 2022, the UN published a full assessment using remote sensing. Its results were in line with its earlier reports of falling global deforestation rates.

Where estimates differ is that satellite methods often measure 'tree cover loss'. This is not the same as deforestation. Deforestation is defined as the *permanent* conversion of forest to another land use, such as pasture, cropland, cities or roads. Tree cover loss includes deforestation but also includes trees that are temporarily lost due to wildfire, agroforestry or the periodic harvest of timber plantations. Since these trees regrow, they are not within the UN's definition of 'deforestation'. Consistent long-term data on tree cover loss doesn't exist, but recent data show that rates are still very high, and increasing in some regions.

Overall, the data shows us that deforestation rates are still worryingly high. Tragically, nearly all of this loss is happening in the tropics, where biodiversity is highest. But *global* deforestation probably peaked decades ago. And there a range of examples – some that we'll see later – that show how countries *can* reduce deforestation dramatically with the right tools and policies.

Where we are today

Where are we losing and gaining forest today?

Looking at the history of deforestation – and it's a long one – gives us perspective on how much forest we've lost, and why countries cut it down in the first place. We need to halt deforestation, and we need to do it quickly. Losing forest in the tropics while we regain it in temperate countries is not enough. There are so many things that are lost

when we cut these forests down. We lose a lot more than carbon. When we cut a tropical rainforest down, we lose the equilibrium that it had accumulated over centuries or millennia. Tropical forests are teeming with unique wildlife; rebuilding those ecosystems will take a long time, if they bounce back at all. Preventing one hectare of tropical deforestation in the first place is much better than *replanting* one hectare of forest. It's not the same as buying an offset for your summer holiday flight.

When we look at which countries are losing forest, and which are gaining it, there is a clear divide. Rich countries tend to be regrowing their forests. Low- and middle-income countries are losing theirs. This is no coincidence. Forest cover follows the classic U-shaped curve that also tracks a country's development. In the deforestation sphere, we call this the 'forest transition' model.[18, 19, 20]

This curve has four stages, which are defined by only two variables: how much forest a country has, and how this is changing from year to year.

In Stage 1 – **the Pre-Transition phase** – a country has lots of forest and is not losing much of it over time. Deforestation might not be zero but is at a very low level.

In Stage 2 – **the Early Transition phase –** countries start to lose forests very rapidly. Forest cover falls quickly, and the annual loss of forest is high.

In Stage 3 – **the Late Transition phase** – deforestation starts to slow down again. At this stage, countries are still losing forest but at a lower rate than before. At the end of this stage, countries are approaching the 'transition point'.

In Stage 4 – **the Post-Transition phase** – countries pass through the transition from losing forest to gaining it. Forests start to regrow naturally, or countries may replant them. At the start of this phase, a country might not have much forest left, but it is making a comeback. Hopefully, by the end of Stage 4, a country will have not only regrown some of its forest, but will be closing in on historical levels of cover. This might even be a whole stage of its own: Stage 5.

From England and France to the USA and South Korea, countries have followed this very predictable U-shaped pattern. But why – and how does this link with economic development? Let's think back to why people cut trees down. They either want the materials – for energy, for buildings, boats or paper – or they want the land to grow food. As countries break out of the deadlock of little population or economic growth, their demand for both increases. We need more fuelwood to cook, more houses to live in and, importantly, more food to eat. That's when countries start to transition from Stage 1 to Stage 2. They start to cut down forests, and this gets faster and faster as the demand continues to rise.

But as countries get richer this demand slows. Instead of using wood for fuel, people switch to fossil fuels (or now, hopefully, more renewables and nuclear energy). Crop yields increase so we need less land for agriculture. This is when a country moves into Stage 3 – deforestation slows down considerably. Finally, a country reaches a stage of development where deforestation comes to an end. Agriculture is very productive,

population growth is slow, no one wants to burn wood for fuel, and we find other materials to build things. Countries reach Stage 4 – the point where forests make a comeback.

Most low- to middle-income countries are in the tropics and subtropics, so 95% of the world's deforestation happens in the tropics.[21] This is bad news. Tropical forests are home to some of the richest and most diverse ecosystems on the planet. They're home to over half of the world's species.[22] These forests also store lots of carbon; cutting them down is terrible for climate change.[23]

It's quite clear: we need to stop deforestation in the tropics. Since forests follow the development pathway of countries, this might happen on its own if we just sit back and let things play out. Countries will get richer and eventually reach Stage 4. But this will take too long. We won't be able to tackle climate change, and we'll lose too much wildlife in the process. It would be tragic if low- to middle-income countries followed the same path as industrialised countries.

The good news is that they don't have to. They're not in the position that Britain was in two centuries ago. We have technologies that help us to make agriculture productive. We have institutions that can enforce policies and regulations. We have satellites to help us track and monitor deforestation across the world. We have alternatives to using wood for energy. And we have each other: an international network of collaborators to share knowledge.

We need to support lower-income countries through this transition quickly. Or, better yet, skip stages 2 and 3 completely. We have the tools to do this. The question is whether we are motivated enough to use them.

How much of the Amazon have we lost, and are we losing it at record rates?

The Amazon rainforest is 14% of the world's total forest, but takes up a much bigger share of the global conversation. People look at what's happening in the Amazon and extrapolate from it.

But with so many news headlines reporting on it, it's hard to get a real perspective on what's going on. How much of the Amazon has been cut down? How much do we have left? And are deforestation rates really at an all-time high?

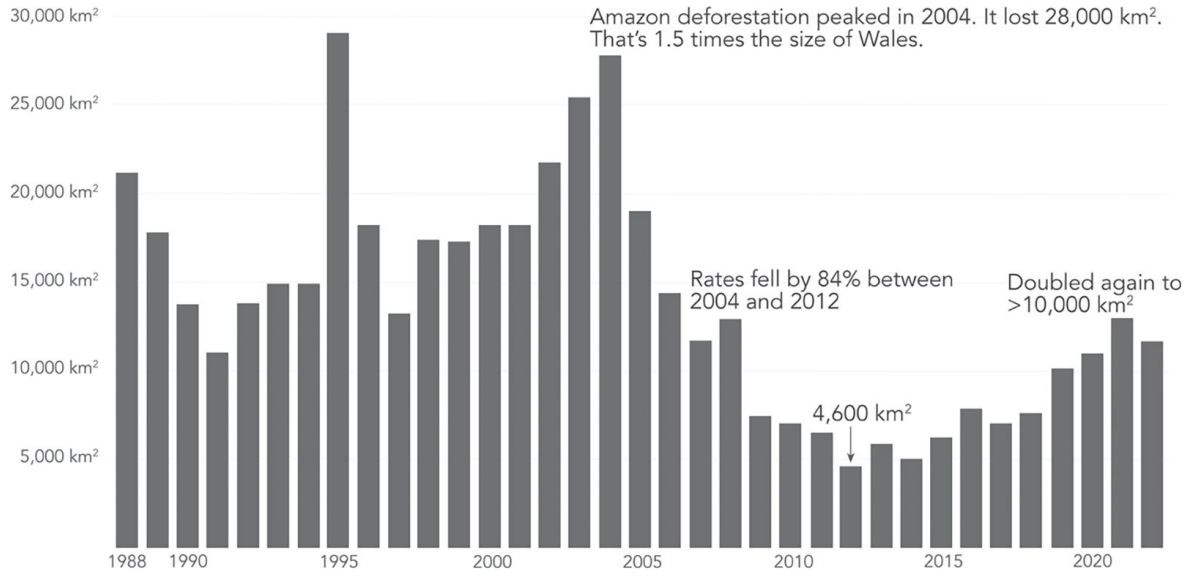
The Amazon basin spans 7 million square kilometres (km^2) – an area the size of Australia. The actual rainforest is 5.5 million km^2 – an area 23 times the size of the UK. Around 60% of it is in Brazil, with the rest split across other South American countries.

Most deforestation has occurred in Brazil, the majority in the last three decades of the 20th century, so we can use 1970 as the starting point of when deforestation really kicked in. Pre-1970, the Brazilian Amazon spanned 4.1 million km^2; today, that stands at 3.3 million km^2. This means we've lost around 20% of the Brazilian Amazon.

Deforestation rates have been a bit lower in neighbouring countries, so we've lost around 11% of the Amazon as a whole.[24]

Now, to the question of how much of it we're still losing. While *global* deforestation rates peaked in the 1980s, in the Amazon these rates continued to climb in the 1990s and early 2000s, in fact doubling from 15,000 km^2 a year to almost 30,000 km^2 in just a decade. When Lula da Silva became president of Brazil in 2003, he vowed to turn things around. And he did. By the end of his term in 2010, he had reduced deforestation rates by 80%, from 25,000 to 5,000 km^2. In the years since then, rates stabilised then began to climb again, although nowhere close to where they were at the start of the 21st century.

Today, deforestation rates in the Amazon are less than half what they were in the early 2000s. But still more than double what they were at their lowest point. This makes a few things clear. First, we have passed the peak of Amazon deforestation. Headlines about all-time highs are wrong. Despite an uptick in rates over the last few years, much less of the Amazon was cut down than in the past. Second, progress can happen quickly. Brazil managed to slash deforestation by 80% in just seven years under Lula da Silva's presidency. In October 2022, he was re-elected as the Brazilian leader. That should give us hope. Anyone who says it's impossible to end deforestation by 2030 has not seen how quickly things can change. Third, this won't happen on its own, and if we get complacent we will see things just as quickly slipping back to where they were.



Deforestation in the Brazilian Amazon peaked in the early 2000s

Deforestation rates are measured in square kilometres (km^2).

What are the drivers of deforestation?

'Ben & Jerry's does not produce any ice cream that contains palm oil,' says a banner at the top of the ice-cream company's website.[25]

In 2017 it got rid of the last few delicious chunks that still contained the stuff. It was lauded for its commitment to sustainability. Customers who had boycotted the brand filled their freezers with cookie dough again. A PR stunt or not, it's obvious why they'd want to declare themselves palm oil-free. Everyone hates palm oil. It has become the poison of the food industry.

A few years ago I also really hated palm oil. It was 2018 and time for the Great British Christmas TV ad competition to start. Which of the big brands would bring the nation to tears and win? Well, that year, Iceland's[fn1] advert was produced by Greenpeace. In the cartoon ad, a young girl has an orangutan swinging around her bedroom. It's causing havoc, throwing her chocolate away, and crying at her shampoo. 'There's a rangtan in my bedroom, and I don't want her to stay. So I told the naughty rangtan that she had to go away,' narrates the actress Emma Thompson.

The scene then cuts to the rainforest. 'There's a human in my forest, and I don't know what to do. You destroyed all of our trees for your food and your shampoo … He took away my mother, and I'm scared he'll take me too. There are humans in my forest, and I don't know what to do. They're burning it for palm oil, so I thought I'd stay with you,' she says to the little girl. Iceland then announces at the end of the video that it's removing palm oil from all of its own-brand products.

The advert never actually made it to our television screens. Regulators banned it for being too political. Perfect. Just what Iceland needed for it to go viral online. What sparks more outrage than a *banned* political ad? I was furious.

I held this position for several years. When people asked me for recommendations on living sustainably, eliminating palm oil was one of my top tips. I cheered on the Ben & Jerry's of the world.

Then, in my role at Our World in Data, the time came to tackle our big project on deforestation. The idea was to complete the full global picture: how much forest has been cut down, from where, what's driving deforestation, and what can we do about it. I knew palm oil was going to be a big deal. I wondered if the modern story of deforestation might even be built around it. I started digging into the research.

I read countless scientific papers and policy documents. I thought the message from the experts would be clear: palm oil is a leading driver of deforestation, and we have to stop it in its tracks. I expected recommendations of a boycott. There were none. In fact, the advice was that boycotting palm oil was a terrible idea. Do that, and we'll make tropical deforestation worse not better.

The more I read, the more humbled I became. I had got this wrong. Palm oil, deforestation and food are complicated problems, and I had been won over by simplistic messages that played on my emotions. When faced with such a problem, it's tempting to look for a villain: 'You're the problem, so once we get rid of you, everything will be fixed.' Palm oil fitted the role perfectly.

Let's return to the emotive, complex topic of palm oil. Are orangutans really losing their forest at the mercy of palm oil? Was the Iceland advert right? Yes and no.

Indonesia and Malaysia produce around 85% of the world's palm oil. It's undeniable that both countries have cut down forests to make space for their palm plantations. What's less clear is *how much*. The International Union for Conservation of Nature (IUCN) set up a task force to assess the environmental and biodiversity impacts of palm oil, and what we could do about them.[26] Their estimates for how much global tree loss was driven by palm oil ranged from 0.2% to 2%. When we look at how much of the world's primary forests – which are the old, diverse forests that haven't been cut down in recent times – it's in the range of 6% to 10%.

That's a lot of forest – a lot of orangutan homes – chopped down. But, at a global level, palm oil has not been significantly worse than many other drivers. What about Indonesia and Malaysia specifically? Palm oil was the biggest driver of deforestation in Indonesia in the first decade of the twenty-first century, responsible for one-quarter of it.[27] But its contribution has been shrinking, and in the last few years it has actually been one of the smallest drivers.

What makes it difficult to put a concrete number on palm oil deforestation is that it depends on whether you only consider palm plantations that immediately replaced existing forest, or whether you include plantations that replaced forests that had already been logged for wood and paper. In a paper in *Nature*, researchers used satellite imagery to assess what types of land palm oil plantations had replaced in the Borneo region of Indonesia and Malaysia.[28] They found that three-quarters of the oil plantations were grown on land that had been forested in the 1970s. But three-quarters of post-1973 oil plantations were grown on land where the forest had already been chopped down for the paper and pulp industry. Only a quarter of the oil plantations replaced forested virgin land.

So we don't quite know how much deforestation has been driven by palm oil. Definitely some. Much less than other products such as beef. Nonetheless, it has been responsible for the tragic loss of forests and we should do something about it. Our gut reaction is often to just cut out a product completely. That's what Ben & Jerry's did. Most consumers want brands to follow this lead. But it wouldn't solve the problem. In fact, it might make it worse. Cut out palm oil and you'll replace it with another oil. Most of the alternatives are no better.

Before we get into the *environmental* sustainability of foods like palm oil, I should address some concerns about their health impacts. There has been a recent backlash against 'seed oils', which is an umbrella term for refined vegetable oils such as soybean, canola, corn, sunflower, rapeseed and palm oil. Critics have argued that these oils are bad for our health, contributing to diabetes, heart disease and other illnesses. They say we should be eating alternatives such as coconut, avocado or olive oil instead.

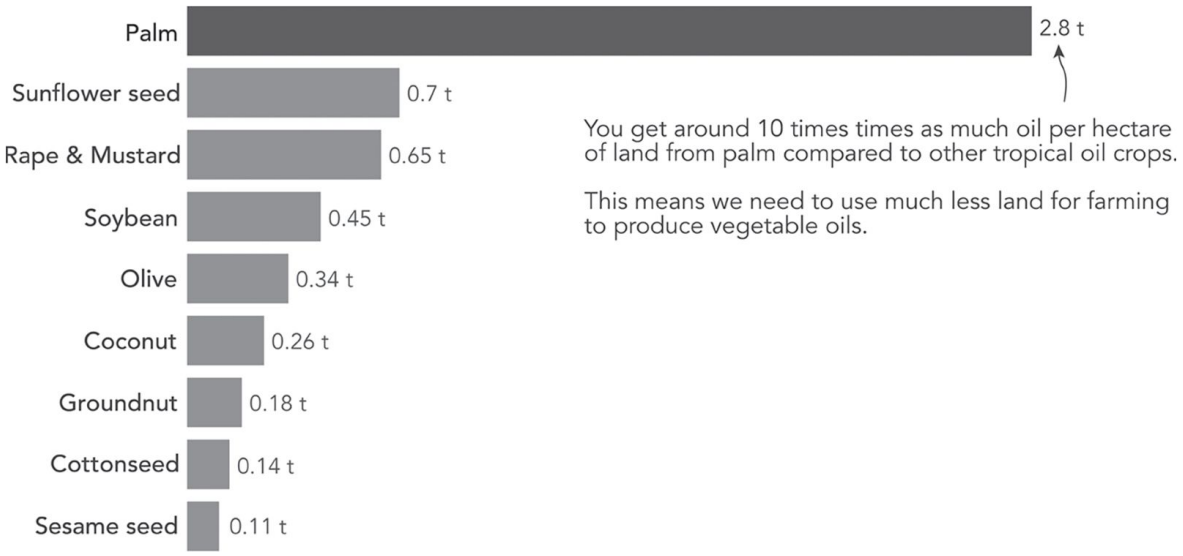
I've seen no credible evidence to support this. The basic argument for why seed oils are bad is that they contain a lot of omega-6s, which people argue are linked to inflammation.[fn2] But many studies point to the opposite: that higher consumption of

omega-6s is associated with a *lower* risk of disease. Researchers at Harvard University have loudly pushed against this backlash.[29] A meta-analysis covering 30 studies found that omega-6s *lowered* the risk of heart disease: those with more in their bloodstream were 7% less likely to develop it.[30] Another study followed around 2,500 men for an average of 22 years, and found that those with the highest blood levels of omega-6s had a much lower risk of dying from any disease. Studies show that they lower cholesterol and blood sugar.[31] And the American Heart Foundation found that getting 5% to 10% of your calories from omega-6s reduces your risk of heart disease.[32] That's not to say we should eat seed oils in excess. Or that alternatives, such as olive oil, do not also have massive health benefits. But I'm not concerned about eating seed oils for health reasons.

Now, back to the environmental credentials. Palm oil is an insanely productive plant. It's why it has been so successful. It gets incredibly high yields – much higher than any of the other options. One hectare of palm currently gives us 2.8 tonnes of oil in return. Olives give us 0.3 tonnes. Coconuts give us 0.26 tonnes – that's 10 times less. Groundnuts, just 0.18 tonnes.[fn3]

Think about what that means. If we were to boycott palm oil and replace it with one of these alternatives, we would need far more farmland. If every company were to follow Ben & Jerry's lead and use coconut and soybean oil instead of palm, we would need about 5 to 10 times as much land devoted to oil crops. Where is that land going to come from? Coconut is a tropical crop. It's going to come at the expense of tropical habitats. That doesn't sound like the sustainability solution to me. It would be a disaster.

Here's another thought experiment to drill this point home: let's consider how much land the world would need to produce all its vegetable oils from any one of these options. We currently use 322 million hectares to grow oil crops. That's an area the size of India. If we were to get all of it from palm oil we'd need just 77 million hectares – four times less. We'd free up a lot of land. On the other hand, if we got it all from soybean oil, we'd need *more* land: 490 million hectares. From olive oil we'd need twice as much land as we currently use – around 660 million hectares. Two Indias. Again, we might be able to use a bit less land if *all* of these crops went to oil production, but we'd still need *much* more land than if we used palm oil.



Palm oil is much more productive than other oil crops
The amount of vegetable oil we get from one hectare of land.

In a large-scale consumer survey in the UK, palm oil was deemed to be the least environmentally friendly of the vegetable oils.[33] Forty-one per cent of people thought palm oil was 'environmentally unfriendly', compared to 15% for soybean oil, 9% for rapeseed, 5% for sunflower and 2% for olive oil. And yet, for all of its flaws, palm oil has actually been a 'land sparing' crop, at least in a world that demands lots of vegetable oil. It gets a bad reputation, but it is surely the best of a bad bunch.

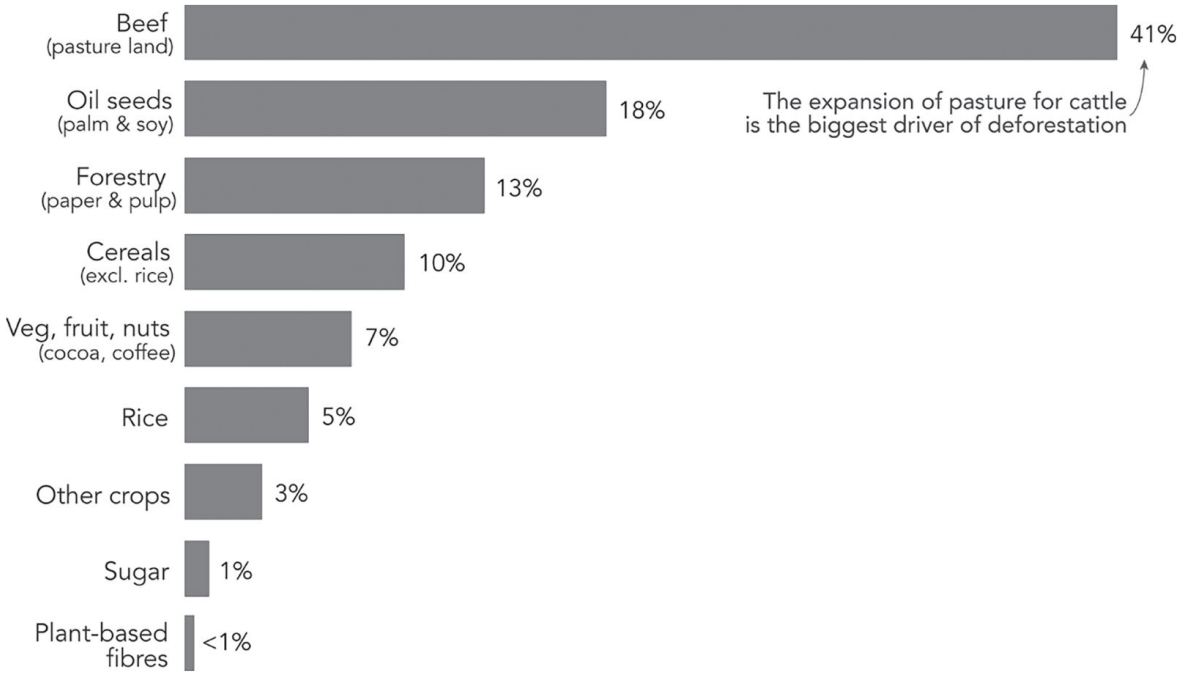
Deforestation is almost entirely about farming: around three-quarters of it is driven by the conversion of primary forests for agriculture or plantations for the paper and pulp industries. The single biggest driver, by far, is beef.[34] Forest clearance to make room for cows to graze on is responsible for more than 40% of global deforestation.[35] South America is home to most of this destruction. In fact, Brazilian beef production alone is responsible for one-quarter of global deforestation.

The next largest category is oil crops. This spans a wide range of crops, but is dominated by two: soybeans and palm oil. However, deforestation rates for both have been falling rapidly over the last decade, which might be a sign that some of the world's policies are making a difference.[36, 37]

The expansion of paper and pulp industries is another key driver of tropical deforestation. Tree plantations have expanded rapidly, particularly in Asia and South America. In the UK we plant lots of trees to then cut down to harvest wood or make paper. These trees are often planted on non-forested land – or, rather, land that was forest centuries ago but hasn't been for some time. These plantations are sustainable in some sense. They suck carbon out of the atmosphere when they grow, lose some when they are cut down, but suck it out again when they are replanted. This isn't the same in Indonesia, where *old, primary rainforests* are cut down to make space for plantations,

releasing a lot more carbon and destroying ecosystems that had built up over centuries or more.

Finally, straggling at the back, we have a range of different crops. Crops like cereals, coffee, cocoa and rubber. Many of these – such as maize or wheat – are staples that countries rely on to feed themselves. The challenge that many lower-income countries face – especially across sub-Saharan Africa – is that their crop yields are very low. That's why improving crop yields is so important for the planet, and people too.



What are the drivers of tropical deforestation?
Most of global deforestation happens in the tropics.
Shown are the drivers of the conversion of primary forest over the period from 2005 to 2013.

How much deforestation is caused by trade?

If rich countries are regrowing their forests, and low- and middle-income countries are cutting theirs down, are the wealthy off the hook? Not so fast. Deforestation isn't only about our domestic forests. Countries are also guilty when they import food from poorer countries.

This is similar to the concept of 'offshoring emissions' from the last chapter. Studies have looked at how much deforestation could be attributed to the foods a country imports.[38] This analysis is difficult to do without closely tracking foods throughout the supply chain (which companies should be doing much more of). But the data we do have is surprising. It suggests that most of the world's deforestation is driven by demand in domestic markets. Around 71% of it. Beef – again – is the biggest culprit here since it's often consumed close to home. Much more soy, palm, cocoa and coffee are consumed internationally. Overall, just under one-third (29%) of deforestation happens

for the production of goods that are then traded. I was taken aback by this finding: I had thought global trade would contribute more.

It's not just rich countries that import foods, but they are responsible for around 40% of traded deforestation. If we then do the sums, rich countries are responsible for 12% of the world's current deforestation through the products they buy.[fn4]

Rich consumers changing their buying habits will certainly help, but it's not going to *end* global deforestation. This goes against the message that is often portrayed in the media. 'If rich countries would just produce their food locally, this wouldn't be a problem.' If only it were that simple.

How to end global deforestation

Zero-deforestation policies, not boycotts

Ben & Jerry's is not alone in its boycott of palm oil. Many other companies, and consumers, are doing the same. But the message from experts is clear: cutting it out completely would be a big mistake. As seen earlier, if we were to replace palm oil with another oil, we would need to use much more land and potentially risk even more deforestation. But we shouldn't accept that deforestation for palm oil is inevitable. We can use the benefits of its high productivity while protecting the orangutans' forests at the same time. Boycotts won't get us there. What can we do instead?

The biggest recommendation from experts is to make sure that we're buying palm oil that is certified as sustainable, even if that means buying it at a slight premium. The most well known certification scheme is the Roundtable on Sustainable Palm Oil (RSPO). Certified suppliers conduct impact assessments, manage and protect high-value areas of biodiversity, don't clear primary forest, and avoid land clearance through fires. Suppliers can only be certified if their plantations have not replaced primary forest or areas rich in biodiversity.

Studies have shown that the RSPO scheme has been successful in reducing deforestation in Indonesia.[39] But to stamp it out completely, we still have far to go. Just 19% of palm oil production is covered by the RSPO. To have a real, permanent impact, certification needs to cover a much larger number of growers. That's why consumers – that is, you and I – need to demand sustainable palm oil. It puts pressure on food and cosmetic companies. It rewards the most sustainable growers and incentivises others to change their practices and get certified too. But our pressure doesn't stop there. While RSPO standards are obviously better than no standards, they're not perfect. There have been various examples of laxity from the RSPO, so if we want to stamp out deforestation completely, we not only need to get all of our crops covered by these certifications, we need to make the rules tougher too.

Palm oil can be a good choice for many of the food products we buy. But there are a few areas where we should just cut it out. It's used in industrial applications from

shampoos to cosmetics, and substituting there to synthetic oils – oils produced in the lab – could give us what we need with a much lower impact.

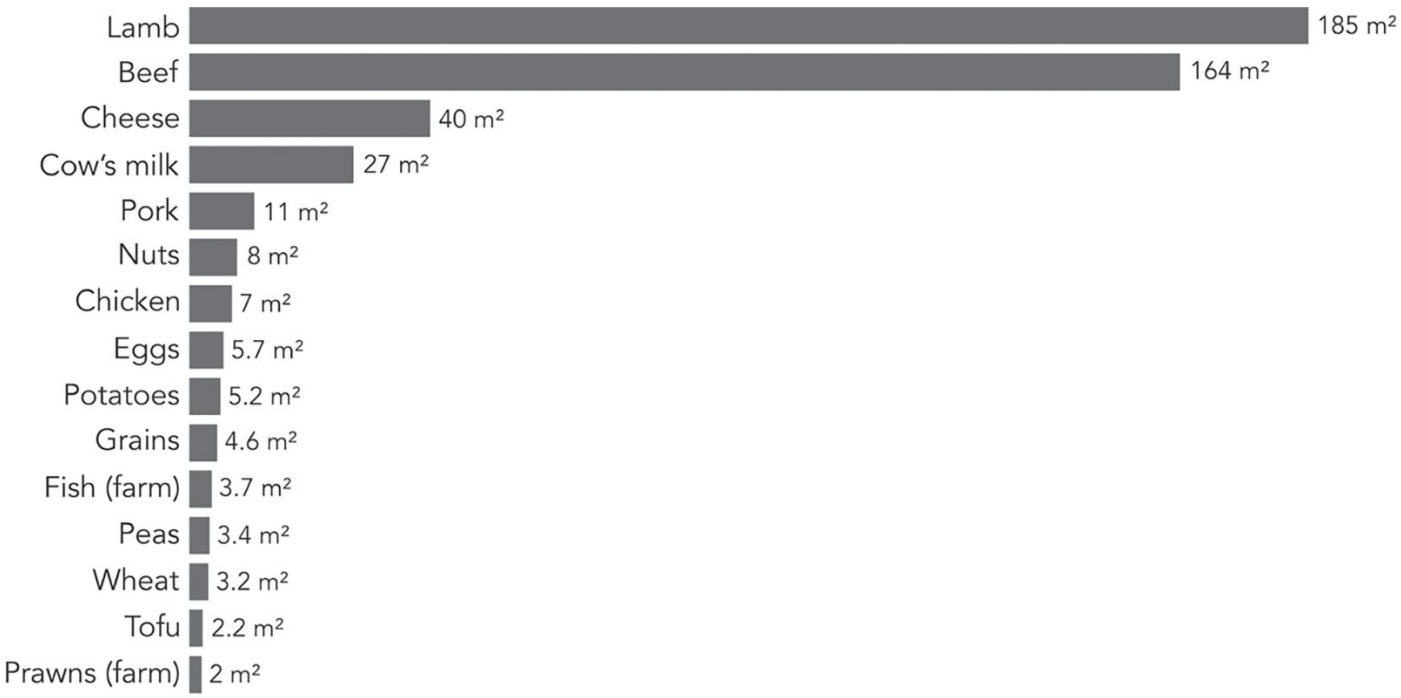
Palm oil is also used in biofuels for transport. Here, we should absolutely stamp it out. Globally, we only put small amounts of palm oil into bioenergy. Just 5% of production. But for some countries – often the richest ones – bioenergy is a big user of palm oil. Germany is one example: 41% of its palm imports go to bioenergy. That's more than it imports for food products. This is incredibly stupid, and terrible for the environment. To be clear: Germany imports palm oil from an area at high risk of tropical deforestation to put it into *cars*. What's even more insulting is that it then counts this towards its 'renewable energy' target. In reality, biodiesel from palm oil results in more carbon emissions than petrol or diesel.[40] Here, a boycott is certainly justified.

Finally, and perhaps most simply, we could eat less oil overall: that would not only reduce our demand for palm oil but would stop us moving to more land-hungry alternatives.

Eat less meat – especially beef

The bad news if you're a cheeseburger fan is that beef gets some very bad press throughout this book. That's because its impacts are so large and cut across so many connected problems. Beef is the largest driver of global deforestation. The most obvious way to reduce deforestation, then, is to eat less of it.

Raising cattle is a very resource-intensive way to make food. Cows need a lot of food, water, emit a lot of greenhouse gases and need a lot of land. When it comes to how much land is needed to produce a kilogram of food, beef and lamb are miles ahead of any other food. The same is true when we compare foods based on grams of protein, or calories. To produce 100 grams of protein from beef, we need 164 square metres (m^2) of farmland. That's a lot more than other meats. Pork takes just 11 m^2 – fifteen times less. Poultry is just 7 m^2. And beef needs nearly 100 times more land than plant-based proteins, such as tofu or beans.



Land use per 100 grams of protein

When I tell people that eating less meat will reduce deforestation, two counter-arguments always come up. The first is that around two-thirds of the land that cows graze on is not suitable for growing crops. So, they say, it's better to use that land for livestock than to try to use it for growing crops. But that's not our only option: we could just leave that land to be forest, grassland or other wilderness.

Globally, we don't need it for food production. As the next chapter will show, by eating less meat the world would actually need *less* cropland than we currently use today. We feed lots of our crops to animals, and by reducing our meat consumption we could use this land to grow crops for humans instead, and we could leave more land to nature.

The second counter-argument is that not all beef is created equal. Lots of people argue that *their* locally sourced beef is much better than the average because it comes from cows raised on large open pastures. It's certainly true: some beef needs much more land than the global average, and some much less. Beef produced in South America, for example, needs *lots* of land.[41, 42] This is terrible news when that land has to be taken from the Amazon rainforest. But the best choice for the climate is often the opposite of what people imagine: cows raised on grassland alone (rather than grasses plus grain) need two to three times the amount of land as the global average. That comes at a climate cost.

What we have, then, are multiple dangers stacked on top of each other. Beef needs lots of land. Cows feeding on grass need *even more* land than those raised on grains and crops. The grazing cows that are raised at the lowest density on expansive grasslands are those in regions that are at high risk of deforestation.

There are three solutions to these arguments. First, we can all try to eat less beef. That is the change that would have the biggest impact. It seems possible that people could cut back a bit, but we're not going to all stop eating beef completely, any time soon. So we need some solutions for the beef that we do still eat.

That brings us to our second solution, which will be unpopular with many: switching to grain-fed rather than grass-fed beef. It needs much less land, which is what we're concerned about when it comes to deforestation.[43] One important conflict that comes up here – and will come up later when we think about other types of meat – is that the goals of animal welfare and environmental impact are not always aligned. Unfortunately, the environmentally friendly or 'efficient' choice is often one that is worse for the animal. How you balance these priorities is up to you.

The third solution is to optimise for beef production in the regions that can do it most efficiently. The 'worst' (where we're defining 'worst' as those that use the most land) 25% of beef producers use up 60% of the total land that is used for beef production. If globally we were able to reduce the amount of beef we eat by 25%, and eliminate this from the 'worst' beef producers, land use for beef production would be cut by a whopping 60%.

When it comes to solutions, we're often presented with extremes. We're told that we all need to go vegan overnight. Or we need to cut out every single food – meat, soy, palm oil, avocados – until there's nothing left. But if we need to pick the truly effective ones, the changes needed are often not as dramatic as we think.

Improve crop yields – especially across sub-Saharan Africa

One of the world's biggest weapons against deforestation over the last century has been a big increase in crop yields. If we can grow more food from a given plot of land, we don't need to cut down forests. This has been a huge success story across Europe, the Americas and Asia. But one region has lagged behind: sub-Saharan Africa.

It's not that crop yields haven't increased there at all. But they haven't kept up with the rest of the world. Let's see how it compares with South Asia. Both regions have increased cereal production since 1980. But they achieved this increase in completely different ways: Africa through using more land, Asia through increasing yields. South Asia uses the same amount of land for cereal production as it did in 1980, but its yields have increased by nearly 150% from just 1.4 tonnes to 3.4 tonnes per hectare. In Africa, yield improvements have been small – they've increased by just 30% (rising from 1.1. to 1.5 tonnes per hectare). To make up for these poor yields it has to use a lot more farmland. Land use for cereals has more than doubled. This extra farmland has to come from somewhere, and it's often from existing forests.

If we look at the decades ahead, population and economic growth means sub-Saharan Africa will have to grow a lot more food. If it can't produce this food through higher crop yields, it will have to cut down more of its beautiful forests which are teeming

with biodiversity. Of course, it doesn't have to be this way. Studies show that if countries across sub-Saharan Africa can close their yield gaps, they can produce much more food without more farmland at all.[44]

The next chapter will look at how countries – not just across sub-Saharan Africa, but everywhere in the world – can do this.

Rich countries should pay poorer countries to keep their forests standing

Centuries ago, when my ancestors in the UK were cutting down the forests, there was no such thing as a 'carbon budget' or an 'emissions target'. Few cared that the populations of wolves or deer might decline. There were no international conferences where leaders wagged their fingers at each other about not doing enough for the planet. If you wanted to cut trees down, you just went ahead and did it.

Rich countries got wealthy from this guilt-free destruction. They freed up land to grow food, they could provide energy from wood, and they could build naval boats, weapons and infrastructure to colonise the rest of the world. It's similar to the story of fossil fuels. Rich countries burned coal freely throughout the 19th and early 20th centuries, generating huge wealth in the process. Low- and middle-income countries have tried to replicate what rich countries did centuries ago, but they are shamed for doing so – we tell them that they have to stop, that they can't keep doing this if the world is to reach its climate targets.

It's an unfair and cruel position to be in. We can pretend that there is no cost to developing countries, but that's a lie. Renewable energy is becoming much cheaper and hopefully, soon, there will be little trade-off between gaining access to energy and keeping fossil fuels in the ground. But for deforestation, the cost is still there. If a farmer opts to leave a forest standing, they are forgoing money and food. There are long-term benefits to countries keeping their forests – they provide important ecological services – but in the short term, there is a clear opportunity cost to stopping deforestation. This is an opportunity cost that my ancestors never had to contend with.

There is a strong case for paying countries to stop deforestation. At the very least, these countries should receive some form of compensation for the money they will pass up. It's a controversial proposal. How much should countries be paid? Who should get this money? How would we know that countries were actually keeping their promises?

Some of these questions are easier to answer than others. We know when a forest has been cut down, and how much of it. Working with local organisations, we can often track down who was responsible. Coming up with a system to verify the compensation due seems doable. One way is to calculate the opportunity cost of a given hectare of forest. Patterns of crop production are quite predictable. Some regions grow soy, others grow maize, and others grow bananas. We can make assumptions about what would be grown on that hectare of forest, and calculate how much money those bananas or soy would get in the market.

The trickier question is agreeing on *how much* countries really would have cut down without the compensation scheme, as there are strong incentives to exaggerate deforestation plans. Looking at previous deforestation patterns would help here. If a country has been cutting down forests at a steady rate of 1 million hectares per year and suddenly claims they would cut down 10 million hectares, we can be pretty sure they're trying to pull a fast one.

There are some smaller programmes that have already had some success with compensation schemes. The most well known – the REDD+ scheme – was set up by the UN Framework for Climate Change. It has achieved some transfer of payments from rich countries to poorer ones, and has shown that these transfers can be successful in reducing deforestation and carbon emissions.[45] However, most of the funding has been provided by only a handful of countries – Norway has led the way, followed by the US, Germany, the UK and Japan.[46] And this funding has been nothing on the scale that is needed to bring tropical deforestation to an end.

The obvious question here is: what's in it for rich countries? Well, for a start, it seems like a no-brainer if leaders care about climate change and biodiversity as much as they claim to do in conference speeches. If they think that bringing global deforestation to an end is one of our most pressing challenges, supporting these efforts would be the obvious thing to do. And to go beyond the ethical case to the economic one: halting deforestation is actually a relatively cheap way of stopping carbon emissions. It's much less expensive (and easier) than stopping people's beef consumption, or decarbonising air travel.

This doesn't just have to be about one country supporting another. Companies and the private sector can get involved too. Many already pay in some way to *offset* their emissions through tree planting. Paying to prevent deforestation in the first place would have an even greater impact. If we want to spend our dollars in a way that maximises positive climate and biodiversity impacts, then stopping deforestation is a good bet.

Things to stress less about

Cities and urban areas have a small impact

Many people imagine that the rise of cities has come at the cost of the world's forests. These concrete jungles seem at odds with their green cousins. Perhaps a move away from urban to rural areas – a dismantling of these dense hubs – would help?

It's a romantic idea, but it couldn't be further from the truth. Our cities and urban areas take up just 1% of the world's habitable land. Agriculture takes up 50%. Our biggest footprint on the world's land is not the space that we ourselves take up, and build our houses on; it's the land that's used to grow our food. This is the biggest driver of deforestation, not the rise of urbanisation.

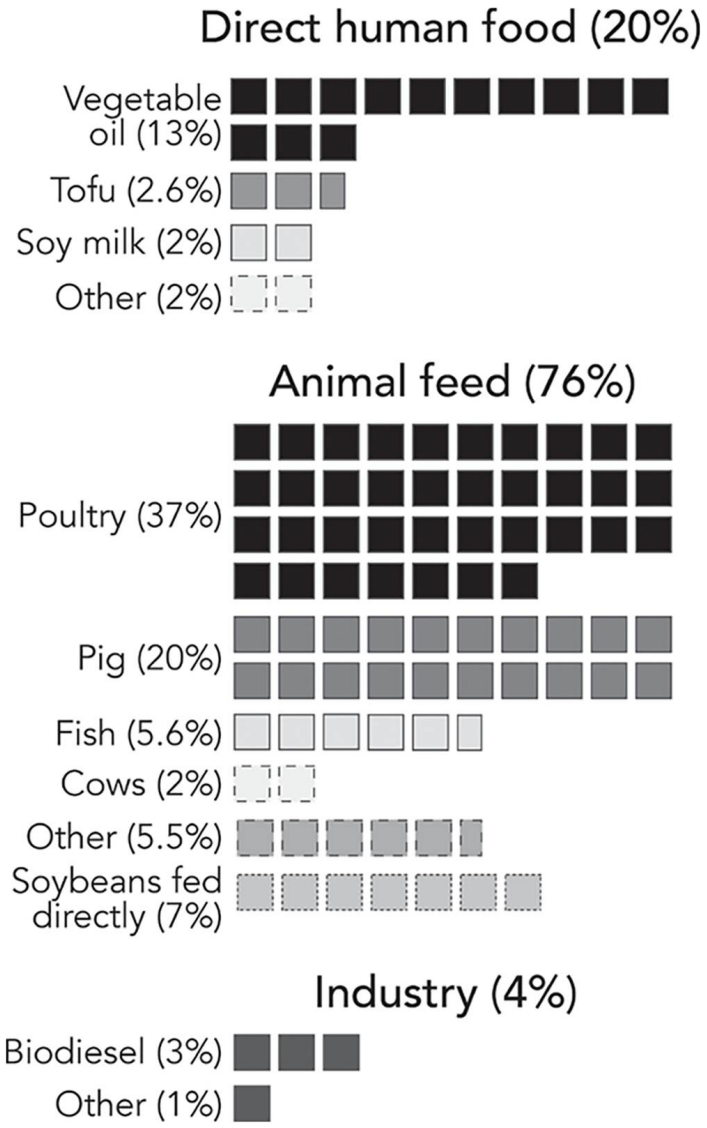
In fact, the migration of people from rural areas to cities has mostly been *good* for protecting our forests. There are still indigenous populations that play a vital role in protecting local forests and ecosystems. They live and maintain a balance in these environments. But this only works at a very small scale. For large populations, the migration to cities and intensification of farming has freed up land for forests to return. Billions of us taking up rural living would be a disaster for the world's forests.

Your tofu, soy milk and veggie burgers are not driving deforestation

A lot of soy is grown in Brazil. Brazil is home to the Amazon. The Amazon is being cut down. Join the dots and we quickly reach the conclusion that our tofu, soy milk and veggie burgers are killing the rainforests. People are faced with a dilemma. They want to eat less meat and dairy, but they fear that the replacements are just as bad. This isn't true.

Brazil produces around one-third of the world's soy. Argentina produces another 11%. In the past – particularly in the 1990s and early 2000s – soy was responsible for deforestation, both directly and indirectly. But it isn't your tofu or soy milk that's driving this. Around three-quarters of the world's soy is used for animal feed: to raise chickens and pigs mostly, but also some cows and fish too.[47] One-fifth goes directly to human food, and most of that is for vegetable oil. Just 7% goes to the classic 'vegan' products such as tofu, tempeh and plant-based milks. This is particularly true for soy grown in Brazil. Nearly all of its soy – 97% – uses genetically modified (GM) varieties, which are more likely to be used for animal feed than human consumption. In fact, GM soy is not allowed for direct human consumption in some markets, such as the European Union.

It's very unlikely that your tofu is killing the Amazon. Switching from meat and dairy to these alternative products is much more likely to save the forest than destroy it.



Three-quarters of the world's soy is fed to livestock
We often associate soy with meat-substitute products, but only a small fraction is used directly for human food.

5

Food

How not to eat the planet

‘Only 60 Years of Farming Left If Soil Degradation Continues’

– *Scientific American*, 2014[1]

One of the most frightening claims about our environmental mess is that the world has only got ‘60 harvests left’, because the world’s soils are degrading so quickly that they’ll be useless by the year 2074. If true, this statistic is so grim that it makes almost everything else in this book meaningless. If that’s not scary enough, in 2017, Michael Gove, the UK’s environment secretary, warned that the UK had only *30* harvests left.

Google ‘harvests left’ and you’ll find hundreds of thousands of results. These claims have made front-page news in the *Independent* and the *Guardian* several times, and they’ve been repeated by leading environmental campaigners. The figure they report is sometimes as little as 30 years and other times it’s a ‘generous’ 100 years. One thing the claims do have in common is that they are nonsense.

The ‘60 harvests left’ headline seems to have been made by someone at a farming conference held by the UN’s Food and Agriculture Organization in 2014. How did they come to the figure of 60? No one knows. The FAO has never provided anything to back this up, and the person who made the statement has never come forward to defend it. All in all, it sounds like they made it up.

What about the other predictions? The ‘100 harvests left’ figure apparently came from a 2014 study which compared the amount of organic matter in garden allotments in Leicester with surrounding farmland.[2] First, I’m not sure how a single study of a garden allotment in England tells us much about the state of the entire world’s soils. Or even of the UK’s soils. Second, and more worryingly, the study didn’t mention anything about the ‘number of harvests left’. It certainly didn’t mention the number 100. The botanist James Wong tried – and failed – to track this source down.[3] I also tried, and found

nothing. Again, the number appears to have been made up. As for Michael Gove's '30 year' claim: who knows.

The specific number doesn't actually matter, because *there is no number*. Ask a soil scientist how many harvests the world has left, and they will laugh. The concept has no scientific meaning. The world's soils are so diverse and heterogeneous: some are degrading, some are improving, and many are stable as they are. The idea that there is a deadline by which the world's soils will just die – apparently all at the same time – is bonkers.

When soil scientists looked at the 'lifespan' of soils across the world, they found that they spanned five orders of magnitude.[4, 5] A thinning soil is bad; a thickening soil is good. Some soils were thinning quickly and could be in trouble within the next 100 years. Some were still depleting but had a 'lifespan' of thousands or tens of thousands of years. And others were not degrading at all: they were thickening.

It's not that soil loss isn't a problem. It really is. We need to find ways of farming that rebuild soils rather than depleting them. But the idea that we only have 30, 60 or 100 harvests left is just wrong. These zombie statistics are frustrating but they do have one silver lining: they are a great way of knowing which campaigners and reporters are more interested in a headline than the truth. It's a red flag for someone to make such a big claim without bothering to check if there is anything to it.

Similar headlines on global hunger might make you think that we are always just on the brink of running out of food. But step back to look at the data and you'll see that, again, this is just wrong.

'Today we're going to talk about how to feed everyone without wrecking the planet at the same time.' The audience went quiet, which I was grateful for. I was just 21 years old and giving my first lecture to a room of undergraduates at the University of Edinburgh. I was bricking it. I had just two goals for the lecture: keep as many people awake as possible, and have them leave with something they didn't know before.

'The average person needs around 2,000 to 2,500 calories a day. If we were to split the world's food production equally among everyone, how many calories would the average person get?'

If you want to have a shot now, take a guess.

'Put your hand up if you think we could all have at least 1,000 calories.' Everyone put their hand up. Phew. They were willing to play along.

'Keep your hand up if you think we could have at least 1,500 calories.' Around 10% to 20% put their hands down. The rest kept them raised.

'What about 2,000 calories?' A further 50% of the room put their hands down. Less than a third were still hanging on.

'Two and a half thousand calories?' Nearly everyone put their hands down. Less than 10% were still in the game.

‘Three thousand calories?’ Out of around 100 students, only one person was hanging on.

‘Three and a half thousand?’ The last hand went down. The game was over.

I grinned. This was my Hans Rosling moment. ‘If we split the world’s food production equally between everyone we could each have at least 5,000 calories a day. More than twice what we need. Or, to put it another way, we produce enough food for a global population twice the size that it is today.’

The room was silent. No one was asleep. I’d hit my two goals before I’d even put my slides on the screen.

I wish someone had told me that fact while I was doing my degree. I wish I had looked more closely at how food production had changed across the world. I wish I had spent more time looking for data, and less time reading the news headlines.

If I had been in the audience in that lecture theatre I would have put my hand down at 2,500 calories per day. The world could maybe *just* produce enough food for everyone, but because some people overeat, some go hungry. So, global hunger must be getting worse.

Thankfully I was wrong on that. The world has made dramatic progress in reducing hunger in recent decades. Although rates of undernourishment are still tragically high, with nearly one in 10 people in the world not getting enough calories, this figure is far lower than it was in the past. For nearly all of our history, most of our time was spent trying to hunt or produce enough food for everyone. Nutrition was often incredibly poor. Go back a few centuries and most people barely got enough to eat.

The fact that hundreds of millions still go hungry while we produce enough to feed a population twice our size is truly shocking. But knowing that the world is capable of producing so much food should give us all the means and motivation we need to fix the problem. It *is* solvable. Hunger and famine still exist today, but they’re political and social in nature. The limits to us feeding everyone are entirely self-imposed. This is a unique position in human history: until the last century our ability to feed large numbers of people well was constrained by our ability to hunt down animals, then our ability to grow more food from the limited land we had. Now it is only constrained by our choices of what to do with the food we produce.

How we got to now

The endless struggle to have enough food

The evolution not just of food *systems* but food *cultures* is so vast, so varied, so individual, that I can never do it proper justice in just one chapter of a book. But to understand where our food systems are today we need some context for how we got here.

The earliest humans – dating back millions of years, from the *erectus* to the *neanderthalensis* to *sapiens* – didn't *grow* their own food. They took from what was already there: they hunted animals and foraged for fruits, nuts and seeds. There is a common misconception that hunter-gatherers ate lots of meat and very few carbohydrates. It's the classic 'paleo' diet that many people follow today. But when we look at archaeological evidence, and the diets of indigenous tribes today, we don't find any universal 'paleo diet'.[6] It varies a lot between groups, but also across the year. During dry seasons they eat more meat; in the wetter seasons, more berries and honey.[7] In some months meat makes up more than half of their food; in others it makes up less than 5%.

We might think that these small populations lived in perfect balance with nature. Unfortunately not. As we'll see in the next chapter, slowly but surely, humans contributed to the extinction of many large mammals. What's staggering is how few humans there were at the time. The global population was in the order of millions. The total impact of our hunter-gatherer ancestors might not be comparable to ours today, but the notion that they lived in perfect balance with other species is a fantasy. Humans have always competed with other animals, first hunting them directly, impacting landscapes with fire, and later fighting them for space to grow crops.

Most of human history involves long stretches of incredibly slow, linear change. But there are a couple of key inflection points, innovations that took us on a different path entirely. Agriculture was one of them. It started around 10,000 years ago, and allowed us to develop larger societies of people, all built around a single place. Rather than going with the whims of 'nature' we could begin to shape it ourselves. The very purpose of farming is to shape the environment, it's about nurturing the soil to make the conditions just right for what you want to grow, and painstakingly getting rid of the intruders – the weeds and pests – that get in the way.

Farming wasn't easy. (It's still not easy.) In fact, it might initially have had a detrimental impact on nutrition and health. When archaeologists look at the skeletons of humans across time, they tend to find that those in early farming societies were shorter than their ancestors, and shorter than their neighbours in foraging tribes.[8] Staple crops such as cereals and tubers grow very well. They're a great source of calories and carbohydrates. But not on their own: if you're relying on these foods for the bulk of your calories then you're going to be deficient in important nutrients. The transition from a diverse diet that included meats, fruits, vegetables, seeds and other foods to one dominated by cereals probably worsened the diet for the average person. But what it did do was feed a lot more people. Human societies could grow, with enough calories to go around. The agricultural revolution was probably bad for the individual, but advantageous for the population as a whole.

Our battle with agriculture has been centred on one thing: having enough nutrients in the soil at the right time. Until a century ago our ability to grow more was limited by a key element: nitrogen. Nitrogen is the building block of life. It's the basis of proteins and is essential for the successful growth of all plants. If a soil doesn't have enough nitrogen, crops will grow poorly if they grow at all. It's the most abundant element in our atmosphere – making up 78% of it. But it's inert in the form we find in the atmosphere. That means plants can't use it: they need it to be in a reactive form where it can react with hydrogen, carbon and other important biological elements. Only a tiny fraction of the world's nitrogen is available in this reactive form that plants and animals can use to grow.

Our ancestors had three options to overcome this. *Shifting agriculturalists* moved around to find new lands that were not depleted of nitrogen. This is the 'slash-and-burn' technique. These types of shifting farming systems could support around 10 times as many people as even the most productive hunting and gathering societies. But the continuous movement of these societies was disruptive and didn't allow for the settlement of larger groups.

Sedentary – or so-called 'traditional' – agriculture took this one step further. Rather than moving around to find new nitrogen-rich spots, they stayed in one place and recycled nitrogen back into the soils. *Traditional farming* could provide for 10 times as many as shifting agriculturalists. Large societies and cultures could start to develop.

Traditional agriculturalists had two options for recycling nitrogen back into the soil. The first drew on the miracle of peas and beans. Most crops can't use nitrogen in its atmospheric form. *Legumes* are special because they can pull it out of the air and create usable nitrogen on their own. When you plant legumes you're adding nitrogen into the soil. Not so much that you have an endless supply, but enough to add a decent amount. The second option was to raise livestock and put *manure* on the fields. This was an effective way to add nutrients to the soil, but you needed tonnes of the stuff. It was hard work to gather, and a lot of the nutrients leaked into the surrounding environment rather than being taken up by the crops.

For millennia, human societies got by using these approaches. But they were still limited by nitrogen. But then, in the early 20th century, we hit another inflection point. Our deadlock with nitrogen was finally broken. Fritz Haber and Carl Bosch invented synthetic fertiliser, an innovation that changed the world beyond recognition.

Haber–Bosch: making food out of thin air

One of my favourite websites is called Science Heroes: it ranks the giants of the scientific world according to estimates of how many lives they've saved. We might imagine that someone in the medical sciences tops the list. But no: it's the agricultural scientists, Carl Bosch, Fritz Haber and Norman Borlaug. Many of us owe the fact that we are alive to them.

In the Haber–Bosch duo, Haber did the scientific tinkering, and Bosch was responsible for bringing it to scale.

Fritz Haber was born in Poland (at the time, Prussia, part of Germany) in 1868, and initially worked with his father in the chemical business.[9] After one-too-many failed experiments in the business world he was ousted to academia. There he set to work on tackling the nitrogen problem. Nitrogen exists in the atmosphere in the form of N_2: two nitrogen atoms bonded together. To get it in a form that can be used by plants, we need to turn it into ammonia (NH_3). But pulling this off was no mean feat. Most believed it couldn't be done. Fritz Haber was not deterred. The trick was getting the pressure and temperature *just right*. Nitrogen and hydrogen had to be highly pressurised and the temperature ramped up to 400–500°C. They had to be passed over beds of a catalyst, which would break down the incredibly strong triple bonds holding the nitrogen atoms together. Only then could nitrogen and hydrogen atoms bond together to give us NH_3. In 1909, Fritz Haber managed to replicate the process that peas and beans do so effortlessly. He produced ammonia from thin air.

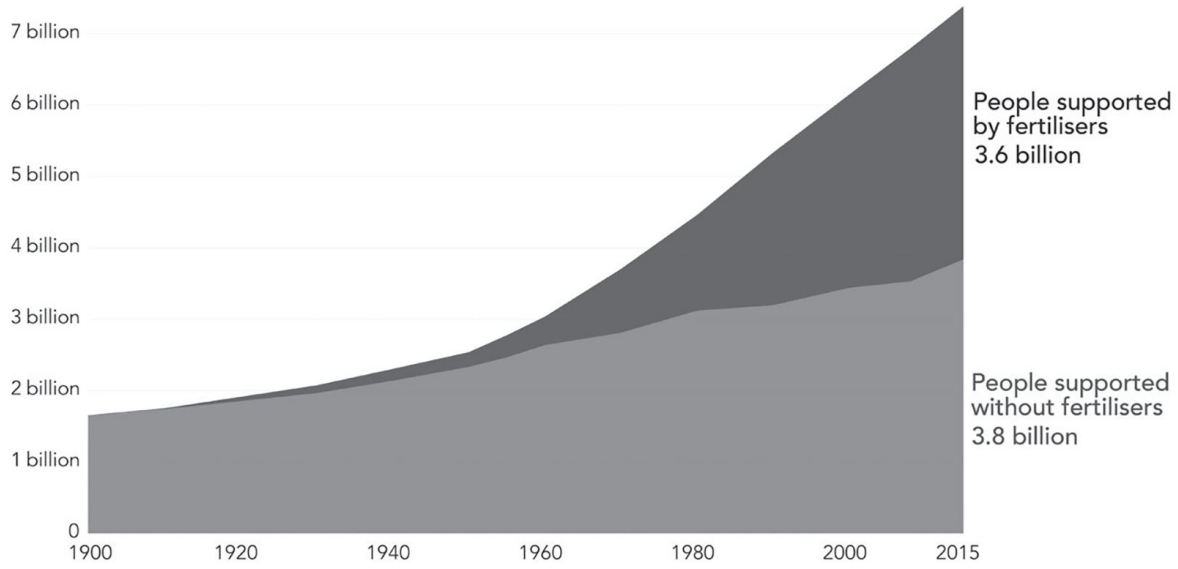
The challenge was now to scale this process. It had to move from a lab demo to something that could feed the world. The German company BASF purchased the rights and got one of their best minds on the project: Carl Bosch. It was his job to take Haber's invention and turn it into something that could sell. It took him just one year. By 1910, synthetic ammonia – from the Haber–Bosch process – was ready to be rolled out into the world.

Both scientists would eventually win the Nobel Prize in Chemistry for their work, Fritz Haber in 1918, then Carl Bosch in 1931. There is no doubt that the two men transformed the world beyond recognition, and their breakthrough changed the farming game completely. It took several decades to make it energy- and cost-efficient enough to launch into the global market, but by the middle of the century, production skyrocketed. The US market gobbled it up, and by the 1980s, it had also become an essential part of agriculture in emerging economies too.

Adding nutrients to the soil allowed crops to be more productive than they ever had before. Crop yields had been stubbornly low for millennia. Suddenly they were on the rise. Fertilisers were not the only innovation in agriculture –irrigation, improved varieties of seeds and acquired machinery such as tractors were also added – but they were critical to growing more food. Around half of the world would not be alive today without the invention of synthetic fertilisers. Several scientists have separately estimated how many people the world could support without these added nutrients, and all converge on a similar figure: around half as many.[10, 11, 12] In the tropics, the contribution of fertilisers might be even higher.

That is why conversations about whether the world should go organic or not get so messy. The reality is that the world *cannot* go organic. Too many of us rely on

fertilisers to survive. As we'll see later, many countries *can* reduce the amount of fertiliser they use without sacrificing food production, but we can't do this everywhere.



Half of the world population is reliant on synthetic fertilisers for food
Without synthetic fertilisers, the world could only support a population about half the size that it is today.

Norman Borlaug: the Green Revolutionist

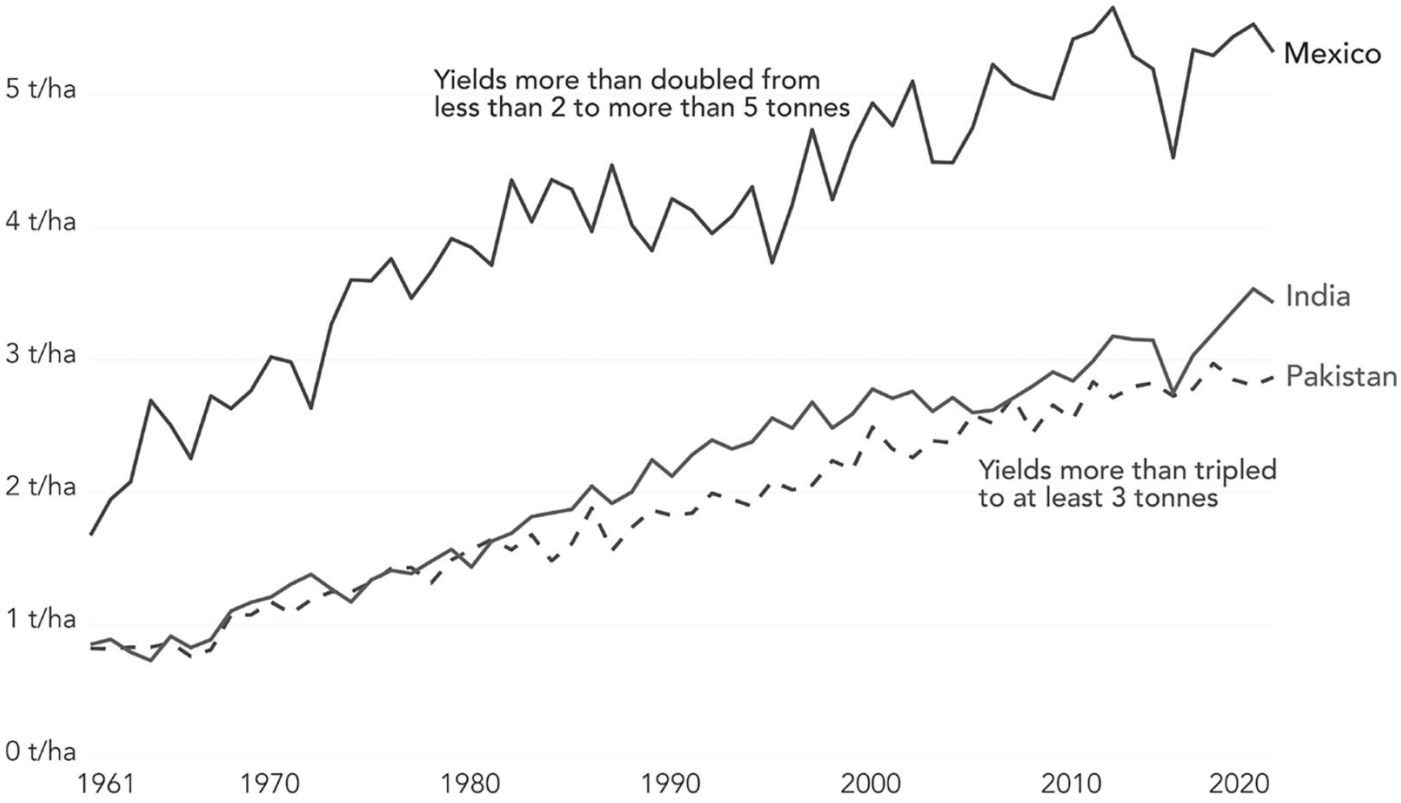
Fritz Haber and Carl Bosch were the agricultural heroes in the first half of the 20th century. Norman Borlaug gets the crown for the second half.

Borlaug was an American scientist, born in 1914, shortly after Haber and Bosch had their fertiliser breakthrough.[13] In the 1940s he was employed by the Rockefeller Foundation and sent off to Mexico to try to solve a problem that many had already given up on. Mexican farmers were struggling with the problem of 'stem rust'. Their wheat was being infected by a fungus, *Puccinia graminis*, which causes disease in the plant. It's a common, but terrible problem for cereal production. The rust makes the harvest and yield of wheat very poor: it sucks up the essential nutrients that the crop needs to grow.

Borlaug was tasked with finding a solution. He started an ambitious series of plant-breeding experiments, such as breeding the same type of wheat at different latitudes and climates, an experiment that went totally against any basic rules of botany – much to his supervisor's despair. The conditions of the programme were rough. The Mexican farmers were not particularly welcoming – they had experienced too many failed experiments of this type before. Borlaug lacked the funding and team for the ambitious project he wanted, but over the course of the next 10 years, he tried more than 6,000 cross-breedings of wheat crops. Borlaug's persistence paid off, and he made a series of breakthroughs that transformed the crops available to farmers across Mexico.

In 1960, Mexican farmers could expect a wheat yield of 1.5 tonnes per hectare. Today, with the improved varieties of wheat that Borlaug unlocked, they can get 5.5 tonnes per hectare. Crop yields more than tripled, and Mexico went from being a net importer of wheat to a net exporter. Once dependent on other countries, they could now grow more than they'd ever need to feed themselves.

Borlaug's work didn't stop there. He was soon in South Asia, where India and Pakistan experienced the same results as Mexico: stubborn crop yields suddenly skyrocketed. In 1960, they were achieving less than one tonne per hectare. Now they produced more than three tonnes. This transformative change in how crops were produced across the world was later called the 'Green Revolution', and Norman Borlaug received the Nobel Peace Prize for his work in 1970. His persistence and willingness to disregard the conventional rules is estimated to have saved the lives of over a billion people. He silenced the calls that the world would soon be on the brink of famine. His cross-breeding breakthroughs showed that even when the challenges seem insurmountable, there is often an opportunity to engineer our way out.



The Green Revolution saw wheat yields rise dramatically
Access to fertilisers, improved crop varieties and agricultural inputs led to a doubling, tripling or greater increase in yields.

The innovations of geniuses like Carl Bosch, Fritz Haber and Norman Borlaug mean we can now grow unimaginable quantities of food – production that far outstrips the amount we actually need.[fn1] Yet there's still panic about overpopulation. 'There are just too many people, that's the problem' is a claim I hear all the time. The notion that global

hunger exists because there are just too many mouths to feed is widespread, even leading to calls for depopulation.

The depopulation argument is not a new one. Throughout the 1950s, 60s and 70s, concerns about the world running out of food ran high. In 1968, the UN published a report titled 'International Action to Avert the Impending Protein Crisis'.[14] That was the same year that Paul R. Ehrlich's book *The Population Bomb* said that population growth is out of control; we will never be able to produce enough food; there will be large-scale famines; and hundreds of millions will starve to death within decades.

Of course, we now know that his predictions did not come true. That's totally fine: nearly everyone who makes predictions about the future turns out to be wrong. What makes his book so terrible are the inhumane policies he advocated for based on this strong (and wrong) conviction. World population had to be strictly managed. Humans were cancer – a reproducing organism that had to be controlled. As he put it: 'we can no longer afford merely to treat the symptoms of the cancer of population growth; the cancer itself must be cut out'.

In the US and other rich countries, he discusses the option of adding temporary sterilants to the water or food supply.[fn2] Rather than providing financial support to families, 'responsibility prizes' could be handed out to couples who reached five years of childless marriage, or men who accepted irreversible sterilisation. Another idea was to have special lotteries where tickets were only handed out to the childless.

That's nauseating. But it's nothing compared to his suggestions for 'underdeveloped countries'. Not only did he suggest sterilisation programmes, but he also proposed a 'triaged' system of who should be left to starve to death. Some countries could be redeemable – they might be able to dig their way out of it. But some countries were a lost cause. Rich countries should withdraw any food aid and support, and just leave them to die. It's not clear how committed Paul R. Ehrlich really was to these ideas. But many – including senior officials in the US government – took his suggestions seriously. He could have cruelly affected the lives of billions based on predictions that turned out to be wrong.[15]

It's possible to feed 8, 9, 10 billion people a nutritious diet without wrecking the planet. We don't need population control to do it; we just need a better plan for how to grow what we need and use it more efficiently.

Where we are today

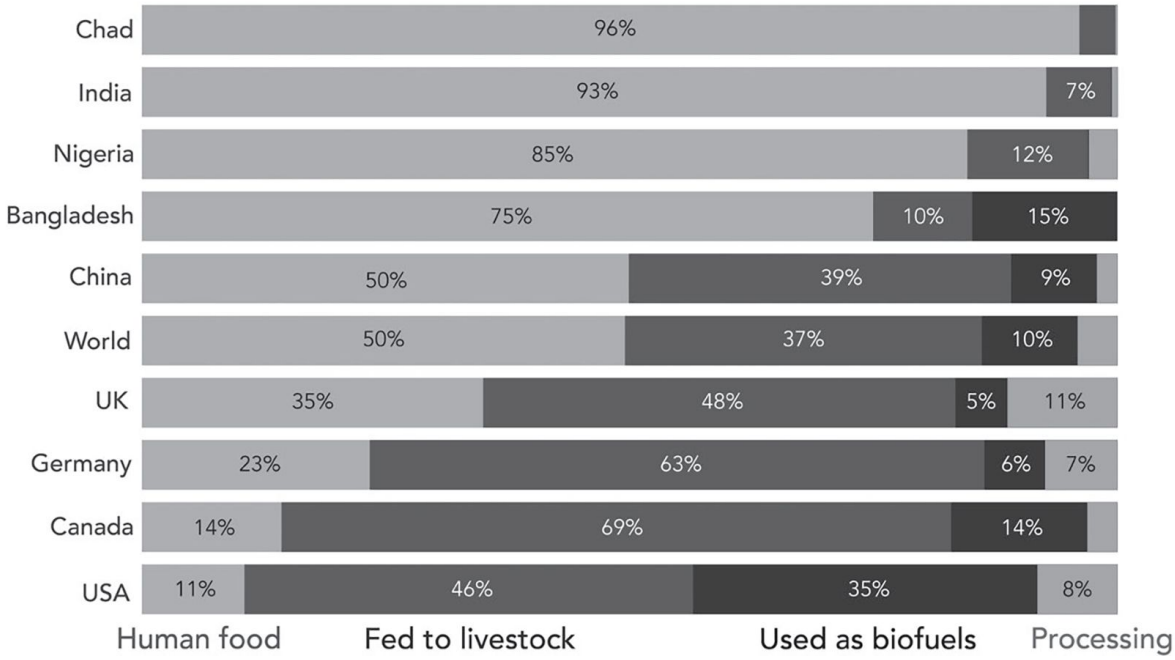
Hungry cattle; greedy cars

So, how can it possibly be true that we produce 5,000 to 6,000 calories[fn3] per person per day, more than double what we need, yet still struggle to feed everyone?

The obvious answer is global inequality. Hundreds of millions don't get enough to eat, but billions get too much. Around four in 10 adults in the world are overweight. For most of human history the biggest battle was to get enough food to eat. Now, the hungry are a minority. The fact that obesity rates have increased so quickly across the world is actually a signal of how new and rare this situation is: evolving in a world of scarcity, we've been programmed to make the most of any food we can get our hands on. So, yes, part of the answer is that globally we eat more than we need. Still, we're not eating 5,000 calories per day. We're probably eating around half of that. The bigger question is how we can possibly lose *half* of the food we produce before it even reaches our plates. That is a woefully inefficient system.

The reason is that we feed livestock and cars, not people. The world produces 3 billion tonnes of cereals every year. Less than half of this goes towards human food; 41% is fed to livestock, and 11% is used for industrial uses, like biofuels. That global allocation is surprising, but when we look at specific countries the balance is jaw-dropping.

Poor countries use nearly all of their cereals for human food. In Chad, Malawi, Rwanda, India, for example, the number is more than 90%. When you can only just produce enough for everyone, you can't afford to put it into cars, or feed it to other animals. Diverting food away from humans is a luxury. Many richer countries take this luxury to the extreme. The amount of maize that the US puts into cars for biofuels is 50% more than the entire African continent produces.[fn4] This is not unique to the US: across the world, feeding crops directly to humans is becoming the minority position. The US is quite unique in just how much is allocated to biofuels. For most other countries it is animal feed that dominates, with our cereals going to hungry chickens, cattle and pigs.



Only half of the world's cereals goes directly to human food
Poorer countries use nearly all of their cereals for direct human food. Richer countries divert more and more towards animal feed and industrial uses, such as biofuels.

It's not just cereals. This is also true of other crops. As seen in the last chapter, around three-quarters of the world's soy is processed into feed and goes into the mouths of chickens, pigs and cows.[fn5]

Meaty dilemma: an inefficient way of making tasty food

When we feed animals, some of the calories go towards building lean tissue and fat that we can eat later. But the majority disappears. How can this be? Where do these calories go?

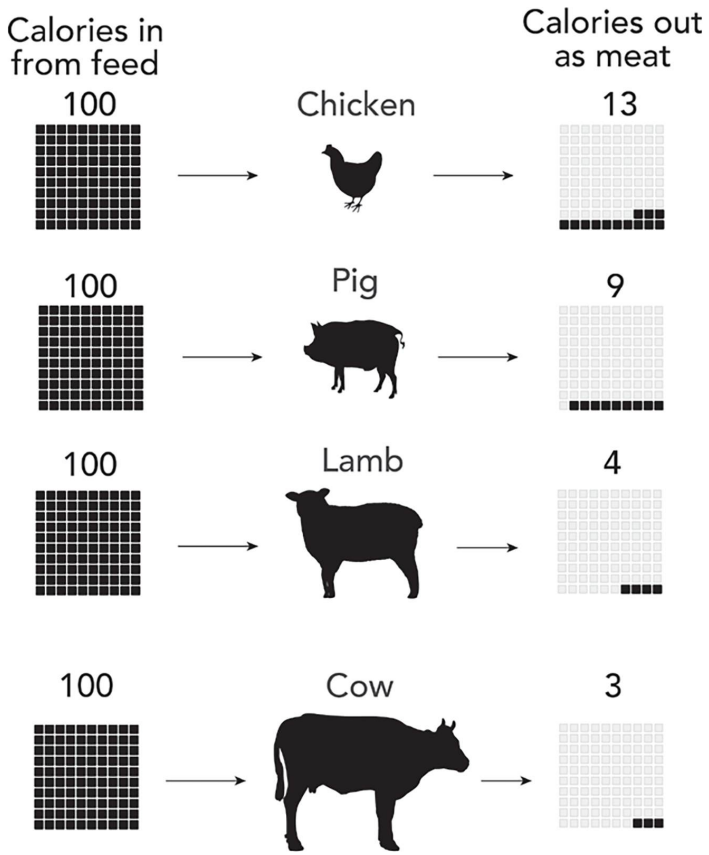
We want animals to gain weight because we get more meat in return. But even if they didn't gain weight, we'd still need to feed them to keep them alive. Those calories are burned in normal day-to-day activities: roaming around, pecking, mooing, keeping all of their organs functioning. It's no different from humans. In a very crude and cruel sense, the calories we feed animals just to keep them alive are a 'waste'. How much 'waste' depends on the animal. The bigger the animal, the more food we need to feed it to keep it alive. Again, it's no different from humans. Arnold Schwarzenegger needs to eat a lot more food than I do to maintain his weight. That's simply because I am a smaller person. Even if we copied each other's daily routine and did all of the same activities, he would probably burn through at least 50% more calories.

This simple relationship is useful: smaller animals are more calorie-efficient. Fish and chickens tend to be the most efficient, then pigs, then sheep, then cows.[fn6] Unfortunately this means the opposite for animal welfare: you'd need to kill more of them to get the same amount of meat. How you balance that moral quandry is up to you.

Measuring ‘calorie efficiency’ tells us what percentage of the calories we feed an animal is converted into ‘eatable’ products for humans. These figures are quite shocking.

For beef, it’s just 3%.[16, 17, fn7] This means that for every 100 calories we feed a cow, we get just 3 calories of meat back in return; 97 calories are effectively wasted. For lamb, it’s around 4%. Better than cows, but still crushingly bad. Pork is almost 10%. For chicken, it’s 13%. Even for the most efficient of animals, the vast majority – more than 80% – of calories are wasted. That fact is quite hard to stomach. Can you imagine buying a loaf of bread, cutting a slice, and throwing the rest – more than 90% of it – in the bin? When it comes to calories, that’s pretty much what we’re doing with meat.

So, the calorie equation doesn’t look great for meat. But what about protein? Here, livestock are also pretty inefficient converters of protein. For pork, lamb and beef, more than 90% of the protein they eat from animal feed is lost. Put 100 grams of protein in, and you get just 10 grams back. Chicken is better, but we still only get 20% of the protein back in the form of meat.



Most calories are ‘wasted’ when we feed livestock for meat
Only a small percentage of the calories we feed animals are converted into meat.
Bigger animals ‘waste’ more calories.

Where meat and dairy products *are* good is that they are what we call a 'complete' protein source. They might lose a lot of the protein we feed them but what they do produce is *higher quality*, with a full spectrum of the essential amino acids we need for good health. Cereals have some but not all of these amino acids. If you were to eat only cereals, you would be protein-deficient.[18] This is not the case with all plant-based products. Pulses such as peas, beans and soy have a very good amino acid profile. If someone has a mix of cereals and pulses in their diet, they can easily meet their protein requirements.

Meat and dairy products are also a great source of micronutrients – things like calcium and iron. We can get these from a plant-based diet too, by picking the right combination of foods. The exception to this is vitamin B_{12}, which is only found in animal products. This is the one nutrient that vegans should be supplementing their diet with. So, technically we don't *need* meat and dairy for a nutritious diet. It's possible to meet these requirements with a well-planned and diverse plant-based one. But this is not feasible for everyone. I could achieve this quite easily because I have a large supermarket two streets away, with every food imaginable there. Most importantly, I am privileged enough to be able to spend as much as I need to on a wide range of foods. I can buy supplements if I need them. And, after studying this for so long, I know what foods I need to make sure I'm covering all my nutritional bases.

Most people in the world don't have it so easy. In poorer countries, more than two-thirds of people's calories come from staple foods such as cereals and tuber crops. In Bangladesh, for example, nearly 80% of calories come from these foods. The majority rely on rice and wheat. For comparison, in the UK, we get just one-third from cereals and root crops. The rest come from a range of sources: fruits, vegetables, pulses, meats and dairy. Having access to different foods, and being able to afford them, is a privilege.

Meat has played an essential role in human diets for millennia. It's wasteful but nutritious, not to mention tasty. However, if we're to build a food system that feeds *everyone* without ruining the planet, we need to rethink our relationship with meat.

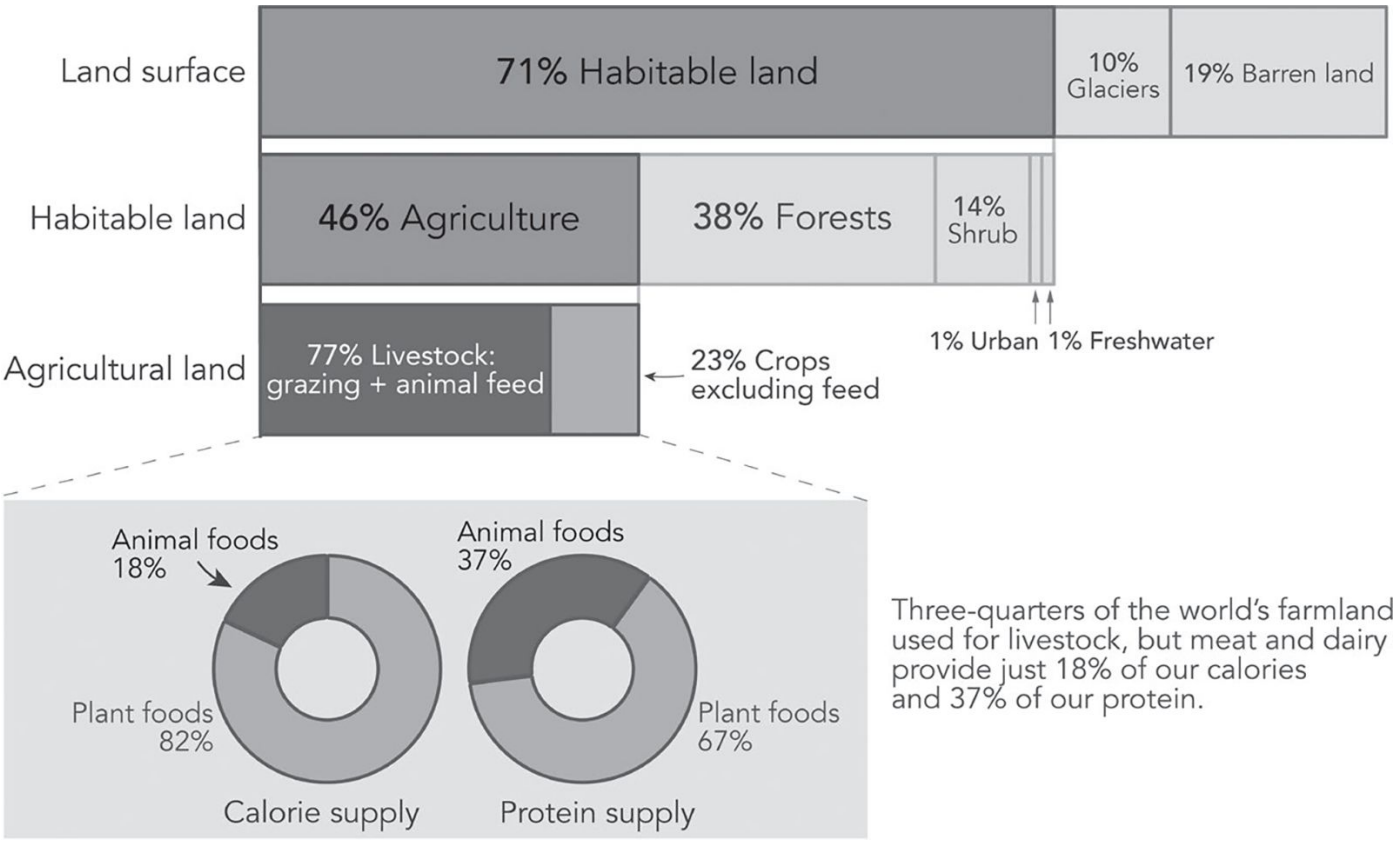
Food: the heart of the world's sustainability problems

Look at any of the world's environmental problems and food lies close to the centre. It really is at the nexus of sustainability. As seen in Chapter 3, the food system is responsible for one-quarter of the world's greenhouse gas emissions. But even if we were to take climate change out of the picture, we would need to fix our food system to tackle our other environmental problems.

Worried about pressures on freshwater supplies? Agriculture is responsible for around 70% of global freshwater withdrawals. In some tropical countries, more than 90% is used for farming.[19] Worried about deforestation? As we have seen, take agriculture out of the picture and the problem almost disappears. Worried about

biodiversity loss? Again, food production is the biggest pressure on the world's wildlife.[20] It always has been. From overhunting animals for food and claiming their habitats for farmland, to killing off ecosystems with pesticides and fertilisers, the largest threat to the world's animals is human demand for food. Worried about water pollution? You guessed it: farming comes out on top. When we put nutrients in our soils and crops, most of them run off the land and into rivers, lakes and the ocean. These nutrients throw ecosystems into havoc: species such as algae take advantage and bloom everywhere. Fish and other animals are starved of oxygen, and our waters turn into zones dead of life.

Zoom out and we can see the scale of the impact that farming has had on reshaping our planet. Today, half of the world's ice- and desert-free land is used for agriculture. Much more land is used for farming than the world has in the form of forests. Three-quarters of this is used for raising livestock – either land for grazing or for growing crops to feed it. What's staggering is how imbalanced this is when it comes to the food we finally eat. Meat and dairy give us just 18% of our calories, and 37% of our protein. We put a lot of resources into livestock, but the returns are not great.



Half of the world's habitable land is used for agriculture
Agriculture is the largest driver of deforestation and habitat loss. Three-quarters of agricultural land is used for livestock.

If we created a global map of the different land uses – grouping each of them together – land for raising animals would take up the whole of North, Central and South America

combined, from the top of Alaska down to the tip of Rio Grande in Argentina.

Many of the environmental problems in farming relate to two things: how much land we use, and how we manage inputs such as water and fertilisers. The solutions we need to feed everyone in a sustainable way come back to trying to reduce the amount of land we use for farming as much as possible. We should give other wildlife as much land back as we can. Globally we are making progress on this, often because of the *intensification* of agriculture: using inputs such as fertilisers to get higher yields. There, too, we are making progress – a fact that comes as a surprise to many.

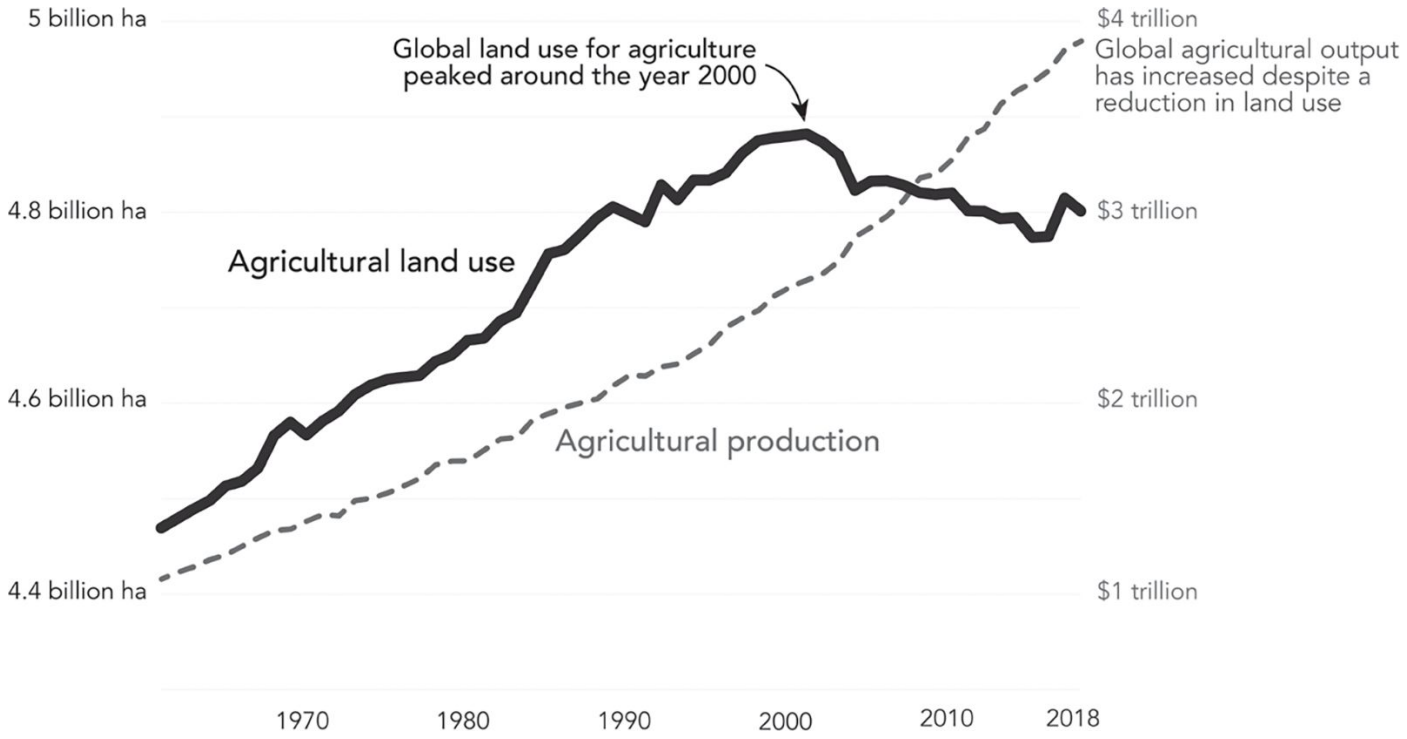
The world may have already passed peak agricultural land

With more people to feed, and people moving to diets that need more land (the more meat we eat, the more land we need), we might assume that our demand for farmland is never-ending. Globally it will simply rise until the population stops growing. That would be very bad news.

Thankfully it is not true. A few years ago a number of researchers predicted that we might be close to peak agricultural land.[21] I have to admit, when I first heard this I brushed it off as nonsense. Surely it wasn't possible. Okay, crop yields were increasing and might *just* keep up with a growing population, but our appetite for meat was also growing quickly. It seemed implausible that we were becoming so efficient that we were countering that too.

I started digging into the data and crunched the numbers. The leading data source – the UN's FAO – suggests that we passed the peak around the year 2000. Other studies have built on this work, finding the same: the world has already passed the peak.[22] What makes me hesitant to declare a 'definitive' peak is that while the data tells us that global pasture land has peaked croplands have not. If croplands keep expanding, it's possible that this victory could be undone.

At the very least, the world is *near the peak* of agricultural land. And yet we continue to produce more and more food each year. There has been a global decoupling of agricultural land from food production.[fn8] That is a momentous moment in our environmental history. The world's wildlife has been waiting thousands of years for us to stop expanding. There is finally the opportunity to make this happen.



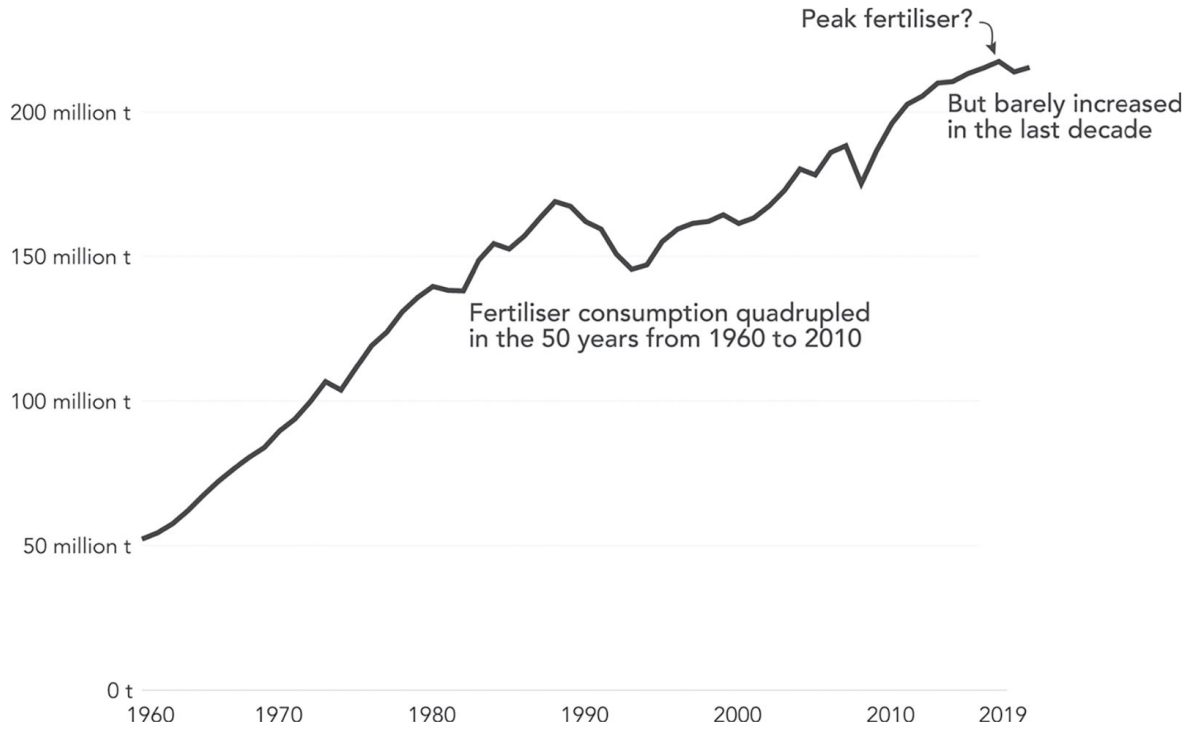
The world may have passed peak agricultural land
Global pasture land has peaked, but croplands have not. Obviously, agricultural land use has not peaked everywhere in the world.

This is definitely not happening everywhere. In many richer countries agricultural land use is falling. In other countries croplands and pastures are still expanding, often at the cost of forests. The decline is managing to more than offset the expansion. The end result *globally* is a decline. It is a strong sign that we can produce more food from less land. If we take these lessons and apply them everywhere then we can achieve this everywhere. It shows that the future of food production does not need to follow the destructive path that it did in the past.

The world will soon pass peak fertiliser

Using less land is all well and good. But one of the reasons we can produce so much more from a hectare of land is that we can use inputs such as nutrients, pesticides and irrigation to raise crop yields. Many people are concerned that we are just substituting one unsustainable practice for another, ending up in a rat race for fertilisers.

In fact, the amount of fertiliser the world uses each year has barely changed in the last decade. Fertiliser consumption grew rapidly in the 50 years before then, more than quadrupling. But this has now stalled. We might just be at the tipping point where fertiliser use starts to decline.



The world may be approaching 'peak fertiliser'
Improved efficiency of fertiliser use means many countries are producing more food from less fertiliser.

With more people to feed, how can this be? Fertiliser use is still increasing in many poorer countries in the world. This is a good thing – we saw earlier just how impactful the innovation of Fritz Haber and Carl Bosch has been.

But fertiliser use has plateaued or is falling in many rich countries. In the US, fertiliser use hasn't increased since the mid-1970s. Meanwhile, food production has increased by 75%. France now uses about half as much fertiliser as it did in the 1980s. The same is true in the UK and the Netherlands. Even in the most rapidly growing economies, fertiliser use is reaching its peak. China has passed it. By 2010, it was using around 25 times more fertiliser than 50 years earlier. That steep upwards line looked concerning. But China's fertiliser use peaked in 2015, and it has fallen since then.

These reductions didn't happen because countries were cutting back on food or going organic and cutting out synthetic fertilisers completely. It's because we were becoming more effective at using them. One of the world's biggest and most impressive studies shows this very clearly.[23] In a trial that spanned a decade, researchers worked with 21 million smallholder farmers across China. They wanted to see if they could help farmers to increase crop yields while reducing the environmental impacts of farming. They were successful. From 2005 to 2015, average yields of maize, rice and wheat increased by around 11%. At the same time, nitrogen fertiliser use *decreased* by around one-sixth. They were literally producing more from less.

With fertiliser use, then, we see a consistent pattern. First, in the poorest countries, farmers use very little fertiliser. They can't afford it. This is bad for them because they get poor yields and earn little money. It's also bad for the planet because they need to

use more farmland. As they get a little richer, fertiliser use starts to rise. Crop yields improve. But, eventually, the focus shifts towards using these inputs more efficiently. Fertiliser use doesn't fall to zero, but farmers learn to use just the right amount to give crops the nutrients they need.

How to feed everyone without destroying the planet

How can we feed an extra 2 billion people this century without destroying the planet?

One thing that should be obvious by now is that we can't go backwards. It's tempting to think we should return to a way of producing food that seems more rooted, more grounded, in how things used to be. These methods can work at a small scale. But they don't feed billions. The maths just doesn't check out.

I've crunched the numbers on how much land we would need to support our current population of 8 billion people using different foraging and farming regimes. Remember: the amount of habitable land on Earth – that's all our ice- and desert-free land – is around 100 million km^2, and we currently use half of it – 50 million km^2 – for farming.

To support 8 billion through hunting and foraging we would need 8,000 to 800,000 million km^2 of viable land. That's 100 to 10,000 times the amount of land we have on Earth. That's also ignoring the inconvenient reality that we'd wipe out all mammals along the way.

What about pastoralism? Small communities that rely on livestock? That is not much better than the most productive foraging societies. We'd need around 3,000 to 8,000 million km^2. Or 10 Earths.

How about a return to early, organic methods of farming? Could we all have our own little plot of land, roll up our sleeves and get back to how farming used to be? For shifting agriculture – the slash-and-burn style – we'd need between 80 and 800 million km^2. Getting closer, but we still don't have nearly enough land to live like that. For more traditional farming in one place we'd need between 8 and 80 million km^2 which – at least towards the lower end – is much more realistic. But this would only work *if everyone ate a plant-based diet* so we could feed them efficiently on croplands. And we'd probably have to cut down many of our forests along the way.

With modern farming we could feed 8 billion people on much less land. Possibly as little as 4 to 8 million km^2 if we achieve very productive farming across the world and move to plant-based diets (which are very big ifs).

So, it's just not feasible for us to go backward. There's just not enough room for 8 billion of us to do so.

How to build a more sustainable food system

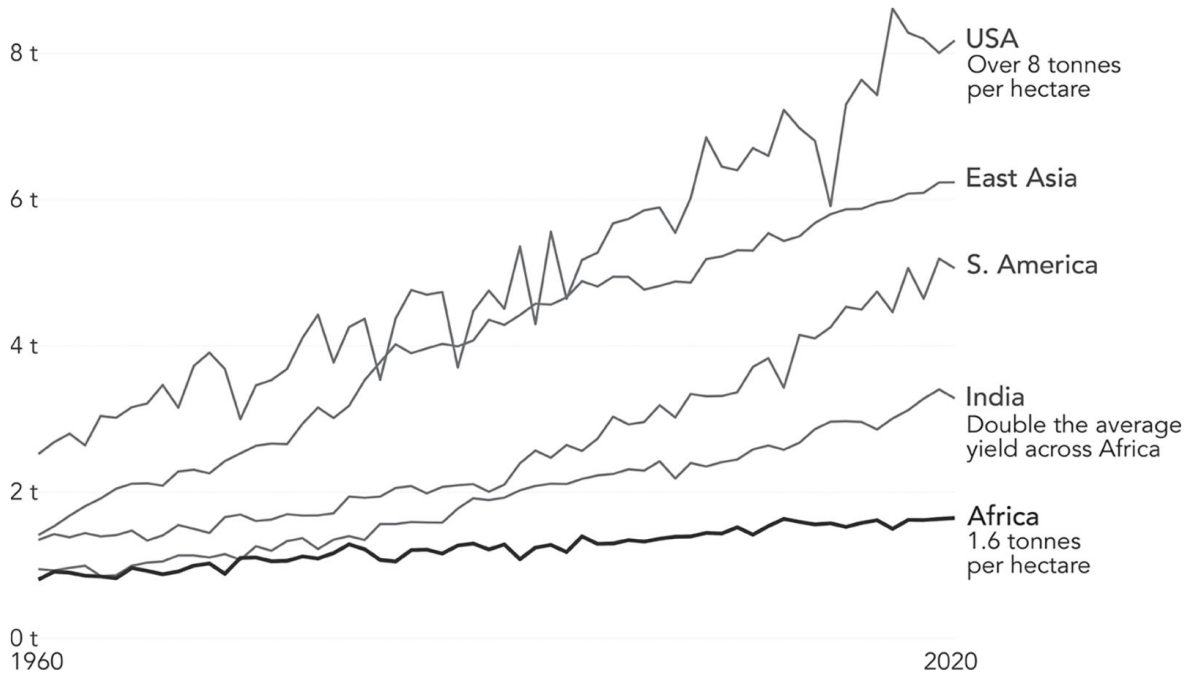
I panic when people ask the dreaded question 'So, Hannah, what do you do?' I know that within a minute I'll be knee-deep in a heated debate about what everyone in the world should be eating. People *love* to discuss it. Everyone has an opinion about it. How and what we eat is deeply personal. Diets often become a strong part of our identity. It becomes tribal. The rules are binary. A vegan is someone who doesn't eat animal products. If you do, well, you're not a vegan. You're out of the tribe. To stay in a proper ketogenic state you have to keep carbohydrate intake very low. Exceed that, and you're knocked out of this state. Organic and GMO-free are both binary labels. It's certified as organic or it's not. It's labelled as GMO-free or it's not. Preaching and shaming are common. I don't *want* to tell people what to eat. It's none of my business. At the same time, I *do* want to give clear and straightforward answers to the basic questions of how we can eat more sustainably. I want to give people the information they need to make an informed decision, then leave them to do so based on what they value. If they don't care about the carbon footprint of their diet, that's fine by me. What I find painful is when people really *do* care about eating sustainably, but they're making choices based on poor information, putting effort into all the wrong places. They're trying hard but not making things any better. In fact, sometimes they're making things worse.

Here I want to give my top recommendations for how we build a more sustainable food system. Whether you take this advice is up to you. Sometimes these recommendations will conflict with other values you have, and that's okay. It's for you to balance your own priorities.

(1)
Improve crop yields across the world

We're now in a unique position. We've broken that deadlock with nature: we can now get more food from less land.[24]

But there is an exception. Most countries across sub-Saharan Africa have lagged behind. Crop yields haven't improved much, and are stubbornly low. The average cereal yield across Africa is half that of India and one-fifth of the yields in the US. This is not only bad for the planet, but for people too. More than half of the workforce across sub-Saharan Africa are farmers, and earn very little money in return. Many live on the equivalent of less than a few dollars per day.[25]



Crop yields across sub-Saharan Africa are lagging behind
Cereal yields are measured in tonnes per hectare.

Africa will need to grow a lot more food in the coming decades. In the next 30 years, it is expected to add another billion to its population, and then another billion in the 30 years after that. Researchers estimate that the amount of land it needs for crops could almost triple by 2050 if yields do not improve.

Improving crop yields – especially across sub-Saharan Africa – needs to be part of the plan. If the region achieves this – if it manages to close its 'yield gaps' of what is biologically and technologically feasible – then it can feed itself without losing any forest or natural habitat at all. The good news is that we know how to do this.

The technologies and investments that have already worked for so many countries – from fertilisers to improved seed varieties to irrigation – will become even more important with climate change. Farmers will need better control over the management of nutrients and water as temperatures rise and droughts become more common and more intense.

Just as Norman Borlaug engineered incredibly productive wheat crops in Mexico, India, Pakistan, Brazil (the list goes on), we can also develop new varieties of crops that are more resistant to drought and can withstand higher temperatures. Many of these innovations also mean that we can have crops that need fewer fertilisers and pesticides. Crops that need fewer chemical inputs, are more resistant to drought, *and* get higher yields – what's not to like? It sounds like a win-win for people and planet. Strangely, many environmentalists are strongly opposed to cross-breeding and genetic modification of crops even though they have been incredibly important for protecting ecosystems and habitats across the world. We need to overcome this opposition. If we want to feed 10 billion people without cutting down more forest, the environmental

movement needs to cautiously embrace rather than shun the advances that will help us grow more from less.

(2)
Eat less meat, especially beef and lamb

You've already seen this recommendation.

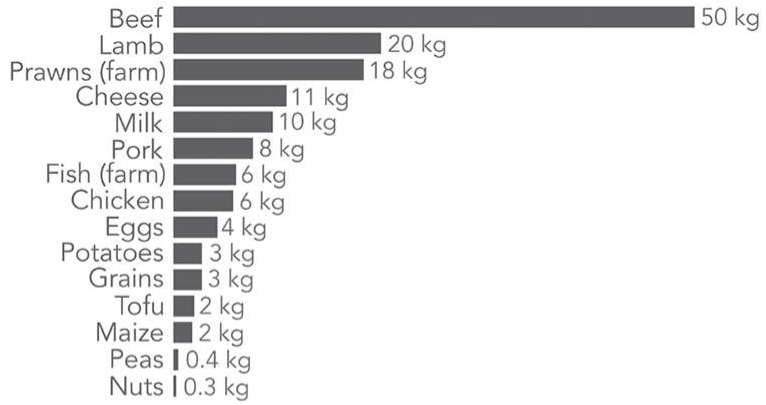
Chapter 3 looked at some of the climate impacts of different foods. The carbon footprint of meat – especially beef and lamb – really stood out. But it's not just about climate change. Because food plays such a big role across many environmental issues, this single change has many positive spillovers. Whether it's greenhouse gas emissions, land use, water use, or water pollution,[fn9] the hierarchy is nearly always the same: beef and lamb are the worst, followed by dairy, pork, chicken, then plant-based foods such as tofu, peas, beans and cereals. This is true whether we compare them in kilograms, calories or protein. The differences here are not small. It's not like we're splitting hairs over using 100 metres squared of farmland rather than 99. It's the difference between using 100 metres squared or 1. Literally 100 times the difference.

So, once again the biggest thing we can do is to eat less meat and dairy. If we want to really change things at scale we need lots of people to get on board. We would cut emissions, land use and water use by much more if half the population went meat-free two days a week than we would from increasing veganism by a few per cent.

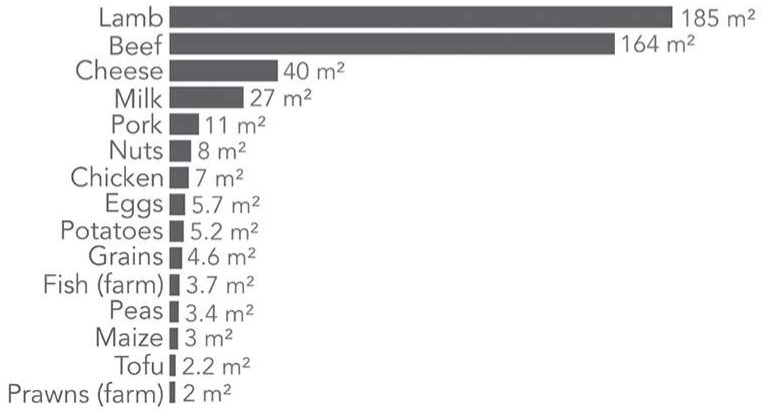
Most people aren't going to change if they're offered an all-or-nothing alternative. One of the worst ways to get someone to reduce their meat consumption is to tell them to go vegan. It just doesn't work. We need to make it simple and enjoyable for people to cut back a bit. That might be Meatless Mondays or meat-free lunches. Often people dip their toes into the water of a more plant-based diet and find it's easier than expected.

But it's not just *how much* meat and dairy we eat that matters. It's also what types. We can have a massive impact by simply switching one type of meat for another. If you're a big beef eater then replacing some of your weekly intake with chicken or fish is the biggest thing you can do. In fact, that change makes much more of a difference than a chicken eater going vegetarian.

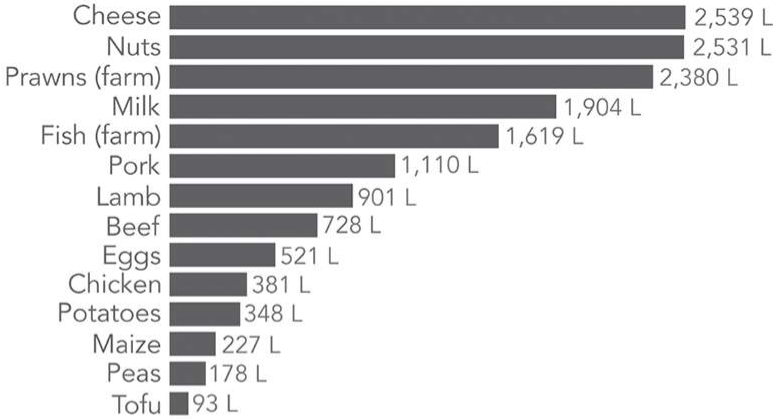
Greenhouse gas emissions



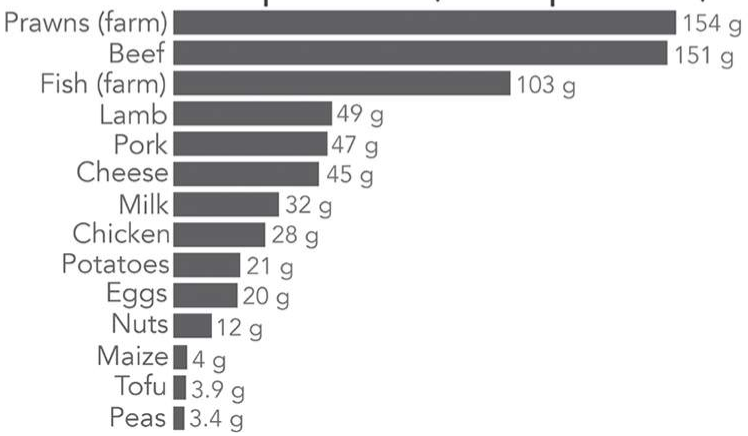
Land use



Freshwater withdrawals



Eutrophication (water pollution)



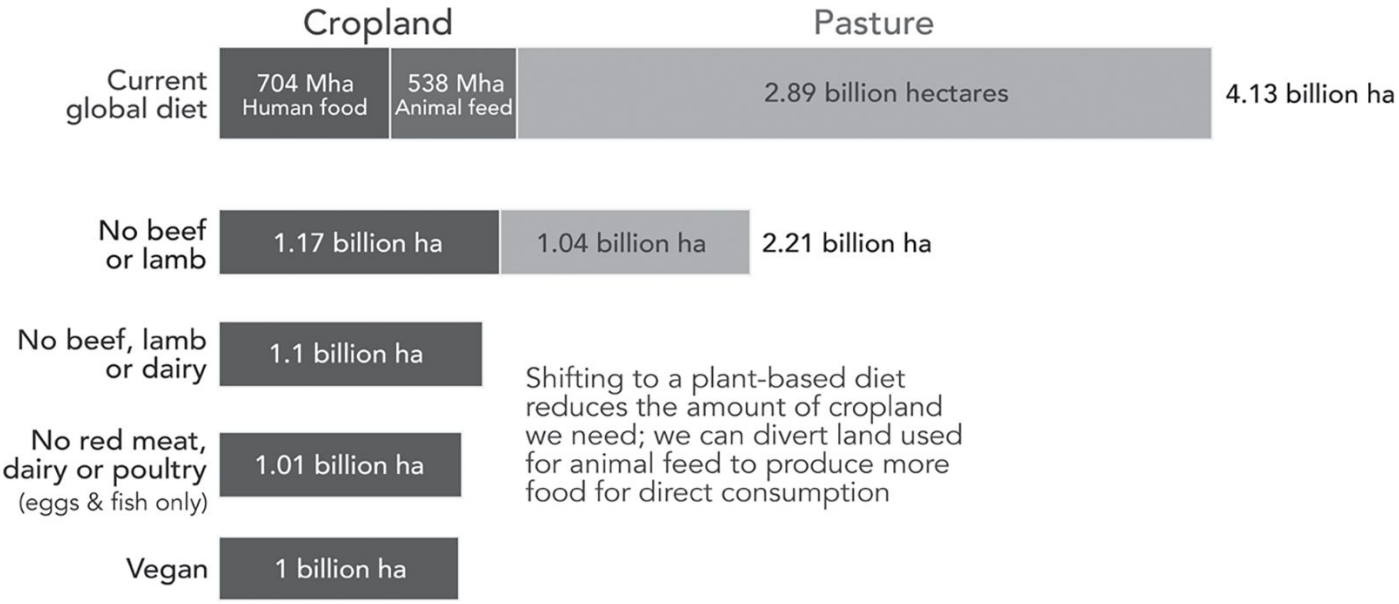
What foods have the largest environmental impact?
Meat and dairy – especially beef and lamb – have a much higher environmental impact then plant-based protein sources. Foods are compared per 100 grams of protein.

We can see this very clearly when it comes to agricultural land use. The world uses around 4 billion hectares of land to grow food.[fn10] Researchers mapped out scenarios of how this would change if everyone in the world adopted different diets. Still, it gives us an interesting look at what our global land use *could* look like. Simply cutting out beef and lamb (but still keeping dairy cows) would nearly halve our need for global farmland. We'd save 2 billion hectares, which is an area twice the size of the United States. That is, by far, where the biggest saving comes from. And it doesn't mean that we all need to go vegan.

If we were to cut out dairy too, we'd halve this land use again to just over 1 billion hectares. Three USA-sized farms saved. But from there, the reductions are marginal. Sure, the vegan diet does minimise it the most: if everyone ate a vegan diet we'd reduce the amount of land we use for farming by 75%. An area the size of North America, plus Brazil. But the savings compared to a diet with some chicken, or some fish and eggs are not that big.

This research also squashes another big concern I hear: 'We can't all go vegan – we don't have enough land to grow crops!' As I've already shown, if everyone went vegan we would need *less* cropland than we use today because we'd save all the land used to grow crops fed to livestock. Less than half of the world's cereals are fed directly to humans. The rest goes to livestock or biofuels. The same is true for soy. We could simply repurpose that food, or repurpose that land to grow different crops.

This all sounds very simple in principle but getting people to change behaviours is difficult. I don't think that enough people will make this change based on the ethical pull alone. If we're to change how people eat across the world we're going to need some new, tasty, meat-like products.



Shifting to plant-based diets could reduce agricultural land use by 75%
Global agricultural land use is given for cropland and pasture for grazing livestock assuming everyone in the world adopted a given diet. This is based on reference diets that meet calorie and protein nutritional requirements.

(3)
Invest in meat substitutes: building burgers in the lab

When I went vegetarian for the first time, my family's carbon footprint got bigger. The reason wasn't me but my brother: he started on a fitness kick at exactly the same time. He was in the gym six times a week, and, as per the conventional fitness advice, he doubled his meat intake overnight. Meat and broccoli for every meal. While I cut back on meat he offset my good intentions, and then some.

He'd never have eaten soy-based burgers and Quorn sausages instead. He said they tasted nothing like meat. The meat-substitute products on the market were really sparse at the time. We would try to sneak them into family meals to see if he'd notice. Chicken fajitas became Quorn chicken-like fajitas. Spaghetti bolognese became spaghetti bolognese with soy-based mince. He was never fooled.

The day I knew the world was on to something – that we were really making progress – is when, some years later, he ate a plant-based meal and didn't notice. His wife sneaked one of the 'plant-based meats' into a chilli con 'carne' and he didn't blink an eye. In fact, he couldn't believe it wasn't meat. If anything, he said it was the best chilli he'd ever had. If my brother can be won over, almost anyone can.

Meat-substitute products are one of the fastest-growing food sectors. Interestingly, it's mostly meat eaters that eat them. Ninety-eight per cent of US consumers who bought plant-based meats were also buying meat products.[26] That's a great sign: we want plant-based meats to be something everyone is open to trying. They should never be a niche product for the vegans and vegetarians of the world.

To really eat into the meat market they need to achieve four things: be tasty, accessible, easy to work into standard meals, and cheap. If we fail on any of these, they will stay on the sidelines forever.

Most people love meat, so the theory behind meat-substitute products is simple: let's try to recreate the experience of meat without the environmental impacts and animal welfare concerns. In just a few years, the world has come a long way. Imitation burgers and sausages used to taste like cardboard. But brands such as Impossible Foods and Beyond Meat – the biggest meat-free companies in the US – are changing the game. They're investing heavily in making burgers that taste and feel just like the real deal. This strategy lies at the heart of their branding.

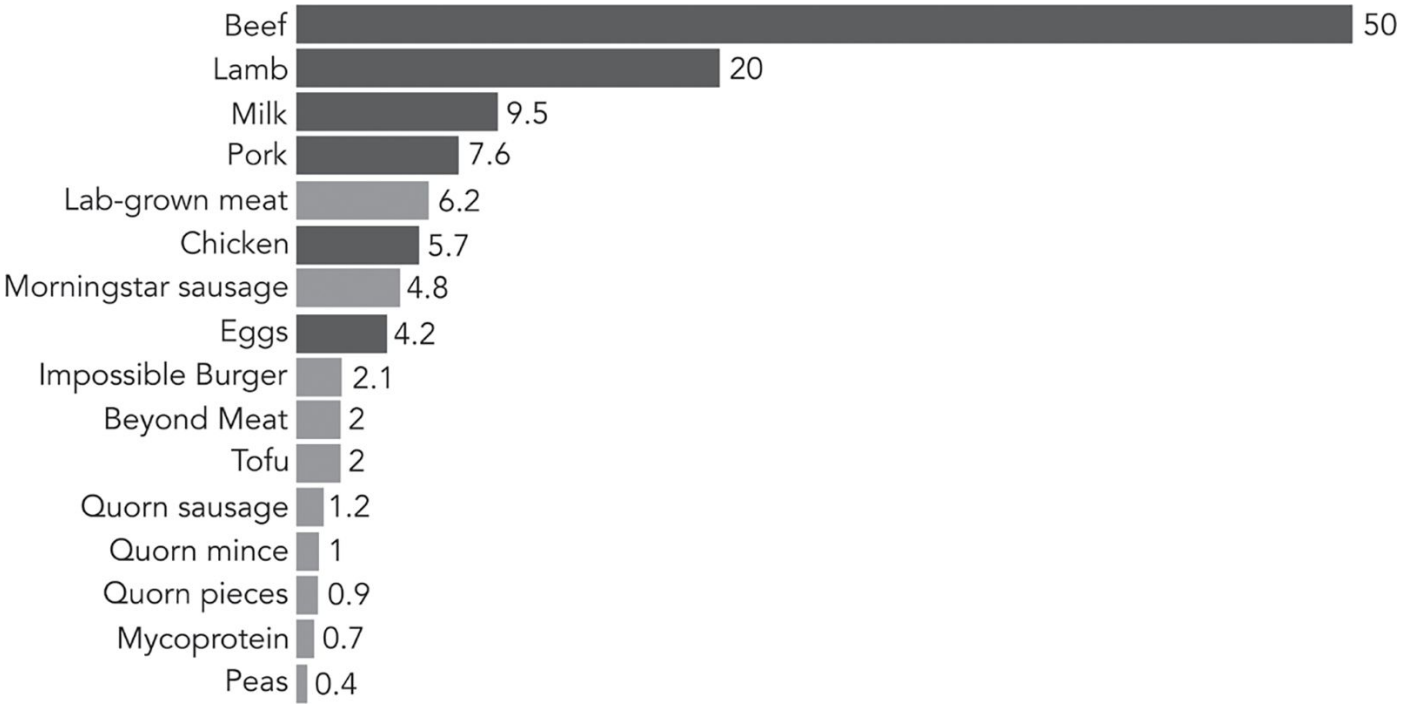
A claim by Impossible Foods makes this abundantly clear: 'Before Impossible Foods, there was meat and there were plants. Back in 2011, we started with a simple question: "What makes meat taste like meat?" Then we figured out how to make it with plants.' The secret to its success is the molecule heme. 'Heme is what makes meat taste like meat. It's an essential molecule found in every living plant and animal – most abundantly in animals – and something we've been eating and craving since the dawn of humanity.'

With their 'bleeding plant-based burger' I think Impossible have succeeded in creating an almost perfect impersonator. A couple of years ago our team was based in San Francisco for three months. There were only a few restaurants in the world where you could get the Impossible Burger, and we were staying right next to one. The first bite I took was like a time machine. I don't find it difficult to be vegetarian – I'm rarely tempted to eat meat – but that was a hard-hitting reminder of what a meaty burger tastes like. It was incredible. I was devastated when we had to leave and return to the UK, where it wasn't available.[fn11] But more products have flooded the market since then, all battling to get closer and closer to the real deal.

Many have questioned whether these products are actually much better for the environment. The answer is yes. They're *much* better than beef.[27, 28] Emissions from Quorn products are 35 to 50 times lower than beef. Switch your beefburger for a Beyond Meat or Impossible Burger and you'll cut emissions by around 96%. This is comparing these products to the global *average* footprint for beef. Substitutes still have a footprint around 10 times smaller than beef from the US or Europe. And even the footprint of the world's lowest-carbon beef is still five times bigger than the Beyond Meat or Impossible Burger, and 10 times bigger than Quorn.

Most also have a lower carbon footprint than pork and chicken, although sometimes not by much. What's different about these foods is that there's lots of room to improve: a big chunk of their carbon footprint comes from the electricity needed to produce them. As the world moves towards a low-carbon energy grid, the footprint of these foods will get better too. That's not the case with meats: we're quickly reaching our limits on how efficiently we can produce animals.

If we're to be successful in moving meat from the field to the lab at a global level, it will have to become much cheaper. People in poorer countries simply can't afford these products yet. If we can make them cheaper than meat, it could really change the game for global nutrition. We could feed the world a protein-rich, nutritious diet while reducing our environmental impacts at the same time. Every time you buy a new substitute product, you're not just lowering your own carbon footprint, you're helping to pull down the price for the rest of the world too.



Most meat substitutes have a much lower carbon footprint than meat
Carbon footprints are shown per 100 grams of protein for each product. This is based on life-cycle analyses, which include emissions on the farm, land-use change, raw materials, food processing, transport and packaging.

(4)
Build a hybrid burger

While many would be happy to tuck into a plant-based Impossible Burger, others will want to stick with beefburgers. Well, maybe they can have their beef but save some too.

One option is to blend beef with chicken, soy or other low-carbon protein sources, to build the hybrid burger. It would still taste like beef. It would have the texture of a normal beefburger. I mean, it still *would be* beef. Interestingly, in blind taste tests people tend to *prefer* a blended burger over a 100% beef or 100% meat alternative version.[29, 30] But when you unblind these tests and tell people that they're eating a 'blended' burger, they tend to be less keen. If we can overcome this mental block, hybrids could make a massive difference.

Let's crunch the numbers on how much of a difference: by my calculations, if both McDonald's and Burger King made all their burgers a 50:50 blend of beef and soy, it

would save 50 million tonnes of greenhouse gases each year.[fn12] That's equal to the emissions of Portugal. It would also free up an area of land bigger than Ireland and save 3 million cows from being slaughtered for meat each year.

That's just two companies. Imagine if we did this on a much larger scale. We could save countries' worth of emissions, countries' worth of land, and millions of animals each year. The real selling point is that consumers wouldn't have to change their eating habits at all. They might barely notice the difference. Better yet, they might find hybrid burgers even tastier.

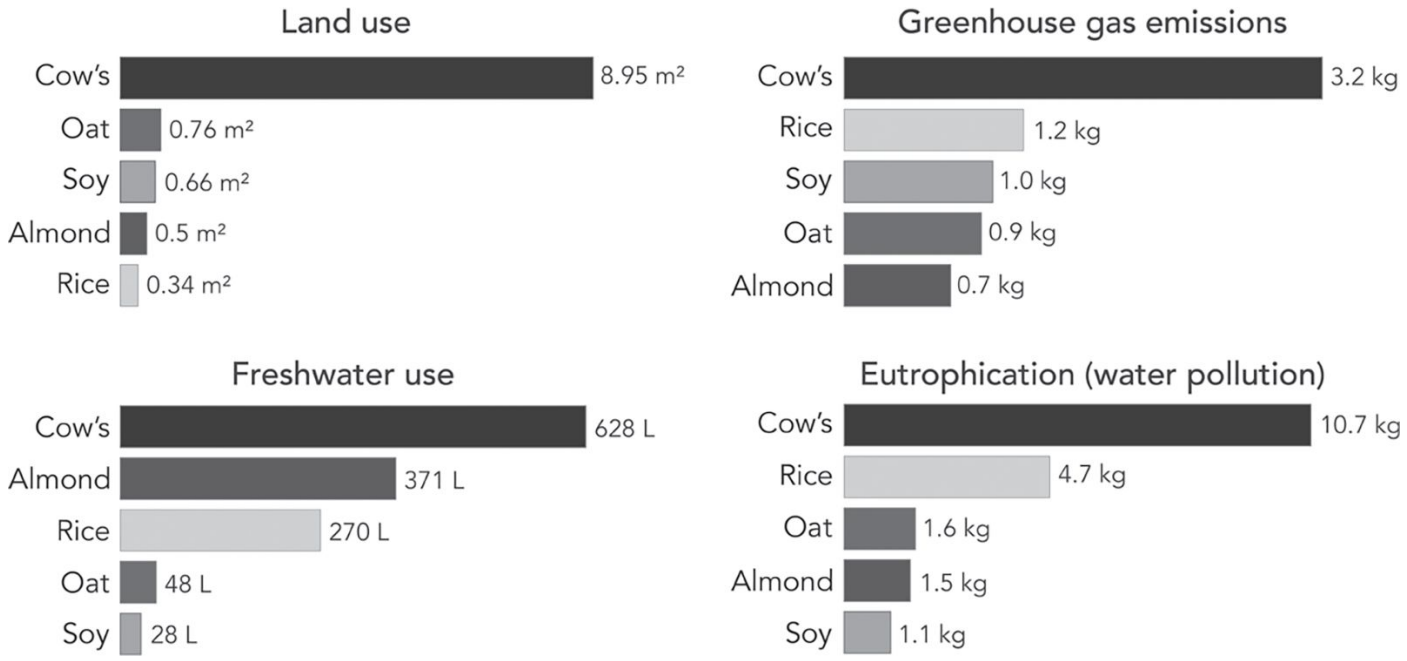
(5)
Substitute dairy with plant-based alternatives

In the typical diet in the EU, dairy accounts for just over one-quarter of the carbon footprint, sometimes as much as one-third.[31]

Many of us are looking to plant-based alternatives. In the UK, surveys suggest one-quarter of adults now drink some non-dairy milks,[32] and it's even more popular in younger demographics, with one-third of 16- to 23-year-olds choosing them. There are now multiple options. But which 'milk' is best? This is one of the most common questions I get asked.

The short answer is: any of them. Take your pick. All of the plant-based alternatives have lower environmental impacts than cow's milk. Cow's milk generates around three times as much greenhouse gas emissions, uses around 10 times as much land, up to 20 times as much fresh water, and creates much higher levels of eutrophication (the pollution of waters with excess nutrients).[33]

Choosing which of the vegan milks is best for you really depends on the impact you care most about. Almond milk has lower greenhouse gas emissions and uses less land than soy, for example, but requires more water. There's no clear winner on every metric. Just pick the one you enjoy the most.



Which type of milk is best for the environment?
Environmental impacts are shown per litre of milk. No plant-based milk wins on all metrics, but all have a much smaller impact on the environment than cow's milk.

I should caveat this by saying that plant-based milks don't have the same nutritional profile as dairy. Dairy milk tends to be higher in calories and protein. It also contains micronutrients, such as vitamin B_{12}, that plant-based milks don't have. But plant-based milks are now often fortified with vitamins D and B_{12}. The replacement of dairy with plant-based milks shouldn't be a concern for those with a diverse diet, and for those who do not rely on milk as an important source of protein. It's possible to meet these requirements from other foods. However, for certain demographics – especially young children, and those on lower incomes with poor dietary diversity – this might be a bad switch.

(6)
Waste less food

Around one-third of the world's food goes to waste.[34, 35] Here, by 'waste', I'm not including all of the energy we lose when we feed crops to livestock or put them in our cars. I'm talking about food that literally rots away, without being used for anything.

That figure of one-third is how much food we waste based on the *weight* of food. It's not necessarily the amount we lose in terms of calories or protein. On the basis of calories it is less – probably around 20%. The reason for this difference is that the foods we waste most of are the heavy, water-laden ones. The fruits, vegetables, sugar cane and tuber crops like cassava. They get bruised and bashed easily, and rot quickly. These foods are great for a diverse diet, and rich in nutrients, but have fewer calories than cereals, grains and meats.

When we imagine food 'waste' we often picture rich people throwing their leftovers in the bin. In many countries, this is the dominant kind. It's the food we throw away at home, in restaurants, or the stuff left on shelves in supermarkets. It is, to some extent, deliberate. We are making a deliberate choice not to eat it.

But globally, and certainly in poorer countries, most waste happens in supply chains, and is referred to as 'losses'. It's usually unintentional, and painful for farmers and food producers because it's money they lose from their pockets. This food is 'lost' in a number of ways. Farmers try to harvest with improper tools and much of the crop is left behind in the field; foods are collected in old material sacks that leak everywhere; crops get infested with pests and diseases; they're left to rot in the sun; and there is often no refrigeration to keep them fresh in transport.

When I was talking to one of my previous bosses – Mike Berners-Lee – about food losses, he remarked that it was 'just a Tupperware problem'. That's stuck with me ever since. He's right. If the world had more Tupperware it would lose a lot less food. In fact, there are studies to prove it.[36] Researchers in South Asia tested what difference it would make to switch fabric sacks for cheap plastic crates. When farmers and distributors transport their food in sacks, you can imagine how bruised and battered their tomatoes and mangoes are by the time they get to the market. As much as one-fifth of food transported this way has to be thrown away. When they used plastic crates instead, these losses were reduced by up to 87%; rather than losing one-fifth, they'd lose as little as 3%.

That's not the only change we need to make in supply chains. We also need to increase refrigeration from farm to market, and while food is at the market. Wrapping produce in materials like plastic (you're shuddering, I know) can increase shelf life and protect from pests and disease. Foods also need appropriate storage locations so they're not left out in the sun. These seem like simple changes, but they would make a massive difference.

Food waste in households, restaurants and shops is a different issue. In principle it should be straightforward: just buy what you need and make sure you eat it. But human behaviour is hard to change. There are some things that can help. Opt for the 'uglier' fruits and vegetables in supermarkets which get left behind like orphans. Don't fall for offers like 'buy one, get one free' or 'three for the price of two', unless you really will eat them. Don't live by 'best before' dates. Many supermarkets are now scrubbing these as people often confuse 'best before' with 'use by' and assume that this is its funeral date. In fact, it's exactly as it describes: probably tastiest and freshest before that date, but still fine afterwards. We need to find better ways of distributing unused food from supermarkets and restaurants. There's no way it should be dumped in landfills when it could be going to perfectly good homes, especially to those who are struggling.

The environmental benefits of reducing food waste and losses are massive, and aren't limited to the environmental costs of the food rotting in the landfill. Sure, that emits some greenhouse gases but it's only a tiny fraction of its impact. The bigger problem is

the waste of all the land, water and greenhouse gas emissions in producing the food in the first place.

(7)
Don't rely on indoor farming

I'm an enthusiast for new technology. So you'd think I'd be a zealot for any innovation that would let us grow food using much less land. That's what indoor, vertical farming promises. Unfortunately, it's a technology I don't think will deliver.

The concept of vertical farming is quite simple. Rather than using energy from the sun to grow crops, we can use indoor LED lights instead. Rather than using soils, we can add nutrients and seeds to water trays – called 'hydroponics'. The magic lies in the fact that these trays can be stacked on top of each other. Vertical farms are a bit like skyscrapers. Megacities struggled to house so many people without sprawling outwards. The solution was to build upwards. Vertical farms could let us grow 10, 20, maybe even 100 times as much food per hectare than a normal outdoor farm.[37]

The use of water and fertilisers is considerably less.[38] All the conditions – temperature, humidity and light settings – can be controlled and crops are no longer at the mercy of the latest pest outbreak or extreme weather event. We can produce all our food in the middle of cities, right where we need it.

If that all sounds a bit too good to be true, it's because it is. The problem with vertical farming is that it needs a lot of energy. The sun is replaced with electric lights which need to be pretty powerful to mimic the fireball in the sky. I wanted to understand just how much electricity we'd need in order to produce some of our food from vertical farms. I looked at lettuce – one of the most popular indoor crops. If the US were to produce all its lettuce from vertical farms, the electricity demand would be equal to around 2% of the US's total electricity use. If 2% sounds small to you, consider that lettuce provides each person with around 5 calories per day. We'd be increasing the US's electricity use by 2% to meet 0.2% of its calorie needs.

Vertical farming is only feasible – and even then, barely feasible – for a few crops. Fruits and vegetables are expensive to grow but also profitable for farmers. The higher costs of vertical farming might just be supported by crops like lettuce, mushrooms and tomatoes allowing some producers to break even or make a small profit. But we can't produce any of our staple crops using vertical farms. Maize, wheat, rice, cassava and soybeans are where the world gets most of its calories from. These crops are so cheap that it becomes woefully expensive to try to grow them indoors. One study estimates that it would cost $18 to produce a loaf of bread from wheat grown in an indoor farm. And that's just to pay for the lighting. The efficiency of these LED lights will improve, but even when we imagine very generous improvements in lighting, the cost of making cereals will be at least six times higher than we currently sell them for.

Another nail in the coffin is that a lot of the environmental benefits disappear when we consider the electricity we need to power vertical farms. Since our electricity grids aren't yet zero-carbon, we'll be emitting some CO_2 to produce that energy. In some cases, we'll be emitting a lot of CO_2. We could argue that soon we'll be able to power these farms from solar panels, and they'll be almost zero-carbon. But we'll still need the land for the panels. Once we include the land use of the electricity source, the land savings from vertical farms can disappear entirely. In some cases, they'll actually need *more* land than a normal field.

I'd love this technology to prove me wrong, but as things stand, indoor vertical farms might work for a few speciality crops but they're never going to feed the world.

Things to stress less about

Eating local – the myth of eco-friendly food

Some years ago I was invited back to my old university to receive an award for science communication. It was one of these fancy functions where everyone stands around, sipping wine, making small talk, and doing the rounds of the room. In case it isn't already obvious: these types of events are my worst nightmare.

At the dinner, I was seated next to one of my old lecturers. It was strange to be seen as peers rather than teacher-and-student. As our meals appeared, the conversation naturally turned towards food. I had ordered the vegetarian option. My lecturer had ordered the lamb. 'I know meat isn't great for the environment, so I don't eat chicken and pork. I eat lamb though, because it's locally sourced and so it has a low-carbon footprint.' I thought she must be joking. She wasn't. I couldn't believe it: how could a lecturer on environmental topics really believe this – that meats have a low-carbon footprint simply because they're locally sourced?

If I was in that position today, I might push or protest a little. But back then I was too shy. I smiled, stayed quiet, and ate the rest of my veggie roast.

But I did walk away from that dinner primed to answer the question once and for all: does eating locally really reduce your carbon footprint? Was it me or them that had it wrong? Over the next year I found scientific paper after scientific paper all pointing to the same conclusion: *what* we eat matters much more for our carbon footprint than how far it has travelled to reach us.

I published these findings – with all of the data – in an article, and somehow gained the reputation of being the 'anti-local food girl'. I'm not anti-local at all. There are many reasons why people might choose to eat locally; maybe they want to support farmers in their community or see where their food is made. Those are totally valid reasons. What's *not* a valid reason is eating locally to have a low-carbon footprint. This is especially true if you're selectively choosing high-carbon foods over low-carbon

ones, just because they're closer to home. Yet eating locally is a recommendation we hear often, even from prominent sources such as the United Nations.

In 2021, Ipsos surveyed 21,000 adults across 30 countries about their knowledge and opinions on climate change. One of the questions was:

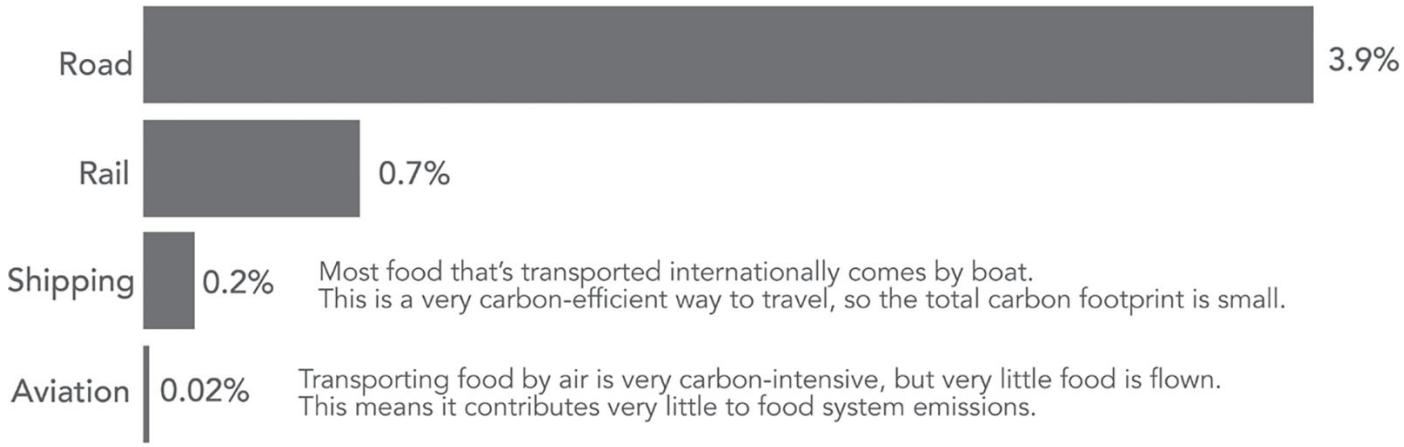
> 'Which of these two actions do you think would most reduce an individual's greenhouse gas emissions?'
>
> a. Eating a diet that is mostly locally produced, including locally produced meat and dairy products.
> b. Eating a vegetarian diet, even if some of the fruit and vegetables have been imported from other countries.

In every country – with the exception of India which has a more plant-based cuisine – people thought locally produced meat was better for the climate than a meat-free diet with some imported foods. Across the sample, 57% thought a locally produced meaty diet was better, 20% thought the vegetarian diet was, with the remaining 23% picking neither option.

The rationale for eating local makes sense; transporting food emits greenhouse gases, so the further it has to travel, the more gases are emitted. Seems right, and it's true. But we have to put the amount of CO_2 emitted during food transport into perspective. The transport part of the food chain only contributes around 5% to all of the greenhouse gas emissions from food. Most of our food's emissions come from land-use change and emissions *on the farm*: the methane-burping cows; the emissions from fertilisers and manure; the release of carbon from the soils.

How can transport be so insignificant? I think many of us imagine that when we eat food from across the world – bananas from Guatemala, soybeans from Brazil, avocados from Peru or cocoa beans from Ghana – it is flown to us. In reality, almost none of our food is flown. Flying is really expensive – companies won't do it if they don't have to. Instead, most international food trade comes by boat, and shipping is actually a pretty low-carbon way to travel. Transporting food by boat emits more than 50 times less CO_2 than transporting it by plane.

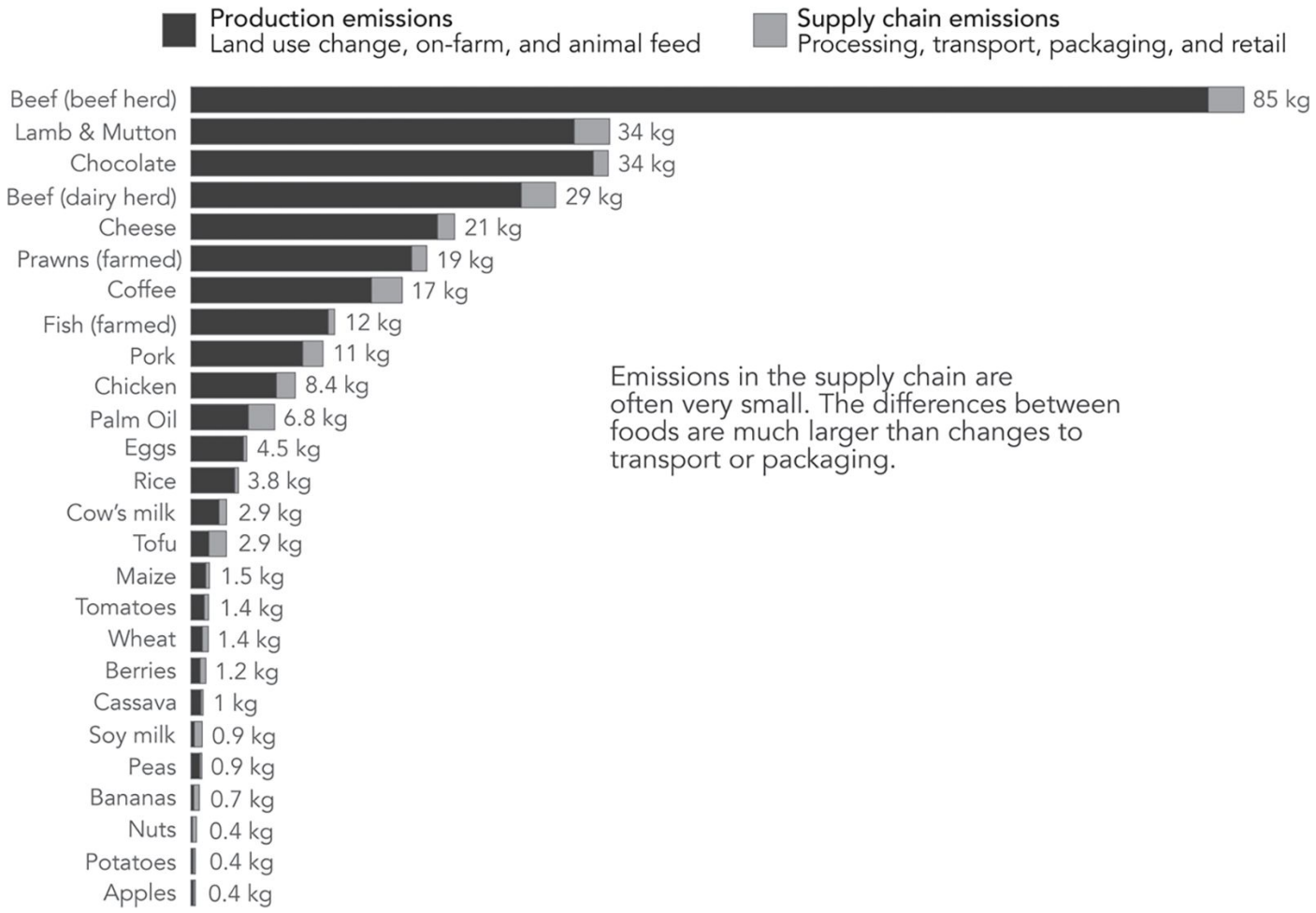
Nearly all of the 5% of food emissions that come from transport is from the roads – the regional or local-level delivery of foods. Shipping of foods is just 0.2%, and aviation even less, at 0.02%.[39]



Transport accounts for a small amount of food emissions
Transport accounts for just 5% of food system emissions. Most of these emissions come from domestic transport on roads, rather than international shipping or aviation.

A common pushback against moving to a more plant-based diet is that the most popularised 'vegan' foods are often produced overseas. Avocados, soy, bananas. Many argue that these products are much worse for the environment than meat produced 'at home'. This is not true because these products are nearly always shipped.

But this doesn't apply when foods are air-freighted. How do we know which foods came by plane? Annoyingly, there is no easy way to tell. I've been advocating for a long time for foods that have been air-freighted to have a small plane symbol on the packet. This is not hard to do, but would make our lives so much easier. Without an air-freight label, there are some general rules we can use. Companies will only choose flying if they need to get the food to us quickly. This means foods that have a *very* short shelf life and would perish within a few days of harvesting, mostly fruits and vegetables that begin to rot very quickly: items such as asparagus, green beans and berries. Fruits and vegetables like bananas, avocados and oranges don't fall into this category. So avoid foods that have a very short shelf life and have travelled a long way (many labels have the country of 'origin' which helps with this).



What you eat matters much more than where it has come from
Transport and packaging emissions are usually a small part of the carbon footprint of our food. Eating a more plant-based diet is more climate-friendly than trying to eat more locally. Emissions are measured in kilograms of carbon dioxide-equivalents per kilogram of food.[fn13]

Another caveat is that it's not that it doesn't matter *where* food is produced, it's that the *distance travelled* is not important. Where food is produced can matter a lot – across the world there are very different farming practices, climates and conditions for planting crops and raising livestock. Even for a single type of food there can be large differences in its carbon footprint depending on how and where it's grown.

This means that eating locally can actually be *worse* for the environment, especially when we opt to grow food where it's not supposed to be grown. The UK is never going to be the place to grow cocoa beans or bananas. We could create a tropical environment in a greenhouse, but that would need lots of energy – far more than is needed to ship these foods from Africa or South America, where they grow brilliantly. There are many examples where importing food often has a lower footprint. Importing Spanish lettuce to the UK during winter months reduces emissions three- to eight-fold.[40] Tomatoes produced in greenhouses in Sweden use 10 times as much energy as importing tomatoes from Southern Europe when they are in season.[41]

When we stop and think about it, it's absurd that 'eating locally' could be useful as a rule for everyone in the world. For Brazilians, eating local beef might mean eating beef responsible for deforestation in the Amazon. A better rule is to eat foods that are grown where the conditions are optimal. That means you should buy tropical foods from tropical countries, cereals from countries that get very high yields, and meats where pasture lands are productive and forest doesn't need to be chopped down for pastures to expand. Depending on where in the world you live, that might or might not be local to you. The point is, it's a consideration that doesn't really matter.

Eating organic – it is not always better for the environment

This one is a hard pill to swallow. When we think about the food labels that best signal environmental responsibility, 'organic' immediately comes to mind.

But in fact it's not obvious that organic farming is better for the environment than 'conventional' farming.[fn14] Organic farming tends to promote better biodiversity – for bugs, in particular. If we were to compare one hectare of organic croplands and one hectare of conventional croplands, we'd probably find healthier ecosystems on the organic farm. But its big Achilles heel is that organic farming tends to give us lower crop yields, which (yes, you know where I'm going) means we need to use more land. That then introduces a trade-off and creates a divide in opinion of how best to preserve biodiversity: should we farm intensively over a smaller area, or should we farm organically, impacting biodiversity over a much larger area.[42] The jury is still out.

What's better for the climate though: organic farming or conventional? Turns out, there's no clear winner. One meta-analysis brought the results together from 164 published studies and 742 agricultural systems to compare their environmental impacts. On greenhouse gas emissions, it was a mixed bag. In some studies, organic won; in others, conventional farming did.

The same meta-analysis showed the unanimous result that organic farming was worse for land use, and also found that organic farming was worse for the pollution of rivers and lakes. We often worry about the damage that putting synthetic fertilisers on our crops does to the surrounding ecosystems, but it's wrong to imagine that this doesn't happen in organic farming. Organic farmers still put nutrients on their crops – often in the form of manure. This means that, unfortunately, a lot of excess nutrients from manure are simply washed away into rivers and lakes where they cause algal blooms and other imbalances in our ecosystems.

There's certainly a place for organic farming – in some local settings it might be better than the alternative – but it doesn't work on a global scale. And it's certainly not the case that it is the green panacea it's often portrayed to be.

As I write this, it's creating havoc for farmers across Sri Lanka. In 2021 the Sri Lankan government suddenly banned the import of fertilisers into the country, wanting the country to move towards an organic farming system. It has been a disaster. Food

production across the country has plummeted and prices have rocketed – the cost of vegetables increased more than five-fold. Sellers said they've never seen times so bad. Most struggle to find vegetables, and when they do, they can't afford them. Many farmers are expecting a harvest of just half of what they're used to. The whole experiment has been a failure, and the Sri Lankan government is quickly trying to roll it back.

This snap decision – that has had devastating impacts for so many – has given us a short-lived window into what the world might look like if we went organic. Let me be clear: there is nothing inherently wrong with organic farming. In many contexts, with good soils and ample nutrients, it can work well. In some situations it *is* the best solution. But it cannot be a blanket solution and it is not going to fix our food system.

People often assume that organic food is inherently healthier than non-organic food. A key concern for consumers is their exposure to pesticides when eating non-organic food, and it's true that organic food tends to record less synthetic pesticides. In a study across three investigations in the United States, organic foods had around one-third of the pesticide residues of conventionally grown produce.[43] This shouldn't surprise us. But the important question is whether we should be worried about these levels of pesticide residues. The World Health Organization has established 'safe' daily intake levels, where exposure has no negative effects on human health. Governments and food governance bodies then have to stick to these levels. And, in many countries, they do.

A study in the US investigated the 10 most common pesticide residues across 12 food groups. They found that all foods had pesticide levels *well* below the limits. The majority (75%) of foods were less than 0.01% of the limit. This means residue levels were a million times lower than the threshold that would have observable effects on our health. There are similar examples from a range of countries.[44] [45] We shouldn't assume that this is the case everywhere, though. There will be countries where food is not handled appropriately after it has been harvested, which makes it hard to be sure that pesticide residues aren't over the WHO limits. As more and more farmers get access to pesticides – particularly in lower-income countries – we need to make sure that regulation and monitoring are put in place at the same time.

In conclusion, in places with good food governance bodies, non-organic food is perfectly safe. And there is little evidence to suggest that organic food is healthier. And if you want my personal recommendation: I never optimise for buying organic food. I don't seek it out. I don't avoid it either. I am agnostic. Much like the 'eating local' story: I know that *what* I eat matters much more than whether it's organic or not. This is the case for its environmental and nutritional impact. I focus much more on what's *in* the wrapper than whether there's an approved label on it.

Plastic packaging – its impact is overhyped

I get it: there's no need for our food to be wrapped in five layers of plastic. Companies overdo it, often adding extra bits of packaging so that they can make products look pretty, or show their branding off. But a move to *zero* packaging would be a disaster. We'd end up with even more food waste, which would be worse for the environment.

Once again, *what* you choose to eat and making sure that it actually gets eaten matters much more than what it's wrapped in. The carbon footprint of the plastic packaging is tiny compared to the footprint of the food wrapped inside it. Just 4% of food's emissions come from packaging.

Chapter 7 will look at plastics and their impact on the environment in more detail. For now, my recommendation is to ditch the excess packaging when you can. Bananas don't need to be wrapped in plastic – they already have a skin. But for many foods the plastic is there for a reason: it keeps our food safe and fresh, and it stops us from throwing it in the bin, which makes a much bigger difference.

If we do all of this, what could the world look like?

The year is 2060. Everyone has – remarkably – read this book, and put these recommendations into action. What does the world look like?

There are 10 billion of us. So we didn't get wiped out – that's a good start. Impressive progress in agricultural technologies and access to better seed varieties mean that crop yields have continued to increase across the world.

We have also made progress on slowing climate change, but, as expected, the world is still warmer. Thankfully these innovations in crops have allowed us to develop varieties that are resilient to warmer temperatures and periodic droughts. Even in tough times, farmers still get a decent harvest.

Countries across sub-Saharan Africa don't simply grow enough to feed themselves; they are also large exporters to the rest of the world. Rich countries have rolled back their aggressive and stifling trade policies, and rely on them for their cocoa, coffee and tropical fruits. High returns on agriculture mean that not everyone in the family needs to work on the farm now. Kids instead go to school, then university, and become teachers or start businesses in the city. The farmers work less and get paid considerably more per hour. Since they have managed to increase food production through higher yields, their beautiful forests are still standing.

Everyone in the world has a sufficient and nutritious diet, not just in terms of calories, but also protein and essential micronutrients. We eat a diverse range of foods. Some people still eat animal products, but the world as a whole eats much less than it did in the 2020s. Diets are much more plant-based; we have a wide variety of grains, fruits, vegetables and pulses. We've figured out how to make perfect analogues of dairy from plant-based products. They taste exactly the same.

The amount of land the world dedicates to farming is just a fraction of what it was in the 2020s. Take an aerial shot and we can see forests regrowing where they once used

to be. Wild grasslands are making a comeback. Ecosystems are springing back to life.

This might sound like a magical, overoptimistic vision of the future. But take any one component on its own, and there's no obvious reason why it can't be done. Sure, it might not be simple or straightforward. But it is doable. We can have this future if we want to.

6

Biodiversity Loss

Protecting the world's wildlife

'Two generations of humans have killed off more than half the world's wildlife populations'

– *Washington Post*, 2018[1]

Versions of this headline pop up every two years when the World Wildlife Fund publishes its big report on the state of the world's wildlife. All of them misinterpret the numbers. But that doesn't stop them going viral.

It's not surprising, and I have no right to mock. The metrics we use to measure biodiversity are often tricky to grapple with, and many of us find ourselves tied up in terms that we've misinterpreted, including me. Several years ago I was interviewed on US National Public Radio about some of the world's most important statistics. I wanted to highlight the worrying decline in wildlife, so I picked the headline numbers from the World Wildlife Fund's Living Planet Index (LPI). I can't remember exactly what I said – and it's too painful for me to go back and listen – but I panicked. I said something along the lines of 'the world's animal populations have declined by 68% since 1970'. This isn't true – that's not what that metric shows. It's embarrassing – given that part of my job is trying to correct public miscommunications of data – that I stumbled so badly.

I can't take back my mistake, but I can try to make sure we get this reporting right in future. Why are these headlines wrong, and what does the Living Planet Index really show? Well, it tries to measure the change in species *abundance* – how many individuals there are – across more than 30,000 animal populations. A 'population' is defined as a species within a geographical area. So, despite being the same species, the African elephant in South Africa and the African elephant in Tanzania are counted as different populations. The Living Planet Index measures the *average* change in the size of these populations. To show how easily this metric can be misinterpreted, let's run through a quick scenario.

Take the real-life example of two populations of the black rhino: one in Tanzania and one in Botswana. In 1980 there were 3,795 rhinos in Tanzania, and only 30 in

Botswana. Over the next few decades intense poaching in Tanzania plunged its population to critically endangered status: by 2017 there were only 160 rhinos left. Things in Botswana actually improved over that time: its 30 rhinos increased to 50. The Tanzanian rhinos obviously did not fare well: they lost 96% of their population. In Botswana, their numbers increased 67%.

If we calculate the average change of these two populations, we get a value of −15%, which means the black rhinos saw an average decline of 15%. For simplicity here, I'm using the 'arithmetic mean'. In the LPI, researchers use the 'geometric mean', which is slightly different but has the same problem of averaging across many populations and being sensitive to outliers. Headlines might report that 'we've lost 15% of black rhinos', but that's wrong. In 1980, the total number of the animals was 3,825. We then lost 3,615 of them. This means we lost 95% of the rhinos! The LPI is a very different measure from the number or percentage of individual animals lost.

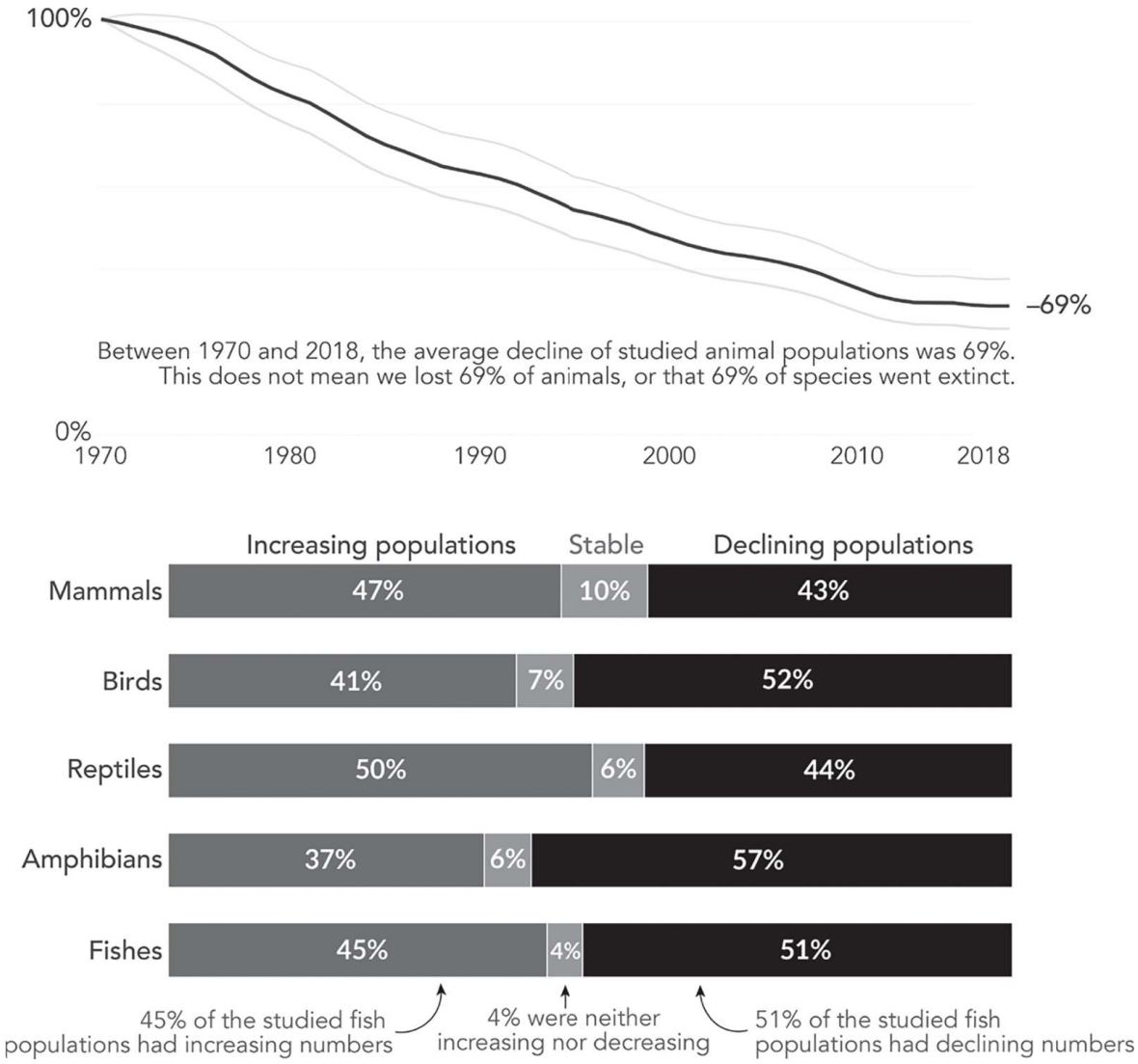
This highlights an even greater danger when reporting the LPI. By averaging these two populations we're left clueless about the status of either of them. The black rhino in Tanzania has lost 96% of its population and has become critically endangered. On the other hand, something is going very right in Botswana. It might mean we don't prioritise the Tanzanian black rhino when we really need to. And we might lose out on an important lesson from Botswana on how to increase numbers in critically endangered populations.

So, what the Living Planet Index actually tells us is that by 2018, *on average* these numbers have declined by 69% since 1970. There is no doubt that many animals are seeing a worrying and accelerated decline. But dig a little deeper and we find that something is going right for some animals too. When we look at the direction of change we find a very mixed picture. Almost half of the animal populations were increasing, and half were decreasing.[2] Forty-seven per cent of mammal populations increased, 43% decreased and 10% didn't change at all. Forty-one per cent of birds increased, 52% decreased and 7% didn't change at all. Just as many populations have increased in size as have decreased. To get such a large *average* decline across all populations, those that are declining must be doing so much faster or at a much bigger magnitude than those that are increasing.

These results don't tell us that we shouldn't worry about the state of global wildlife. There is no doubt that we're destroying biodiversity at record rates – many species are speeding towards extinction. But to solve this problem we need to make a big deal about the ones that are struggling so badly.[3] To tell the real story on biodiversity, we have to be conscious of how the headlines are communicated.

As we'll see later, losing 69% of the world's species within decades would mean we were just inches away from mass extinction. Thankfully we're still far from that point, and we have more than enough time to turn things round.

The northern white rhino is about to go extinct. Najin and her daughter, Fatu, are the only two left. Sudan, the last remaining male, died in 2018. The fall of this beautiful animal is a tragic one. Go back to 1960 and we'd find more than 2,000 of them, most living in Sudan and the Democratic Republic of the Congo. Since then, their numbers have plunged from intense poaching.



We have not lost 69% of wildlife, but many populations are struggling
The 2022 Living Planet Index reported a 69% average decline in wildlife populations since 1970. Only some wildlife is struggling: around half of populations were increasing, and half were declining.

As the last two rhinos are female, the prospects for reproduction look slim. But this hasn't stopped scientists and conservationists from pouring time and money into saving them. Najin and Fatu live in Ol Pejeta Conservancy, a protected wildlife area in Kenya. They're watched by armed guards all day, every day. Their horns have been sawn off to deter poachers. In labs across the world, scientists are trying to develop reproductive treatments – stem cells, hybrid embryos, embryo implantations – to bring these rhinos back from the brink. It's an international effort with low odds of success.

Why are so many people dedicated to saving this single species? It doesn't really make sense. It's expensive to protect only two individuals, money and time that could be used in a range of other ways. Not least in trying to restore populations of the *southern* white rhino – its cousin species that is still going strong, but under threat. It's not just the scientists and conservationists who have become invested in this project. Many of us have been drawn into the story.

This touches on the bigger question of why we care about biodiversity at all. The scientist in me wants to make a practical argument about why I care about the rhinos. Humans rely on balanced ecosystems. We need biodiversity to survive. That's mostly true, but not always. There are some species where this functional value is obvious. For others, it's less clear-cut. Ecosystems are complex: the needs and dependencies between species are intricate. We are notoriously bad at understanding them. There are countless tales throughout history of us meddling with ecosystems and making a mess. As the ecologist and economist Garrett Hardin coined in the First Law of Ecology: 'You can never merely do one thing.' If you don't consider second-order effects (the effects of the effects) then you're asking for trouble.

So, for many of the species where the functional value is not obvious, the value might instead be hidden via an intricate web of prey, predator and ecological connections. We don't see it until things go wrong. This is why understanding which species we 'need' and which we don't is not clear-cut. What makes this even more difficult is that different measures of biodiversity tell us to 'protect' different species and parts of the world.[4] We should always be humble about this when we are tempted to go meddling.

But there are still cases where the importance – or non-importance – of a species is obvious. The northern white rhino is a good example of a 'non-important' species. Najin and Fatu are not essential to sustaining life that we rely on. By keeping them in a guarded enclosure they're actually cut off from wild ecosystems. If they disappeared, there would be no ecological collapse. We'd be perfectly fine. To put it bluntly: we don't *need* them. If Najin and Fatu died tomorrow, nothing would break except our hearts.

So, there's more to our attachment than the functional argument. Wildlife is beautiful and makes us happy. We find joy in nature: looking for bumblebees or butterflies in the garden, searching for squirrels in a forest, or fish on an ocean dip. Even when we don't see wildlife for ourselves (I've never seen a rhino), it's enough to know that it's out there somewhere.

In his book *Do We Need Pandas? The uncomfortable truth about biodiversity*, the ecologist Ken Thompson argues – as is probably obvious from the title – that we give disproportionate attention to the species that provide the least functional value (the pandas) and we ignore the species that really do matter for our survival (the worms and bacteria).[5] For a long time I tried to push back against this disconnect, but finally accepted that it's okay to be motivated by either or both at the same time. If something,

anything, drives us to take positive action we should harness it. For some people it will be about the ecological contribution to human survival. For others, it will be celebrating the beauty of the life around us, or standing up for the rights of other species.

For many, like me, it will be some combination. A combination that doesn't always make logical sense. In the foreword to Thompson's book, Tony Kendle captures my scientist/human dilemma beautifully:

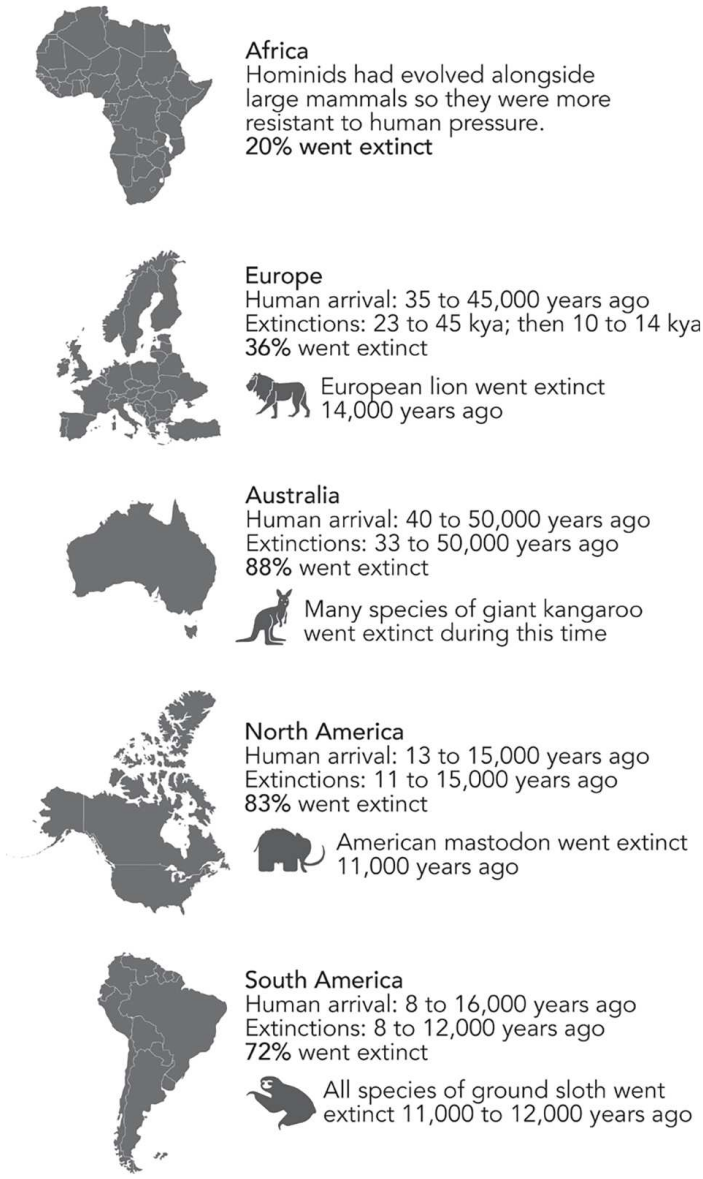
> This lack of comfort with subjectivity betrays an issue that cuts to the heart of the conservation challenge and the role of science. Sometimes we fight hardest to protect things because they move us, not because of objective valuation of their functional importance … Bacteria keep us alive more than bears do, but the bears help us to have lives worth living.

How we got to now

We might love big animals more than bacteria and worms, but that hasn't stopped us from hunting them. The most visible and profound impact that humans have had on the world's wildlife lies in the transformation of our own kingdom: the mammals.

The question of when humans migrated out of Africa, and first laid roots across the world's continents, is one that has been hotly debated and contested. We now have many archaeological clues about these timings. But there is another way to trace the journey of humans across the planet: looking at when mammals went extinct. Wherever we see large mammals dying out, we find our ancestors' footsteps not far ahead.

Not long after humans reached Australia, species of giant kangaroo were killed off. When we reached North America, the American mastodon went extinct. Our arrival in South America was the end of the ground sloths. This wave of mammal extinctions stretched across the globe from around 52,000 to 9,000 BC in an event called the Quaternary Megafauna Extinction.[6] 'Megafauna' are big mammals – those weighing over 44 kilograms, which span everything from sheep to mammoths. At least 178 of the world's largest mammal species died out.



The extinction of large mammals follows the footsteps of human migration
The Quaternary Megafauna Extinction killed off more than 178 of the world's largest mammal species from 52,000 to 9,000 BC. These extinctions closely mapped human migrations across the world's continents.

Some have argued that it was a changing climate that killed these animals off. But there is now compelling evidence to suggest that our ancestors also played a crucial role in their downfall.

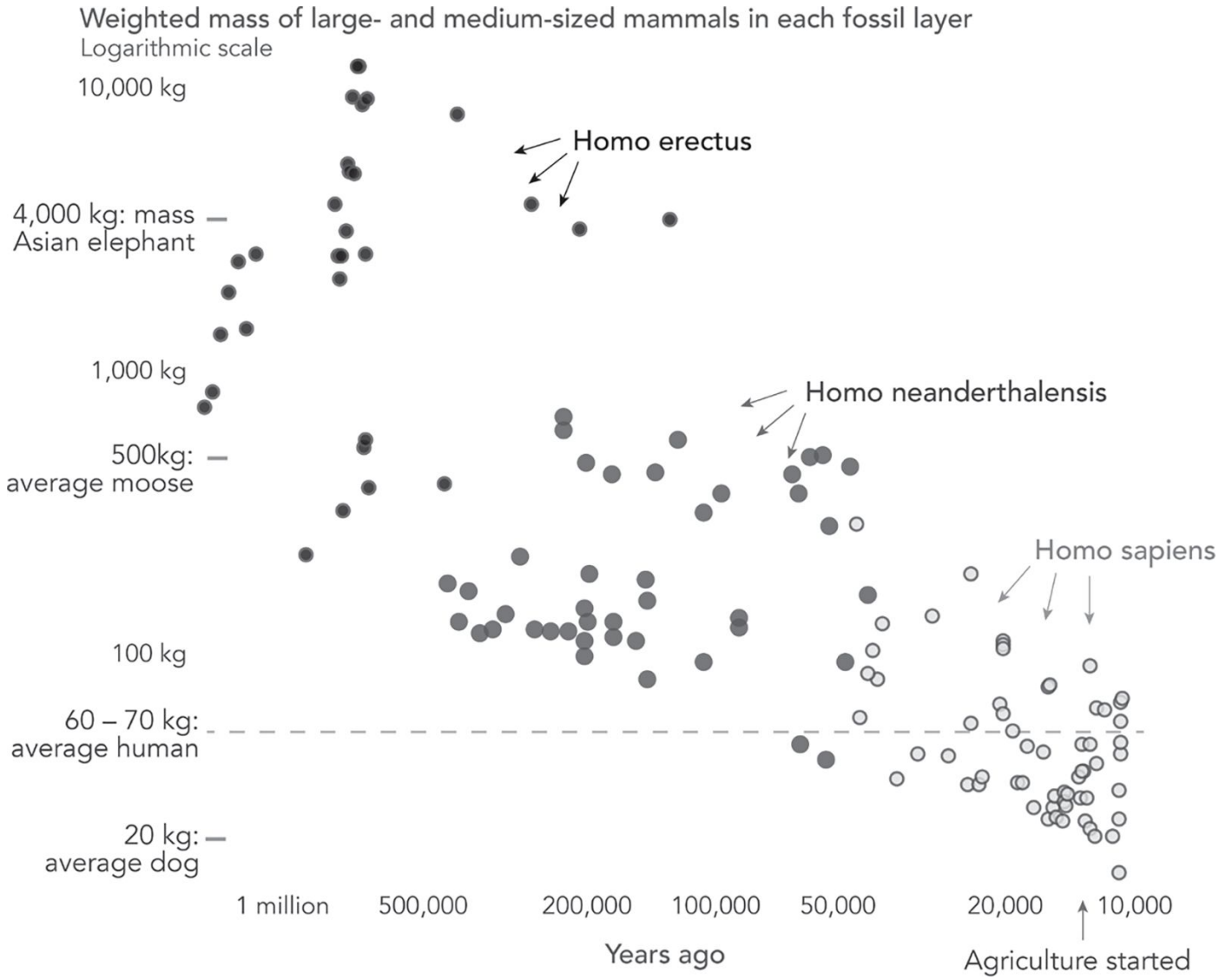
The final trail of evidence in this murder mystery comes from the fossil record. Look at the size of mammals over human history and we see one clear trend: they've got smaller.[7] The evidence for this decline is found in many records from across the world.

In the Levantine – the Eastern Mediterranean – researchers have reconstructed the mass of mammals going back more than a million years and found that the mean mass of hunted mammals decreased by more than 98%.[8] One and a half million years ago, our

Homo erectus ancestors were roaming the Earth with mammals that weighed several tonnes. There were the 'straight-tusked elephants' (which weighed between 11 and 15 tonnes), the southern mammoth, and incredibly large hippos. Species by species, these majestic animals began to disappear. Nearly all the mammals that went extinct were big. If the climate alone was to blame, it wouldn't make much sense that it was *only* the biggest mammals that suffered. Big mammals do have lower reproductive rates which make them more vulnerable, but we'd expect smaller mammals to be partly affected too. The climate doesn't discriminate, but humans do.

It's likely that tens of thousands of years ago, our ancestors played a heavy role in killing off hundreds of the world's largest mammals. They possibly did this through overhunting; but fire and other pressures on natural habitats possibly played a role too.

There were never more than *5 million* people alive at any given time during this period. Nearly 2,000 times less than live on Earth today. A global population half that of my home city – London – drove hundreds of the largest mammals to extinction. That is hard to imagine. It goes against the common environmental narrative we see today: that ecological damage is the result of uncontrollable population growth. If a mere 5 million could transform the whole mammal kingdom, this is obviously not true.



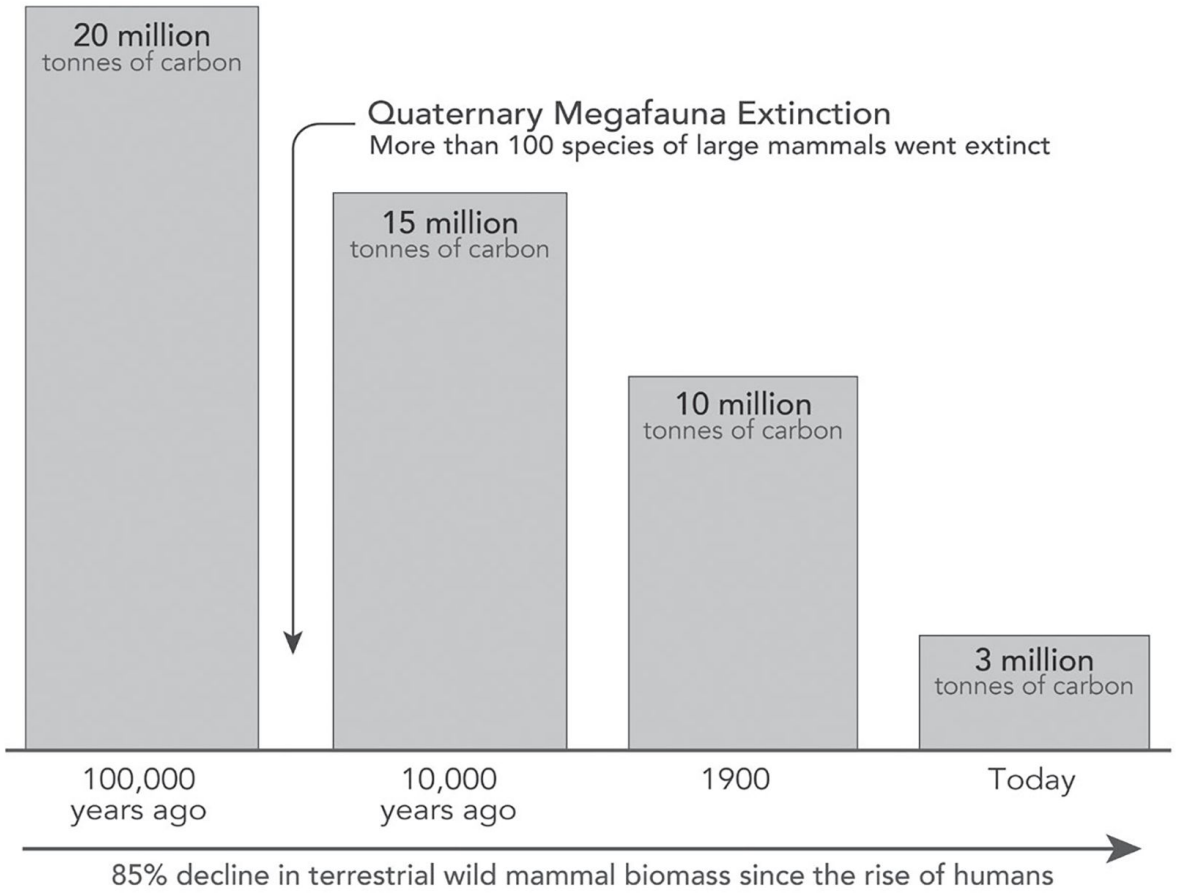
Hunting has driven the largest mammals to extinction
Fossil samples from the Levantine region show us that mammals have become smaller and smaller through time.

The reshaping of the world's mammals didn't stop there. Before the onset of agriculture around 10,000 years ago, the biggest threat to animals was us hunting them directly. Once farming kicked off, it was the destruction of their habitats. Slowly but surely our farmlands expanded. It took a lot of land to grow even a small amount of food. As seen in Chapter 4, this came at a huge environmental cost. Vast swathes of forests were cut down. Grasslands were taken over. Whole ecosystems were completely transformed. The homes and corridors of many great species were first shrunk, then eliminated completely.

This series of events was like a left jab followed by a right uppercut. It annihilated the mammal kingdom. There has been an 85% decline in wild mammal biomass on land since the rise of humans.[9, 10, 11] Biomass is, basically, the amount of 'stuff' that we are made up of. Each animal is measured in tonnes of carbon, the fundamental building block of life. For context, one tonne of carbon is equal to around 100 humans or two elephants.

Researchers estimate that 100,000 years ago terrestrial wild mammals weighed in at around 20 million tonnes of carbon. The Quaternary Megafauna Extinction killed off one-quarter of this biomass, reducing wild mammals to 15 million tonnes. By the year 1900, as agriculture expanded across the world, this biomass was cut by another 5 million tonnes. Wild mammals had been reduced by half, even before the onset of the 20th century and its rapid population growth and global industrialisation.

The rate of decline over the last 100 years has been even faster. Wild mammal biomass is now down to 3 million tonnes of carbon. Just 15% of what roamed the planet 100,000 years ago.

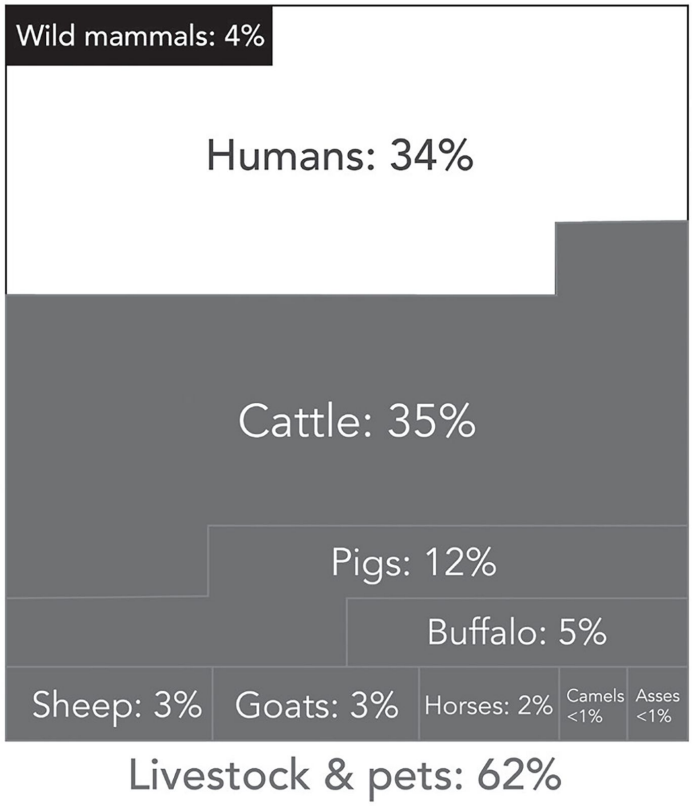


Humans have been driving wild mammals into decline for a long time
Estimates of the total biomass of wild mammals on land. Wild mammal biomass has declined by 85% since the rise of humans.

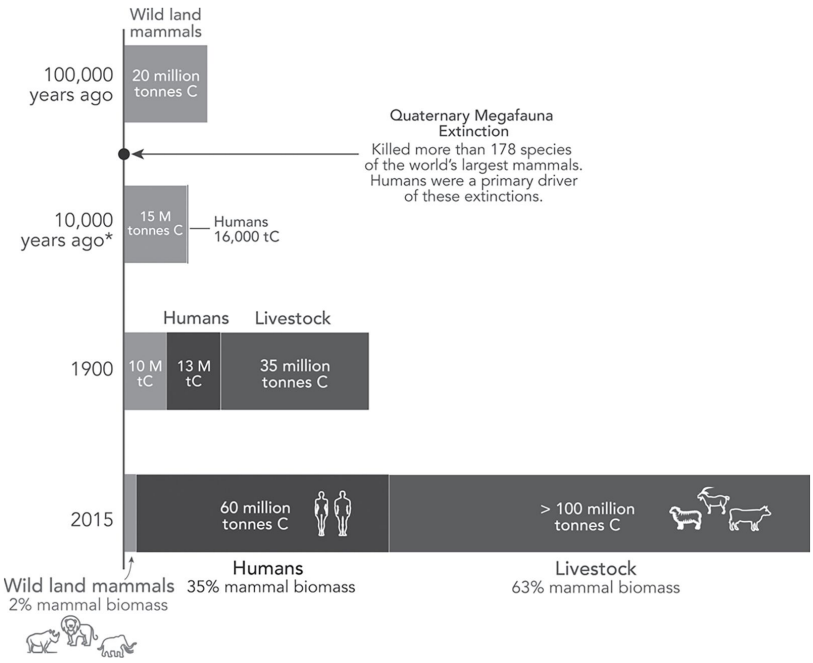
But it's not just this massive *decline* in wild mammals that has changed. It's also what has been added in its place. The whole balance of the world's mammals has been tipped, with humans and our livestock taking over. We can see this when we tally up the biomass of humans and our cows, pigs, goats, sheep and other farm mammals.[fn1]

By 1900, wild mammals made up just 17% of total mammal biomass. Humans made up 23%, and our livestock, a whopping 60%. This imbalance is even more dramatic today. Wild mammals make up a tiny 2%, humans 35%, and our livestock 63%.

Even if we add in marine life – mostly whales, which pack a lot of carbon – it brings wild mammals up to just 4% of the total pie. The mammal kingdom today is dominated by humans. The 8 billion of us weigh quite a bit. Almost 10 times more than wild mammals. But it's the animals we raise to eat that really change the picture. Cows alone weigh almost 10 times as much as all wild mammals combined. The biomass of all the world's wild mammals is about the same as our sheep.



Most mammals are now humans and their livestock
Mammals are compared based on their biomass, in the year 2015. Wild mammals are just 4% of total mammals.



Wild mammals have been crowded out by humans and our livestock
The world's mammals are compared in terms of their biomass. This is measured in tonnes of carbon.

While the *diversity* of the mammal kingdom has decreased, its total size has expanded a lot. Ten thousand years ago, all the world's terrestrial mammals – including us and our livestock – weighed in at an estimated 20 million tonnes. This is now around nine times larger. Humans have increased the size of the mammal kingdom almost 10-fold.

Here we're focusing on mammals, so wild birds or poultry aren't included. But for birds, the story is the same: we have twice as much chicken biomass as wild birds.

Humans make up a tiny fraction of all life on Earth: just 0.01% of it.[fn2] But we have been the ones that have reshaped it beyond recognition. As the environmentalist, Stewart Brand, put it: 'We are as gods, we might as well get good at it.'

Where we are today

How many species do we share our planet with? It's such a fundamental question for understanding the world around us, but it's one that continues to escape the world's taxonomists.

The ecologist Robert May summed it up nicely in a paper published in the journal *Science*:

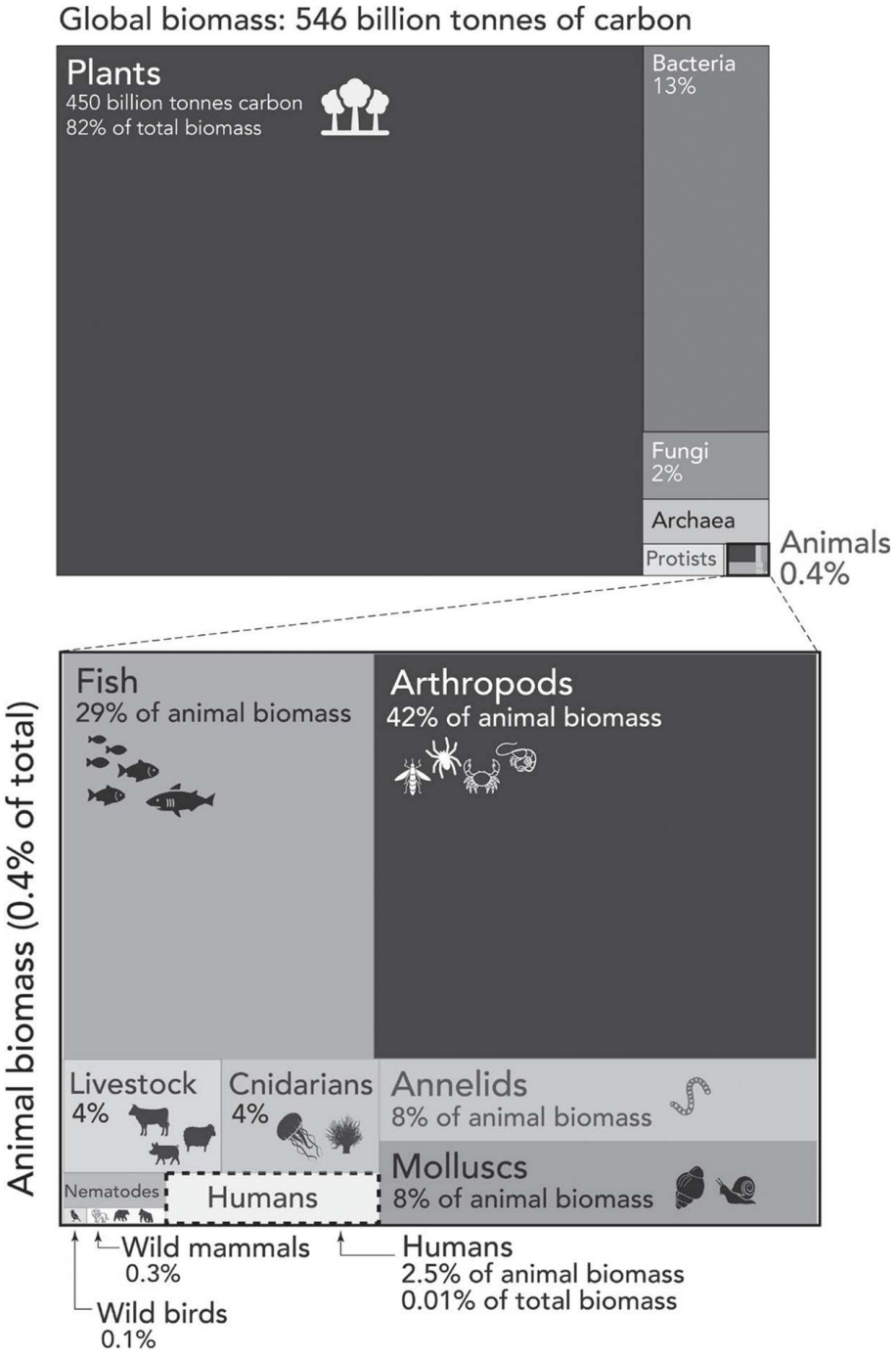
> If some alien version of the Starship Enterprise visited Earth, what might be the visitors' first question? I think it would be: 'How many distinct life forms – species – does your planet have?' Embarrassingly, our best-guess answer would

be in the range of 5 to 10 million eukaryotes (never mind the viruses and bacteria), but we could defend numbers exceeding 100 million, or as low as 3 million.[12]

One of the most widely cited estimates is around 8.7 million species on Earth today: 2.2 million in the ocean, and 6.5 million on land.[13, fn3] Researchers tend to agree on the most well-studied taxonomic groups – the mammals, the birds and the reptiles. Where they disagree is in counting all the tiny and inaccessible life forms we can't see: the insects, fungi and other microbial species.

The honest answer to 'how many species are there?' is that we don't really know. But recent estimates lie somewhere in the range of around 5 to 10 million.

We know very little about most of those 10 million species. The IUCN Red List tracks the number of described species and updates this figure annually. In 2020 it listed 2.12 million species. That's a lot of species with missing entries.



Life on Earth
Humans account for just 0.01% of life on Earth, as measured by biomass. But our impact is much, much bigger.

Humans make up just 0.01% of Earth's life

In one study, researchers looked at how biomass is distributed across all the organisms on Earth. It made clear that Earth is a planet of plants. Or, more specifically (and despite our rapid rates of deforestation), a planet of trees. They dominate life on Earth, accounting for more than 82% of biomass. Surprisingly, in second place is the life we

cannot see: tiny bacteria make up 13%. And while nearly all our focus is on the animal kingdom, it accounts for only 0.4%.

When we zoom into the animal kingdom we see it is dominated by insects and fish. These are the animals we rarely see because they are nestled in trees or soils, or inhabit the unknown waters of the ocean. Humans make up a truly tiny fraction: just 0.01% of the total, and 2.5% of animals.

The Insect Apocalypse

'The Insect Apocalypse Is Here' was a headline in the *New York Times* that took the world by storm.[14] The term has stuck ever since. We now take it as a given that the insects are on their way out. But – as you might expect by now – it's not quite as simple as that.

Rachel Carson's 1962 book, *Silent Spring*, was one of the inspirations that pulled me into the field of biodiversity. She was a pioneer of her time, one of the first to warn about the demise of ecosystems from our indiscriminate spraying of the insecticide DDT. Carson was a trailblazer, putting science and integrity before popularity. So, scientists have been worried about this issue for a long time. But it's only really in the last five years that terms such as *insectaggedon* have become part of scientists' vocabulary. The world really got talking in 2017 when a study in Germany reported that flying insect biomass had declined by more than 75% in just 27 years.[15] These results were shocking. If 75% had gone in less than 30 years, they might vanish completely within a decade. And if *all* insects were disappearing at this rate, perhaps the world would soon be insect-less.

As Edward O. Wilson put it: 'Insects are "the little things that run the world".'[16] We know that insects form one of the bedrocks of healthy ecosystems. Some of them – such as bees and butterflies – are important for food production. I used to think that our food system was entirely dependent on the world's pollinators; that without them we would starve. But this is not true. Around three-quarters of our crops depend on pollinators to some extent, but only one-third of the total food we produce does.[17, 18, 19] This is because many of our largest producing crops – staples such as wheat, maize and rice – are not dependent on them at all. These staple crops are pollinated by the wind. Very few crops are completely dependent on pollinators. Most would see a drop in their yields if the bees disappeared, but they wouldn't collapse completely.

Taking all this into account, studies suggest that crop production would decline by around 5% in higher income countries and 8% in low to middle incomes if pollinator insects vanished. I don't say that to undermine the importance of insects. They are crucial. They decompose organic matter to make nutrients available to plants. They keep our soils healthy. They lie near the base of the food chain, allowing the ecosystems that are built on top of them to thrive. They play a key role in the diversity of our crops,

and they are *essential* to some foods: Brazil nuts, fruits including kiwis and melons, and cocoa beans would not grow without them. A world without pollinators would mean a world without chocolate. That's not a world I want to live in. So, sure, we might be able to get enough calories without them, but our diets would lack diversity and farmers across the world would struggle to make a living.

How worried, then, should we be about the state of the world's insects? We should be concerned, but things are not *quite* as bad as many believe. We don't have a clear answer on what's happening to the world's insects because they're so hard to measure. Counting ants is much more difficult than counting elephants. We struggle to work out how many insects we have *today*; imagine the challenge of trying to estimate how many there were decades ago. With other animals we can get great clues from skeletal remains or historical records. But no one was really counting earthworms in the 19th century, and they didn't leave much in the way of ecological footprints.

That's why we often cling to the findings of a single study, like the one that hit the headlines from Germany. We take the trend of one insect species in one single location and extrapolate it to the rest of the world. These studies are informative, but we should be careful about extrapolating too much. The findings from a single species of beetle at a site in Cheltenham does not tell us how insects are doing across the world.

When we look at a wider range of studies, the picture is more complex. The largest meta-analysis on insect populations to date comes from the scientist Roel van Klink and his colleagues, published in *Science*.[20] They brought together the results of 165 studies, spread over 1,676 different sites, and which took place between 1925 and 2018. The studies varied in length – but the average was 20 years.

They found a very mixed picture, and there was no consistent pattern. Some insect populations really were plummeting. Others were doing just fine. In fact, some were flourishing. By aggregating the results, the researchers found that the average trend for insects on land was downward. Populations were falling by an average of 0.9% per year. The decline was most steep in North America, where sites were averaging a decline of 2% per year.

The opposite was true for freshwater insects – they were *increasing*, at an average rate of 1.1% per year. This increase is consistent with other studies. A large analysis from the UK showed the bounce-back of many insect species over the last few decades;[21] one from the Netherlands found the same.[22]

This seems almost unbelievable. How can freshwater insect populations be *increasing*? Well, water quality has improved. The US implemented its Clean Water Act in the 1970s, and water pollution fell significantly. Pollution regulations have been very successful in the EU too. This is good news: effective environmental policies *can* turn things around. Importantly, these regulations didn't ban chemical inputs completely. The US and the EU didn't stop using fertilisers or pesticides; they put policies in place

to use them more efficiently and carefully. It doesn't have to be all or nothing, despite what many environmentalists argue for.

Studies from South America, Africa and Asia have found that the downward trend for insects on land is just as bad – if not worse – in the tropics.[23] This shouldn't surprise us; this is where deforestation rates are highest, agriculture is expanding, and natural habitats are disappearing most rapidly. It's also where the richest sites of biodiversity are. There's even more to lose.

My point is not that the world's insects are flourishing. In many places they're not: they're in a steep decline. But it's not true that this is happening everywhere, and to every species.[24, 25]

There's still a lot that we can do to protect the insects that are in serious trouble. The tricky part is that there is no single reason why they're struggling. As one paper puts it, human-driven insect decline is 'death by a thousand cuts'.[26] Insects are facing many pressures, from climate change to habitat loss, from pesticides to the introduction of new species, which means there's not one thing we can just 'fix'. In some cases, it's probably going to force some trade-offs.

The automatic response of many when they hear about the 'Insect Apocalypse' is 'Ban fertilisers and pesticides completely'. I get this, but it would be a terrible decision. In the last chapter we saw how vital nutrients have been. They are essential for feeding the world, but also reduce the amount of land we need for farming by increasing yields. That's land that would have cost us forests, grasslands and natural habitats. Turning a thriving ecosystem into a farm is one of the worst things you could do for insect biodiversity.

I hate to admit it, but I think the loss of some insects is inevitable. But by minimising the amount of farmland *and* by using fertilisers and pesticides more cautiously and efficiently, we can reduce these impacts. There are many solutions in the realm of biotechnology that help us use agrichemical inputs sensibly: we can engineer crops that are naturally more resistant to pests and disease so we need fewer pesticides; we can make more productive crops so that we need less land to grow our food; we can use scanning technologies to pinpoint *exactly* where we need to add fertilisers, and where we're wasting our resources.

Are we heading for a Sixth Mass Extinction?

Watching the populations of our most cherished animals dwindle is painful. Year by year we find fewer nests in the trees, fewer footprints in the soil and smaller herds in satellite images. As tragic as a population *decline* is, it's a realm away from the complete loss of a species. When we are watching a species in decline – when we have a downward sloping chart – we can cling to the hope that we will reach the trough and numbers will climb again. Indeed, this has happened many times. The African elephant,

the Asian elephant and the blue whale were all on course for a wipeout. But we pulled on the handbrake just in time, and populations have started to recover.

Over the last decade the number of African elephants in Namibia has doubled.[27, 28] In Burkina Faso they've increased by 50%. In Zambia, South Africa, Angola, Ethiopia, Malawi and several other countries, populations are on the up. After enduring a steep decline there were just 15,000 Asian elephants left in India by 1980. Their numbers have now risen to almost 30,000.

Whether a trend is sloping up or sloping down, there is no reason to believe that it *has* to continue that way. We nearly always have the opportunity to turn things around. But when that line hits zero – as it does in an extinction event – our hopes of a turnaround vanish. It's done. It's finished. That loss hits differently. Yet it's one that the planet has experienced many times over.

Ninety-nine per cent of the 4 billion species that have ever lived on Earth are now gone.[29] Extinctions have been a natural part of the planet's evolutionary history.[30] Without them, we wouldn't be here today. Species go extinct, and new species arise. This is evolution-in-action.

The fact that extinction events are a 'natural' part of the planet's history provides the perfect cover for those that want to deny that humans are destroying the world's ecosystems. If extinctions happen all the time, who's to say that it's humans causing them? And if they're a natural part of the evolutionary process, why fret?

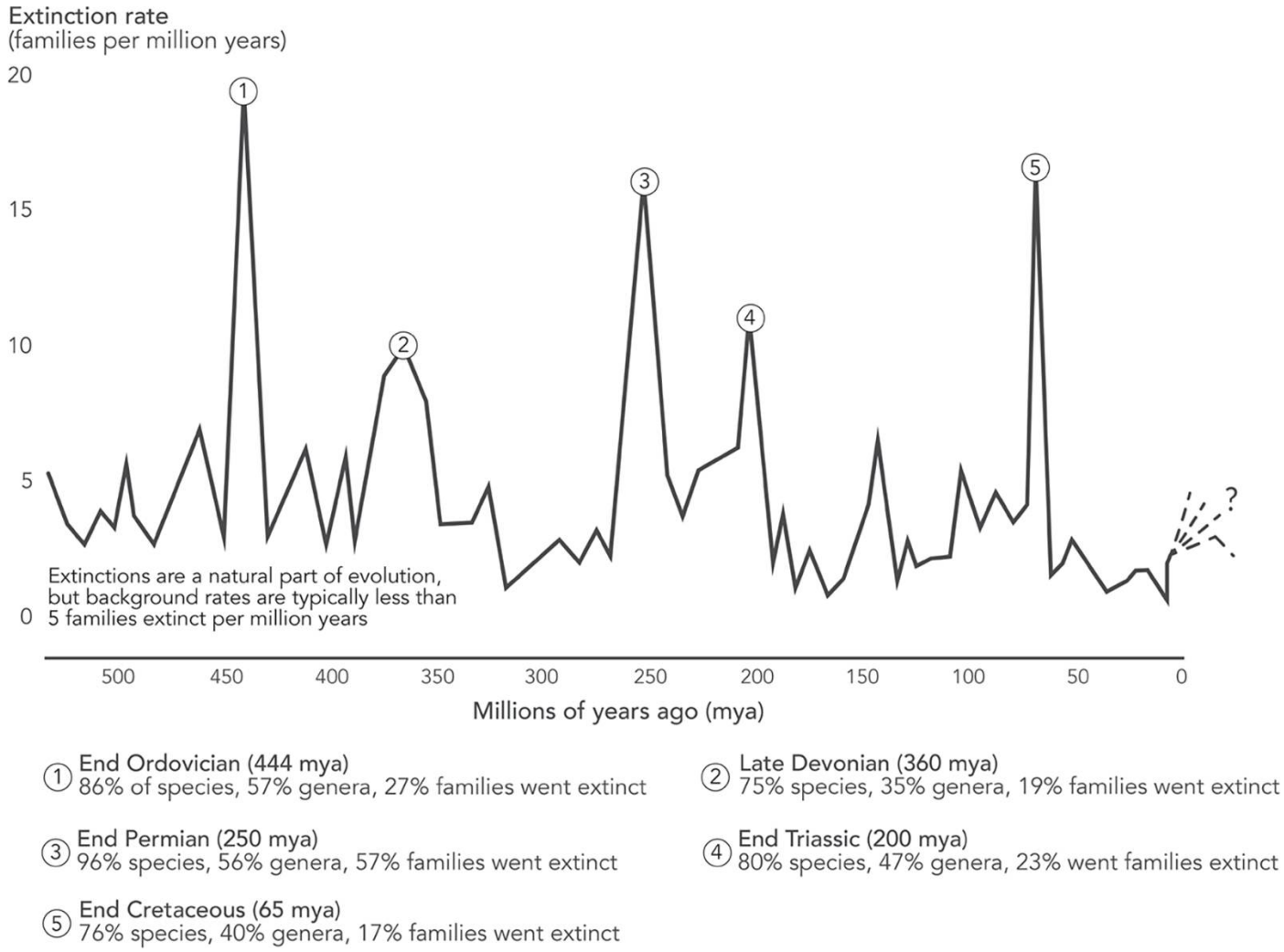
The problem is not that many of the world's beautiful species are going extinct. The problem is that they're going extinct much more quickly than we would expect. So fast, in fact, that many think we're heading for a mass extinction event. The Sixth Mass Extinction.

The media headlines make for grim reading: 'We can't stop our planet's next mass extinction event, researchers say' (CTA News); 'End of the world warning as Earth enters "sixth mass extinction event"' (*Daily Express*). Google 'Sixth Mass Extinction' and you'll find thousands more. None of them instil much hope. But is there any truth to these claims? Are we really heading for – or are we already in – another mass extinction event?

We first need to understand what we mean by a 'mass extinction'. A mass extinction event is when 75% of all species go extinct in a relatively short period of time.[fn4] Here, when I say 'short', I mean something in the realm of 2 million years. A crazily long period of time for us humans to grapple with, but a blink of an eye in the planet's 4.5-billion-year history.

Why is the *speed* of these extinction events important? Well, it's how we differentiate these dramatic changes from the extinctions that we know occur steadily and naturally over time, at what is known as the 'background rate'. At this rate, 10% of species are lost every million years; 30% every 10 million years; and 65% every 100 million years.[31]

We can identify periods of history when extinctions were happening much faster than this background rate. These are mass extinctions. Earth has experienced five of them so far.[32]



'Big Five' Mass Extinctions in Earth's History
A mass extinction is defined by the loss of at least 75% of species within a short period of time (geologically, this is around 2 million years).

In all of these events at least 75% of the world's species went extinct. In the third of the Big Five – the End Permian event 250 million years ago – as many as 96% of species were wiped out.

What caused such dramatic shifts? For most of the world's species to go extinct, the balance of the planet needs to be pushed to the extreme. A driving force of change needs to be strong and persistent. Most of these events were triggered by large swings in the Earth's climate, or changes in the chemistry of the atmosphere and oceans.

The first of the Big Five – 444 million years ago – saw big swings between glacial and interglacial periods. This caused severe changes in sea level and reshaped the world's land masses beyond recognition. At the same time, tectonic plates were shifting – pushing together to form the Appalachian Mountains, causing rock weathering, sucking

carbon dioxide out of the air, and changing the chemistry of the oceans that had been a stable home for many species. The Earth cooled, becoming far too cold for most of the planet's wildlife.

The third extinction event – 250 million years ago – happened when the planet turned into an acidic soup. Intense volcanic activity in Siberia caused the planet to warm and threw sulphur (in the form of H_2S) into the atmosphere. The oceans became acidic baths, acid rained down across the world's landscapes and the chemistry of the planet was transformed. Most of its wildlife didn't stand a chance.

Finally, the most recent extinction: the famous one that killed off the dinosaurs. An asteroid struck Yucatán in Mexico. As the asteroid entered the atmosphere there was probably an intense but short spark of infrared radiation – producing heat so strong that some organisms would have been immediately cooked through.[33] When the asteroid struck the ground, the impact would have kicked large amounts of dust and sulphur into the atmosphere, blocking out sunlight and generating sulphur-laden air. Lands would have frozen over, the rain and oceans would have been saturated with acid, and plants would have died off with barely a glimpse of sunlight.

These events were marked by dramatic changes to the existing air, ocean and land systems. Animals and plants were thrown into a world they did not recognise and were not adapted to. Most of them could not adapt. But some of them could and did. What's perhaps more surprising than the fact that most were killed off is that some survived. Not only did life survive, it bounced back. Between each of the spikes there was a period of recovery where life not only persisted, but thrived. The killing off of some species made way for new ones to emerge.

So, to the key question: are we on course for a Sixth Mass Extinction? Are we already in the midst of it?

To even try to answer this, we need to focus on the two criteria that define a mass extinction: 75% of species, and a period of around 2 million years.

Since 1500 around 1.4% of mammals have gone extinct.[34] Look at other types of animals that are well studied, and it's similar: 1.3% of birds, 0.6% of amphibians, 0.2% of reptiles and 0.2% of bony fishes. That's a lot of animals. It's not close to 75% of the world's species, but the speed at which these extinctions have happened raises alarm bells.

Even if we were to take the fact that 1% of species have gone extinct since around 1500 – just 500 years ago – we can already see that the rates are high. A simple back-of-the-envelope calculation would tell us that if it took 500 years for 1% to go extinct, it would take just 37,500 years for 75% to go extinct – assuming species will continue to go extinct at the same speed.

We can also compare the recent extinction rates to the background rate. The research is quite clear that vertebrates – mammals, birds, amphibians – have been going extinct

100 to 1,000 times faster than we would expect.[35] In fact, researchers think this might be an underestimate because some species have been understudied – some might have gone extinct before we even knew they existed.[36] It gets worse. When we compare modern rates of extinction with the rates during the 'Big Five', we see that we're even outpacing them.

That all paints a bleak picture. When people then ask 'Are we heading for a Sixth Mass Extinction?' the answer seems like it should be 'yes'.

But it's not too late. The bleakness of this picture depends on the assumption that species continue to go extinct as quickly as they have over the last few centuries. That is a massive assumption. One that is wrong. This mass extinction event is unlike any of the others because there is a handbrake. *We* are the handbrake. Earth's previous events were driven by major geological or climatic changes: an asteroid, a massive volcano and clashes of tectonic plates. Once those atmospheric and ocean chain reactions got set in motion, there was no stopping them. This time the driving force is us. And we have the option to stop, to turn things around. If we make the right decisions today then we can slow – possibly even reverse – this damage. In some places, we already are.

Wildlife is making a comeback across some regions

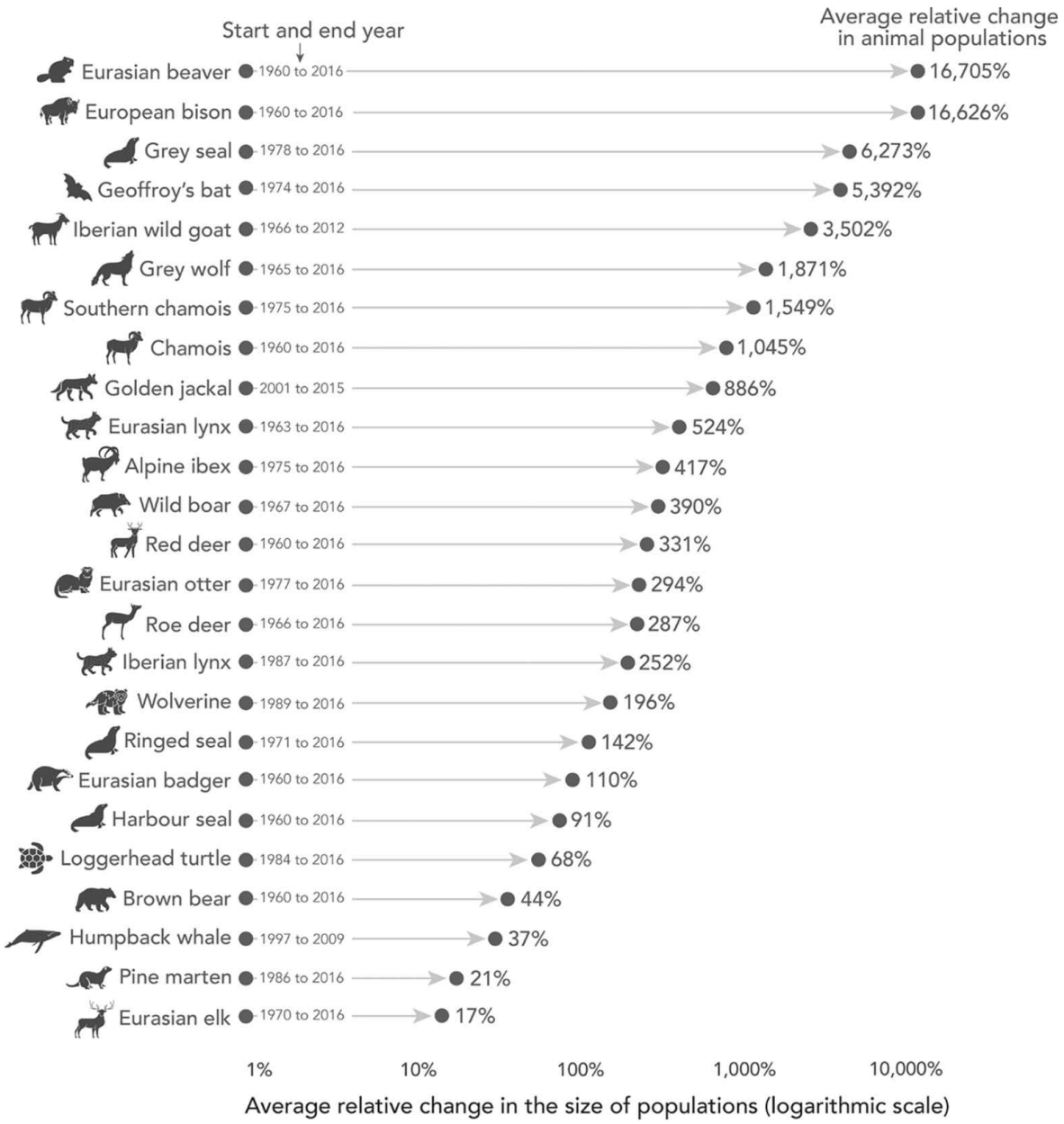
The European bison is the continent's largest herbivore. Archaeological evidence suggests that the bison was widespread and abundant, stretching from France to Ukraine, down to the tip of the Black Sea.[37] The earliest fossils date back to the Early Holocene period – around 9,000 BC.

Bison populations steadily declined over millennia, but experienced the most dramatic fall over the last 500 years. Deforestation and hunting of this iconic mammal nearly drove it to extinction. They had gone extinct in Hungary by the 16th century, in Ukraine by the 18th, and by the early 20th century they had gone completely extinct in the wild, with only tens of individuals kept in captivity. The bison was on the brink of extinction. But it has made an impressive comeback in the last 50 years. By the end of 2021, there were almost 10,000 of them. Across the world, we find examples of successful conservation programmes that have restored animal populations. A coalition of conservation organisations – including the Zoological Society of London, BirdLife International and Rewilding Europe – periodically publish reports on how animal populations in Europe are changing. In their latest report they looked at the change in populations of 24 mammal species and one reptile species – the loggerhead turtle – that have been making a comeback.[38]

Eurasian badger populations achieved an average increase of 100% – a doubling. Eurasian otters tripled, on average. Red deer increased by 331%. The Eurasian beaver has made the most remarkable recovery. It's estimated to have increased 167-fold, on

average. There were likely only a few thousand beavers left in Europe in the first half of the 20th century. Today there are more than 1.2 million.

How has Europe achieved all this? In short, it has stopped many of the activities that were killing mammals off in the first place. Agricultural land use has declined across Europe over the last 50 years. This has allowed natural habitats to return. Another essential development has been countries bringing in effective protection policies such as complete bans on hunting or hunting quotas, designated areas with legal protections, patrols to catch poachers, and compensation schemes for the reproduction of certain species. Finally, some animals – such as the European bison and beaver – made their comeback through breeding and reintroduction programmes.



Wildlife is making a comeback in Europe
Shown is the average relative change in the abundance (the number of individuals) of studied animal populations in Europe. For example, the numbers for Eurasian beavers show the average relative change in the abundance of beavers between 1960 and 2016 across 98 studied populations.

Europe is no outlier. The American bison has become a national icon of the US. Before the Europeans colonised the American continent there were more than 30 million bison. The 19th was a rapid and vicious century of extermination. By the 1880s, there were just a few hundred bison left. Protected parks managed to keep the last remaining individuals safe from hunting, and better laws against hunting mean they have made a comeback over the last century. Today there are around half a million bison across North America, a 1,000-fold increase from their lowest point.

Many of the success stories come from rich countries. But we shouldn't fall into the trap of assuming that a country has to be rich to protect its wildlife. There are success stories from countries across the income distribution.

By the 1960s there were only around 40 Indian rhinos left in the world. They had gone extinct in Pakistan, and the remaining few were spread across India and Nepal. Since then, their numbers have increased 100-fold. There are now almost 4,000 of them. Sub-Saharan Africa is home to one of the world's greatest conservation success stories. Southern white rhinos were once plentiful across the continent. But intense poaching by the Europeans and killings in the conversion of land for agriculture meant that by the late 19th century this beautiful animal was close to extinction. By 1900, there were only 20 left. All were in the Hluhluwe–iMfolozi Park in South Africa – now a nature reserve. Over the course of the 20th century, extreme protection of these species – particularly in African nature reserves – led to a significant and rapid increase in populations to more than 21,000. There are now 1,000 times as many southern white rhinos as there were a century ago.

The idea that animals across the world are going extinct and we are powerless to change it is just not true.

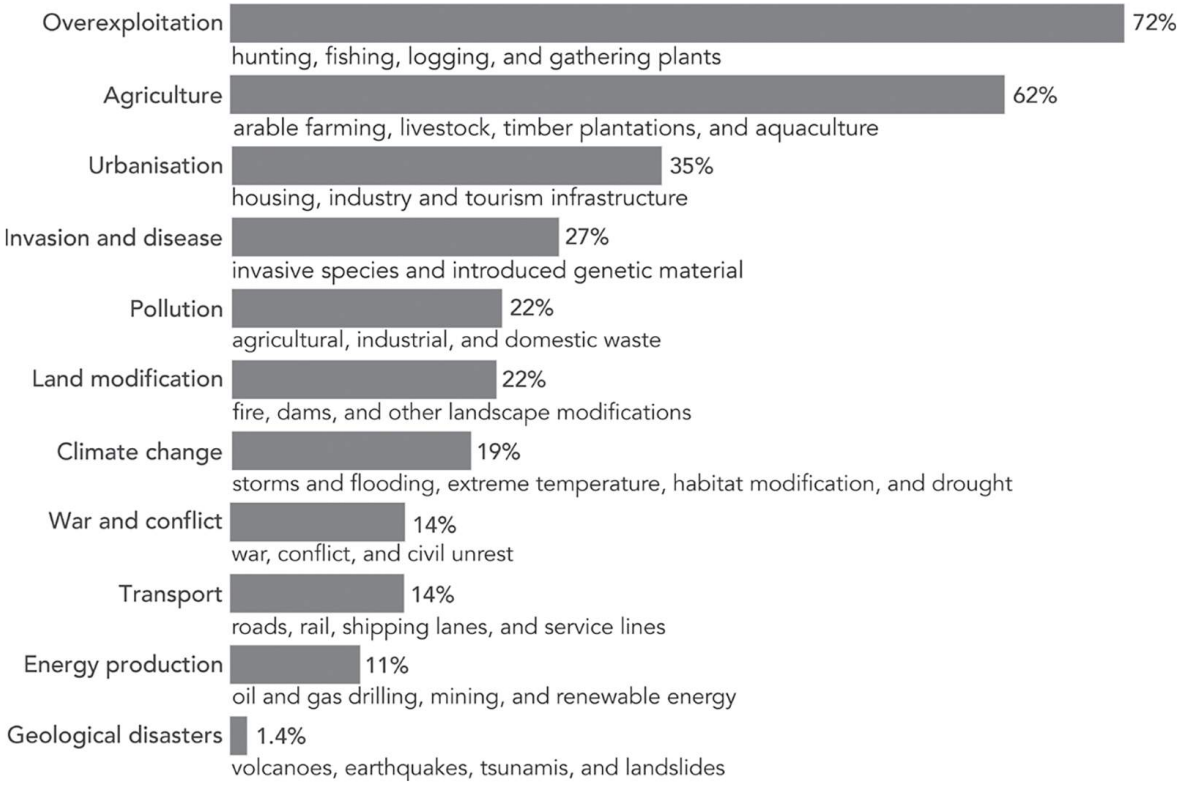
Why do we lose biodiversity?

If we want to save the world's wildlife we need to know why it's disappearing in the first place. Ask people what the biggest threats to wildlife are, and many will answer something like 'climate change' or 'plastics'. We are used to the images of a starving polar bear, a burning koala, or a bird with its beak trapped in the plastic rings from a six-pack.

Sure, these are a threat to some wildlife. But the biggest is often forgotten: how we feed ourselves. It has always been this way. While new threats have emerged, the biggest threats today are the same as the ones in the past. Overhunting and agriculture have been responsible for 75% of all plant, amphibian, reptile, bird and mammal extinctions since 1500. In fact, as we've seen, this goes back even further – our direct competition with mammals drove hundreds of the largest ones to extinction. Not much has changed.

Deforestation, hunting, fishing and farming are all direct threats to our wildlife. They put thousands of species at risk of extinction. Many species face more than one threat.

The good news is that the solutions are cross-cutting: eating less meat would reduce the amount of land we use for farming, climate change *and* biodiversity loss. Stopping deforestation will reduce habitat loss and greenhouse gas emissions.



What are driving the world's species to extinction?
The share of assessed species that are threatened with extinction by a specific driver of biodiversity loss. This is based on a study of 8,688 species that are near-threatened or threatened with extinction on the IUCN Red List. Around 80% of assessed species are at risk from more than one threat.

How do we prevent a Sixth Mass Extinction?

Biodiversity loss is the trickiest environmental problem that I cover in this book, though I still think we can change things.

At the heart of all of the other environmental challenges is the driving force of making life better for humans. There is a very real and tangible need for us to solve them if we want to live long and healthy lives. We want to tackle air pollution because it affects our health; we want to tackle climate change so our cities don't drown; we got our act together on ozone because we were worried about skin cancer. There is a selfishness to our drive to fix these things. By that, I mean at a *species* level – as humans. Collectively, there is a selfish reason to improve the environment around us. Our flourishing depends on it.

Biodiversity is not quite the same. Again, I am *not* arguing that humans do not depend on healthy ecosystems to survive. We do. From the food we eat and the fresh water we drink to the regulation of the climate: we are dependent on the balance of species

around us. The obvious problem is that we often don't know what these species are (remember Hardin's 'you can never merely do one thing').

To add to that, people still view other animals as very separate from them. They miss the true co-dependencies. They seem less important than cutting air pollution or tackling climate change. We see biodiversity loss more as a charitable cause than as a core element of how we move forward.

I don't think we'll put as much direct effort into solving biodiversity loss as our other environmental problems. But what makes me optimistic is that we will reduce it indirectly by tackling all of the other problems. A wonderful by-product of slowing climate change, fixing our food systems, stopping deforestation, ending plastic pollution and protecting our oceans is that we stop piling pressure on the species around us.

Protect our most biodiverse sites from exploitation

The one solution that doesn't overlap with the other problems in this book is protecting biodiversity using so-called protected areas. These are, essentially, areas of land that we try to reduce human use of, leaving it for natural habitats to thrive. They're there to try to restore ecosystems in our absence.

How far this 'protection' goes varies a lot. There are seven categories, ranging from strict nature reserves, where everything but the lightest human use is illegal, to areas where the 'sustainable' use of natural resources such as logging or fishing is allowed.

In 2021, around 16% of the world's land was in a 'protected area'.[39] These are areas of land that are classified as spots of scientific protection. That means the world met the UN's 2020 target for the amount of land that is protected. In December 2022, at COP15 – the biodiversity equivalent of the Paris Climate Agreement – countries signed a deal to make sure this increased to 30% by 2030 (they call it '30 by 30').[40]

Some conservation groups want to take this further – fighting for a '50 by 50' target: protecting half of the world's land by 2050.[41] This campaign is aptly named 'Nature needs half'. This isn't a niche vision – Edward O. Wilson wrote an entire book on the concept, titled *Half-Earth: Our Planet's Fight for Life*.[42] As he put it: 'only by setting aside half the planet in reserve, or more, can we save the living part of the environment and achieve the stabilisation required for our own survival'.

But not everyone agrees with this approach. Naming an area of land as 'protected' is one thing, but ensuring that laws are implemented and monitored, and repercussions assessed, is quite another. A thornier topic is how we view our relationship with wildlife: as part of a combined ecosystem where we all coexist, or separate systems where we have our 'zones' and other species have theirs. Human communities have always lived alongside animals. Rural and indigenous populations still do, with many playing an active role in conservation efforts.[43] Indigenous lands occupy over a quarter of the world's land surface, and overlap with around 40% of all terrestrial protected

areas and ecologically intact landscapes today.[44] Expanding our protected areas from 16% to 50% will increase that even more.

Well-managed protected areas can make a real difference. They can make sure we don't disrupt ecosystems with farming, extraction of materials or other destructive activities. But which areas we protect, and how these regulations are set, is an issue we need to take great care over.

Things to stress *more* about, not less

For most of the crises I've explored there are clear examples of things people should stress less about. But this isn't the case with biodiversity: many people don't think about it at all. Or if they do, they'll sponsor a panda or a polar bear. That's fine: I've nothing against donating to conservation charities.

But they do this, and are often oblivious to the things that they should really stress *more* about. You will recognise this list: they are the solutions in every other chapter of this book. We need to:

- Increase crop yields to reduce farming land
- Bring deforestation to an end
- Eat less meat, and reduce our need for livestock
- Improve our efficiency of, but don't eliminate, chemical inputs such as fertilisers and pesticides
- Slow global climate change
- Stop plastic leaking into our oceans

If we do all of these things, the world's ecosystems can thrive again. Not instead of us, but alongside. Our long-drawn battle with nature will finally come to an end. Just as with every other problem, time is of the essence. Every time we delay, we risk losing another species forever.

7

Ocean Plastics

Drowning in waste

‘By 2050, there will be more plastic than fish in the world’s oceans, study says’

– *Washington Post*, 2016[1]

You might have heard this statistic repeated as fact. It went viral after it was published in a report by the Ellen MacArthur Foundation in 2016.[2] But is it really true? To test this claim we need to know two things: how much fish there is in the ocean, and how much plastic there will be in 2050.

Let’s start with the fish. How many fish are in the ocean? We don’t know. They are notoriously hard to count. Instead, researchers use satellites to estimate how much phytoplankton – microscopic algae – there is. These plankton show as bright shades of green and blue in the ocean, which we can see from space. Algae is near the bottom of the food chain so researchers can then estimate how much ocean life they support.

In 2008, from studies using this satellite imagery, the researcher Simon Jennings estimated there were 899 million tonnes of fish in the ocean.[3] This is the number the Ellen MacArthur Foundation uses.

Except there’s a problem. Simon Jennings no longer backs this number. Several years later he revisited the study and concluded that phytoplankton support much more ocean life than previously thought. His latest estimates are that there are between 2 and 10 billion tonnes of marine life in the oceans. That’s 2 to 10 times higher than he originally claimed. It’s also not possible to say exactly how much of this marine life is fish.

The reality is that we don’t know how many fish there are, but it’s probably much more than the Ellen MacArthur Foundation believes.

What about the plastic? Again, the numbers don’t stand up to scrutiny. A 2015 study estimated how much global plastic might be produced – and leak into the ocean – in 2025.[4] The Foundation then simply extrapolated this growth in ocean plastics out to 2050. This is a bad assumption. The lead author of the original study, Jenna Jambeck,

told the BBC that 'she would not feel confident projecting her work forward beyond 2025 to 2050'.[5]

The problem is that the Foundation assumes that things will continue to get worse and worse, for decades. It assumes we will do nothing to stop plastic pollution, which is not true: in 2050 we will not have the same amounts of plastic flowing into the ocean.

Neither of the original sources – for fish or plastic – supports the numbers the foundation produced. It's a questionable claim. But while I like to dig into the numbers to fact-check them, the comparison is beside the point. It's an arbitrary number. Why does the specific ratio of fish to plastic matter? Any plastic in the ocean is bad; how it compares to fish is meaningless. It would be a problem if it was a half, a quarter, a tenth of the weight of fish.

Plastic waste is a problem across the world's oceans, there's no need to exaggerate it.

It's hard to find a spot on Earth that's free from human influence. Even Earth's highest summit – the peak of Mount Everest – is littered with trash. The one place you might think you could maybe find a pristine spot is far out in the ocean. Sure, around the coastlines and in fishing zones, our mark is everywhere. But in the *middle*?

Imagine, then, Captain Charles Moore's shock when he found himself sailing through the world's largest accumulation of plastic. Moore was made for the ocean – he was a surfer and sailor – and in 1997 he was on his way home to California after the Transpac sailing race, a course stretching from Los Angeles to Hawaii. As he would later recall:[6]

> As I gazed from the deck at the surface of what ought to have been a pristine ocean, I was confronted, as far as the eye could see, with the sight of plastic. It seemed unbelievable, but I never found a clear spot. In the week it took to cross the subtropical high, no matter what time of day I looked, plastic debris was floating everywhere: bottles, bottle caps, wrappers, fragments.

He was the first person to report this giant plastic soup. Moore coined many terms for the debris – a 'swirling sewer', a 'superhighway of trash' – but it was the term from one of his colleagues that stuck: the 'Great Pacific Garbage Patch'.

The 'Great Pacific Garbage Patch' – GPGP for short – is located halfway between Hawaii and California. The ocean currents form a gyre – the Pacific Vortex – where floating debris accumulates and is sucked towards the centre. Most of it is plastic. Some is more than 50 years old, a hydrocarbon time capsule for anyone stumbling across it.

The patch stretches around 1.6 million square kilometres.[7] An area three times the size of France. And that's just the dense part in the centre, not the dispersed plastic around the edges. It's one of the clearest visuals of the extent of our imprint on the environment.

That's the dark side of plastic: the waste that ends up in whale stomachs and strangles turtles. But, as much as it pains me to admit, plastic also has a good side, one that doesn't get the recognition it deserves.

I started writing this book during the Covid-19 pandemic. It seems odd to say that writing about climate change, air pollution and deforestation has been an escape, but it's true. While I'm an environmental scientist by training, recently my role has been very different. I've become a data scientist in epidemiology – a job I didn't quite know I was signing up for. Since the early days of the pandemic my team at Our World in Data have been collecting, visualising and sharing the global data on the evolution of the pandemic, updating every day, for every country, for as many metrics as possible. We quickly became the pandemic go-to for politicians, journalists, researchers and the general public. Even Donald Trump would pull out crumpled printouts of our charts to hold up to the camera on Fox News.

People underpin all of these coronavirus metrics. Patients suffering, loved ones mourning, heroic doctors, nurses, volunteers and scientists saving lives with treatments and vaccines. But plastic underpins them all too. It's there in the masks we wear to stop the virus spreading, the tests we do to check if we've been infected, the vials our vaccines are delivered in, and the oxygen tubes that keep those in hospital breathing. It's impossible to imagine how we would have tackled the pandemic without it.

Plastic really is a wonder material. It's sterile, waterproof, versatile and cheap. *Plastic* is derived from the Greek *plastikos*, meaning 'capable of being shaped or moulded', and it lives up to its name, in that we can make almost anything out of it. We complain that it has become so ubiquitous in our lives, but this is a testament to the fact that it is such a useful material.

While it has its environmental flaws, it also has some green credentials. As we've seen, if we were to get rid of plastic tomorrow, the world would waste more food. That food waste has a massive environmental cost: all of the farmland used to make it, the water used to irrigate the soil, the greenhouse gases emitted for food that would not even reach our mouths.

Or take the use of plastics in transport. Transport – whether in the air, on the water or on the ground – involves moving heavy things from one place to another. That's why it's an energy guzzler and a big contributor to climate change. Plastics play a key role in making vehicles lighter. Without them, we'd use even heavier materials and that would emit even more greenhouse gases.

From food waste to medicine, transport to safety equipment, plastic has become a staple in our lives. Of course, it hasn't always been this way. Plastic is different from the other problems in this book. The rest all have a long history. Plastic's history is a short one.

How we got to now

In 1907, the Belgian chemist Leo Baekeland created the world's first fully synthetic plastic, Bakelite (named after himself).[8] He subsequently would become the 'Father of the plastics industry'. Baekeland was different from many of the pioneers covered in this book. Crutzen, Molina and Rowland wanted to heal the ozone layer. Haber, Bosch and Borlaug wanted to feed the world. Baekeland was honest and clear: he worked on synthetic materials because he wanted to make money. As he put it, he wanted to work on problems that had 'the best chance for the quickest possible results'.[9] The other scientists in this book often had little chance of any positive results, let alone quick ones.

Before Bakelite, the world had shellac, a resin formed from female lac bugs. The lac would be scraped from the trunks of trees in India and Thailand, and heated to form liquid shellac. This material was then used in various ways: as wood varnish to strengthen products, moulded into ornaments and picture frames, as protective casing, and even for gramophone records before the transition to vinyl. Leo Baekeland saw the price of shellac rising – a clear sign that this type of material was in high demand, and the forest bugs couldn't keep up. He wondered if it would be possible to replicate this process in a lab. Could he mimic the work of lac bugs and create resins from scratch?

He started experimenting. He was convinced that the reaction of two organic compounds – phenol and formaldehyde – was going to give him what he wanted. He tried these reactions at a range of temperatures, pressures and ratios of the two compounds. His first 'success' was a non-starter. He produced a product he called 'Novolak'. It was almost there, but didn't quite have the amazing properties that he was looking for.

Finally, after more trials and tinkering he landed on it: Bakelite. It was exactly what he had been searching for. Bakelite, 'the Material of 1,000 Uses' as some scientists now refer to it. Baekeland filed his patent for Bakelite in 1907, and it was granted on 7 December 1909. The birthday of plastics as we know them.

Bakelite was perfect for many of the industries that were emerging at the time, particularly the electronics and transport industries. The fact that it was resistant to electricity, fire and heat meant it could be used for wires, protective casings and appliances, while also becoming the material of choice for a range of high-end items.

Compared to today, the world was using very little plastic. It was still a relatively exclusive product, limited to the United States and Europe. Even as late as 1950 the world was producing just 2 million tonnes of plastic a year.[10] But as its popularity grew and the industry developed, a range of other prototypes came on the market. Plastics with different properties – some that could be flexible, and others that could be made more cheaply. It quickly moved from niche to mainstream.

Plastic production exploded. By the millennium the world was producing 200 million tonnes each year. By 2010, it was 300 million tonnes. And by 2019 it was 460 million tonnes.[11]

Where we are today

The magical properties of plastics that make them so brilliant are also their Achilles heel. Plastic is so sturdy and durable that if we add up the *total cumulative* amount of plastic that we've generated since 1950 it amounts to more than 10 billion tonnes. More than a tonne for every person that is alive today. Most of that plastic is still hanging around in some form.

How much plastic do we use and what do we use it for?

How much plastic waste do *you* produce in a year? Take a quick guess.

The average Brit produces around 77 kilograms. That's the weight of an average man. The average American produces around 124 kilograms. That seems like a lot until we put it into perspective on a daily basis. In the UK that would break down to around 200 grams per day. Still a lot, but not unfeasible to get your head around.

While plastic has become a staple for many of us, this is not the case everywhere. Some people in the world have very little interaction with it, if any. In India, the average works out at just four kilograms per year. The average American produces the same amount of plastic waste in less than hour as the average Indian does in a day.

The patterns of waste across the world are pretty consistent. Richer countries tend to produce more waste per person, and countries with lots of towns and cities do too. Island states such as Barbados and the Seychelles produce a lot of plastic waste because they are built around urban centres. This makes sense: if you live in the middle of nowhere and have few transport links to towns, cities or distribution hubs, how would plastic ever get to you? This probably explains why countries such as India, Kenya and Bangladesh have such a low average per person. Around 60–70% of their populations live in rural areas, compared to less than 20% in the UK and US.[12]

Packaging is the world's biggest use of plastic, unsurprisingly: say the word 'plastic' and people picture a plastic bottle or food wrapper. Forty-four per cent of the world's plastic goes towards packaging. The rest goes to buildings, textiles, transport and other consumer appliances. And when we look at plastic *waste*, not plastic *use*, packaging becomes even more dominant. This is because the 'lifetime' of packaging is very short, typically half a year. We use it once or twice (if it's recycled) then its life is over. This is different from uses like construction: the plastics we use to build and retrofit our houses and offices can be there for more than three decades. In cars, for around 13 years. In electronics, around eight years.

The solution might seem obvious. If we want to stop plastic pollution, rich countries should stop using single-use plastic packaging if it can't be recycled. Otherwise, we should recycle as much as we can. Unfortunately, it's not quite as simple as that.

The 'con' of endless recycling: where does our plastic end up?

What matters for plastic pollution is where it ends up. If we were to say that the plastic problem was simply about how much we *use* then we'd be saying that the plastic sports bottle I've used for the past five years is just as bad as the piece of plastic that gets swallowed by a whale in the middle of the Pacific. These are not the same, and if we want to tackle plastic pollution we cannot treat all cases as equal.

First, we care about how much plastic ends up as *waste*, then we care about where this waste goes. Some plastics are used for a very long time: years or even decades. Of the 8 billion tonnes the world has produced since 2015, a little less than a third is still in use. For the rest of it, assuming it doesn't end up as litter, there are three possible fates: it can go straight to landfill, it can be recycled, or it can be incinerated (a process where it's burned and, hopefully, turned into energy).[fn1] Most plastic goes to landfills.

Even for the plastic that is recycled, it's rare that it gets reincarnated more than once or twice. We think of recycling as the holy grail of environmental action. The label that something is 'recycled' is a signal that it's eco-friendly. Sure, it's good to give things a second life. It's certainly better than burning more oil from scratch to make a new version. But we can't just recycle plastic over and over – at least when it comes to *mechanical* recycling, the type most countries rely on. When people recycle a plastic bottle they imagine it becomes another plastic bottle. It doesn't. It gets degraded and is used for something lower quality. Most plastics can only be recycled once or twice, then they're sent to landfill. Recycling doesn't eliminate waste, it just delays the process a little. A good thing, but not the panacea we might think.

Chemical recycling does offer us the opportunity to recycle plastics endlessly. In chemical recycling, plastics are broken right down into their basic molecular parts.[13] This is a very pure process that stops plastics getting contaminated or degraded. The problem is that it's incredibly expensive.[14] Much more expensive than simply producing more plastic from scratch. That's why companies and countries don't do it. If we could make chemical recycling much, much cheaper then we might be able to close the loop on making new plastics. That is currently way off, but maybe its time will come.

So, even if everyone in the world recycled their plastic (mechanically), we would still have waste. If we wanted to eliminate waste our only option would be to cut out plastic completely. Some might argue that this is what we should be going for, but that would be a mistake. For sure, there are ways that we can cut back. We can and should reduce consumption, but for a range of uses – from medical supplies to food protection – it plays too important a role in our lives.

The good news is that, while we can't realistically eliminate waste completely, we can eliminate plastic *pollution*. The biggest problem with plastic is *how* we dispose of it. When we don't manage waste properly, it turns into a pollutant. It leaks into the natural environment where it plays havoc with wildlife.

What this means is that we won't fix the problem simply by using less. We could halve the amount of plastic we're using globally – a tall order – and we'd still have millions of tonnes of the stuff leaking into our rivers and oceans every year. Until we learn to manage our plastics after we've used them, this problem will not stop. So what do we need to do to fix it?

Here our focus is on plastic that pollutes our rivers, and then our oceans. Plastics gather on dry land too, damaging the wildlife that swallows or gets caught up in it. But flowing water is where most of our plastic waste ends up eventually. It makes its way out into our oceans where it accumulates. This is where the big problem is. In any case, most of the solutions we'll look at try to stop the pollution at its source, before it escapes onto land or into the sea.

How much plastic ends up in the ocean?

When Charles Moore was sailing across the Pacific he was navigating through streams of plastic that had gathered there from across the world. Some came from marine sources – fishing nets, lines and rods – but he was also sailing through waste that had been swept up from the land.

The organisation Gapminder ran a survey asking people 'What share of all plastic waste in the world ends up in the oceans?'[15]

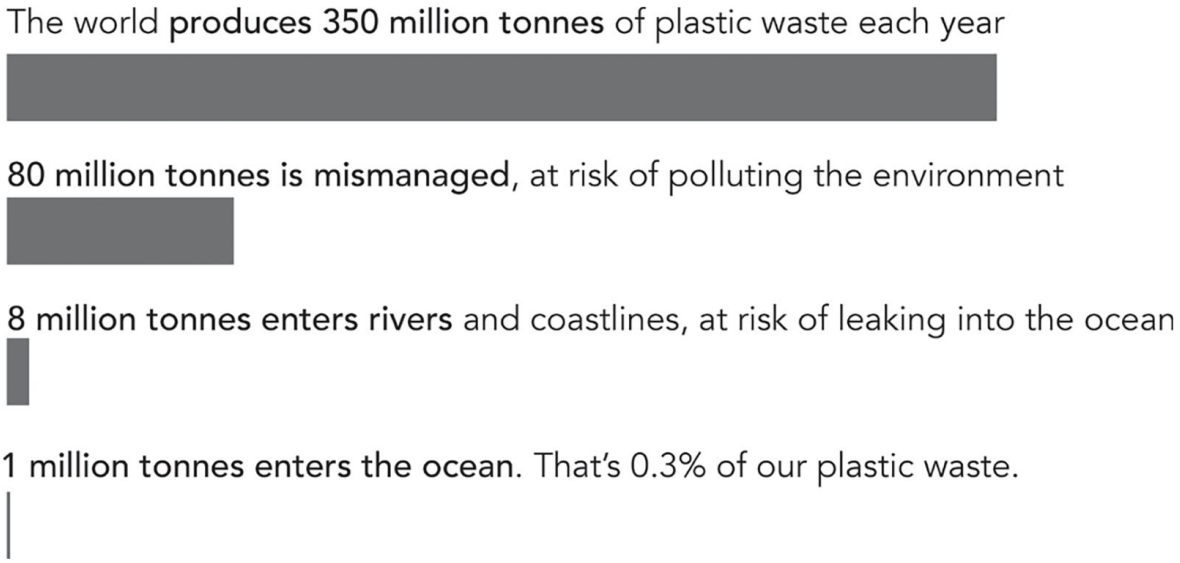
A. Less than 6%
B. Around 36%
C. More than 66%

Eighty-six per cent of people thought that the answer was B or C. The correct answer, as you've probably guessed by now, is A: less than 6%. In fact, it's probably quite a bit less than 6%. Around 1 million tonnes ends up in the ocean every year.

The world produces around 460 million tonnes of plastic each year, and 350 million tonnes of it becomes waste. For this waste to enter the ocean, it needs to be dumped in a way that means it's not contained. When plastic is put into sealed landfills, it's unlikely to escape. It also needs to be fairly close to the coast to get carried out to the ocean from rivers. Our best estimate is that 1 million tonnes enters the ocean each year. That's 0.3% of our plastic waste.[fn2]

I don't say all of this to undermine the scale of the plastic problem. A million tonnes is still a huge amount. Imagine dumping a million tonnes of plastic bottles into the sea, year after year. But we need to understand the problem – the scale of it, and where it comes from – to tackle it. Stopping 1 million tonnes of mismanaged waste reaching rivers is a very different problem from tackling tens or even hundreds of millions of tonnes. Many people might be more optimistic about our ability to tackle plastic pollution if they knew that only a few per cent of it ends up there. If you believe that

more than two-thirds, or even one-third, of our plastics are dumped in the ocean, it can easily feel like your efforts to fix it are hopeless. Thankfully that's not the case.



Only a small fraction of the world's plastic ends up in the ocean
Around 0.3% of the world's plastic waste ends up in the ocean.

Where does the plastic in our ocean come from?

The popular Netflix documentary *Seaspiracy* sparked controversy when it pinned the world's plastic problem on the fishing industry. Many of the points in the documentary were factually wrong – we'll look at some of its other wild claims in the next chapter. But it did get one number right. Well, mostly right, with some caveats.

It claimed that more than half of the plastic in the Great Pacific Garbage Patch came from marine sources – from abandoned fishing lines and discarded nets. This is true: the most recent high-quality study we have estimates that around 80% of the plastic in the Patch comes from fishing industries, with the remaining 20% coming from land.[16, fn3]

But while this is true of the Great Pacific Garbage Patch, it's not true of the oceans as a whole. Some of the plastics that come from rivers make it all the way out into the open ocean, but most of it stays around our coasts. The GPGP sits in a part of the Pacific with lots of industrial fishing activity, so it sucks up a disproportionate amount of ghost fishing materials.

We don't know exactly how much of the plastics across all our oceans come from land, and how much comes from the sea. Our best estimate is that most – around 80% – comes from land, with the rest coming from marine sources.

Where is this plastic coming from? We might imagine that the countries that emit the most plastic are those that *use* the most plastic – the world's richest countries. But that's not the metric we're most interested in. We want to know *where* plastic is polluting the ocean. That's not about how much plastic we use, but where it goes once we're done with it.

If you live in the UK, or a similar rich country, unless you deliberately litter your plastic in a river or on the beach, your plastic is probably not going to end up in the ocean.[fn4] Our plastic ends up in a landfill, in the recycling or burned safely for energy. All of this happens without us thinking about it: we put our rubbish in the bin – hopefully the recycling one – and it gets handled. It's true that many high-income countries also ship at least some of their plastic waste abroad – we'll look at the numbers on this later – but, overall, the amount that's shipped to poorer countries is quite small and doesn't make a bit of difference to the amount that's leaking into the oceans. Maybe a few per cent, at most.

Good waste-management systems in rich countries mean that the quantity of waste that is *mismanaged*, and at risk of leaking into the oceans, is small. This isn't the case everywhere. Waste management is boring and unglamorous, but also pretty expensive. When cities are expanding rapidly, as they are across many middle-income countries, it takes a lot of investment to keep the number of bins and recycling centres in sync with the pace of the growing megacities.

In some countries there is no regular pickup service to take waste to landfill or recycling. If waste *does* make it to a management site, it is stored in open landfills, where it can leak into the surrounding environment. A global map of total plastic use per person would highlight Europe and North America. But the map of *mismanaged* plastic per person is the opposite. The rich countries are in the dark, while South America, Africa and Asia are brightly lit. The mismanaged plastic waste per person in Malaysia was 50 times higher than in the UK – 25 kilograms compared to just 500 grams per year.[17] As seen earlier, not all of this mismanaged waste ends up in the ocean, but it makes it much more likely.

Let's look at where plastic is entering the ocean. Boyan Slat is one of my favourite environmentalists. In fact, he might object to being called an environmentalist, because the Dutch entrepreneur is a doer, not a talker. He doesn't just study problems, he tries to fix them. His obsession with fixing the plastic problem started when he was just 16 years old. When he went scuba diving and found more plastic than fish, he knew something had to be done. He started a degree in aerospace engineering, but like all the best entrepreneur stories, he dropped out to start his own venture.

First, Boyan and his team developed high-resolution models of where plastics were entering the world's rivers, and how they got from there into the ocean. Academics tend to do this stuff out of curiosity, or for fun. But this study had practical consequences for Boyan and his team. They were grappling with engineering solutions not only to haul plastic *out* of the ocean, but to stop it getting in there in the first place. To do this, they needed to know where it was coming from, and how much plastic they would have to stop in its tracks.

They estimated that in 2015 the world spewed around a million tonnes of plastic into the ocean. One-third of the 100,000 river outlets they modelled were dumping plastic

into the sea. That flags an important point in itself. We might assume that most rivers are gathering plastic and adding to the problem. It's the opposite. The *majority* of rivers are contributing very little. That is also good news for Boyan Slat and his team: they have 'just' one-third of the world's rivers to tackle, rather than all of them. In fact, the problem is even more concentrated than that. Although tens of thousands of rivers are emitting some plastic into the ocean, most of it is concentrated in a much smaller number. Eighty per cent of the ocean plastics came from the 1,656 rivers that emitted the most.[fn5] Eighty-one per cent of the plastic being emitted into the ocean comes from Asia. That number seems very high, but previous studies have estimated a similar amount.[18]

This is a staggering share, but it makes sense. Asia is home to 60% of the world's population. Many of these populations are dense and situated close to major rivers. The continent is also home to some of the world's fastest-growing economies, countries like China, India, Malaysia, the Philippines and Bangladesh that have been breaking through from poverty to booming economies. When countries transition from low to middle income, consumers start to produce and use more plastic. They close in on the consumption habits of the rich. The problem is that the waste infrastructure to handle all this lags behind.

Looking at the other continents, around 8% of plastics come from African rivers, 5% from South America, 5% from North America. Europe and Oceania combined contribute less than 1%. It's hard to accept these figures. It tells a story that we don't really want to hear. As a European, I want to think that we can play a big role in fixing this problem by cutting back on our plastic wrappers, ditching our single-use shopping bags, and recycling our used milk cartons. Sadly, this isn't true. If everyone in Europe stopped using plastics tomorrow the world's oceans would hardly notice the difference.

While our river plastics might not have much of an impact on the world's oceans as a whole, they still matter a lot for Europe's coastlines where they tend to gather and stay.

Nearly all of the plastic around European coastlines has come from European rivers. The same is true in other regions. So our global oceans might not notice much of a difference if Europe cut out all of its plastics, but European coastlines definitely would. This is especially true of the Mediterranean Sea. It's a closed basin, and almost all of its plastic has come from the countries around it.

If Europe wants pollution-free shorelines then it's almost entirely in our control to achieve that.

Are rich countries dumping their plastic overseas?

Now it's time to come to the knotty question about whether rich countries are just 'dealing' with their waste by shipping it elsewhere. It's a question I get asked often. It's similar to the question of whether these countries are reducing their carbon emissions by offshoring them elsewhere. If it was true for waste, it might actually be good news.

The solution to global plastic pollution would be simple: just ban countries from exporting their waste.

Unfortunately, it's not that straightforward. The waste that rich countries are shipping overseas is a small slice of the pie. Cutting it out might stop a few per cent – maybe up to 5% – of it from leaking into our oceans. A contribution for sure, but not a silver bullet.

The UK has played a dirty hand when it comes to plastic waste. It's common for countries to buy recycled plastic from others. The UK, then, was supposed to be selling clean, recyclable waste that other countries could reuse in the manufacturing of other stuff. But scandal after scandal has hit the headlines about countries sending it back because our packages were full of contaminated samples that couldn't be recycled. We were, quite literally, dumping our waste overseas.

The UK is not the only one. Other countries have been equally bad trading partners. Some recipient countries decided they'd had enough. In 2017, China said it wouldn't import any more plastic waste, and banned it.[19] It had been the world's largest importer, which meant there was then a lot of plastic that needed to go somewhere. It went to neighbouring countries in Asia, like Vietnam, Malaysia and Thailand. But they too had soon had enough. In 2021, Malaysia sent more than 300 containers of contaminated waste back to where it came from, and finally banned plastic imports. Turkey also recently told the UK it would stop taking its plastic.

These dodgy dealings make it sound like the global trade of plastic waste is a huge issue. But to understand *how* big, we need to look at the data.

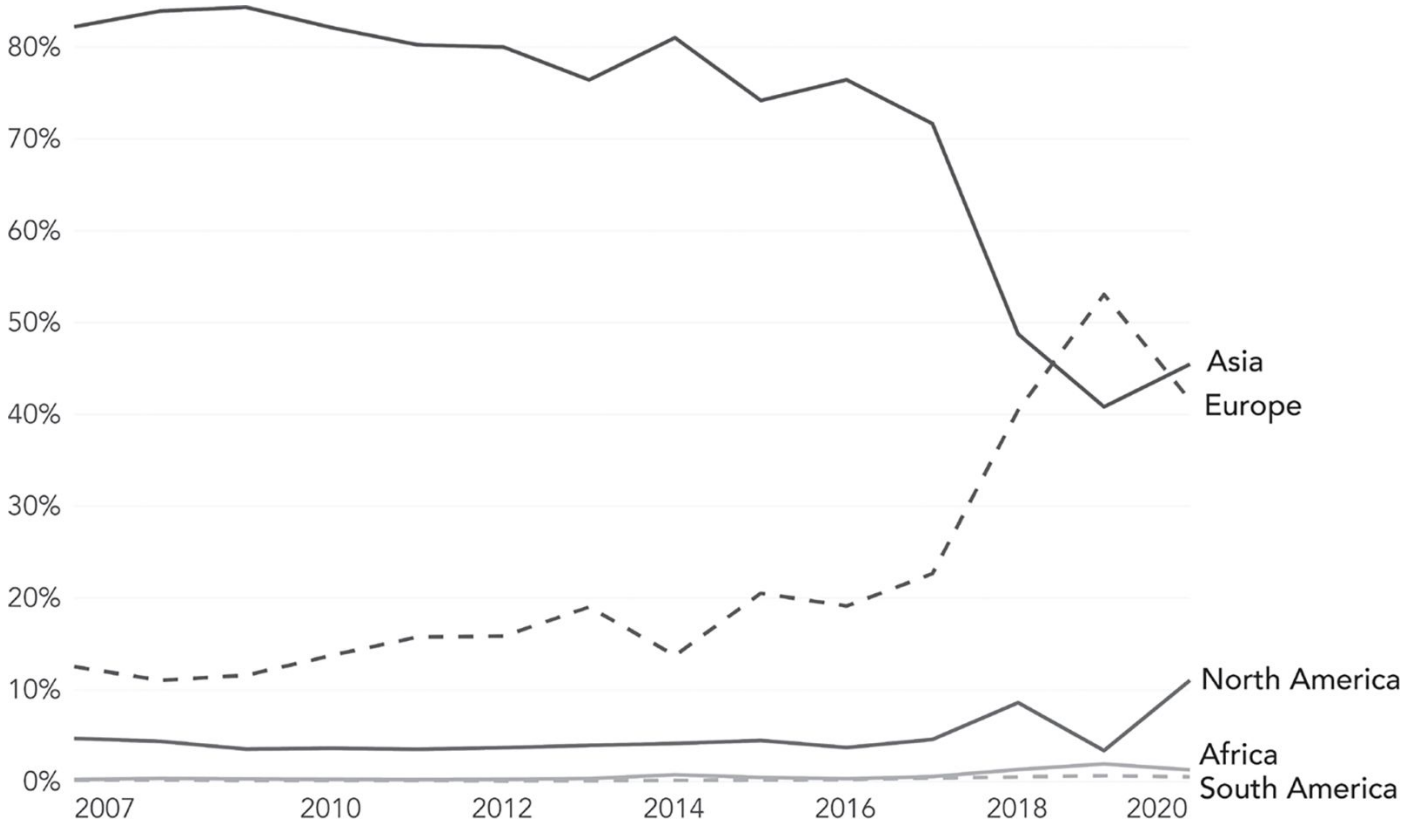
Every year, around 5 million tonnes of plastic waste is traded across the world.[20] That certainly sounds like a big number. At least until we put it into the context of the amount of plastic waste that we generate: around 350 million tonnes. This means that around 2% of global plastic waste is traded.[fn6] The other 98% is handled domestically.

Still, if those 5 million tonnes are at high risk of leaking into the ocean, maybe banning plastic trade would solve the problem. To see if this is viable, we need to look at where the waste is being sent from and where it's going. In 2018 the top five exporters of plastic were the US, Germany, Japan, the UK and France.

How *much* of their plastic waste do rich countries trade? Let's take the example of the UK. In 2010, it generated an estimated 4.93 million tonnes of plastic waste. It exported 838,000 tonnes, which is about 17%. That's a substantial fraction – nearly one-fifth of it. The UK is one of the largest exporters. For context, the US exported about 5% of its plastic waste in 2010, France exported 11% and the Netherlands exported 14%. Most rich countries are net exporters of plastic waste.

Where does this plastic waste go? This is where things get surprising. A few years ago, Asia was the biggest importer of plastic, by far: 70% to 80% of it ended up there. But when those countries got tired of the rich world dumping their waste on them, this share fell rapidly. Now Europe is the biggest importer of plastic waste.[21] It imports

more than half of the world's traded waste. While European countries are the biggest *exporters*, nearly three-quarters of it goes to other countries in Europe. Some of the biggest exporting countries are also the biggest importers. Germany exports plastic to its European neighbours such as the Netherlands, Turkey, Poland, Austria and the Czech Republic. But it also receives a lot – different types of plastic – in return.



Asia used to import nearly all of the world's traded plastic waste, but not any more
Each region's share of the world's imports of plastic waste.

The dramatic decline in Asian imports shows us how quickly regulations can change things. China, Malaysia and several other countries banned plastic imports and the balance of plastic trade was turned upside down. This shift is good news. As seen earlier, Europe emits very little plastic into the oceans. Because it is now the biggest importer of plastic waste, this means that most of the world's traded plastic is at low risk of ending up in the sea.

This brings us to the crucial question: how much do rich countries contribute to plastic pollution through their exported waste?

In 2020, low- to middle-income countries – where plastic waste was at a 'higher risk' of entering the ocean – imported around 1.6 million tonnes of plastic waste from rich countries. Here 'rich countries' include all countries in Europe and North America, plus Japan, Hong Kong and OECD countries from other regions. How much of this plastic ends up in the ocean?

We don't know for sure – the probability that mismanaged waste ends up in the ocean varies a lot by country – but we can think about a worst- and best-case scenario. I've done some back-of-the-envelope calculations, and estimate that rich countries would contribute between 1.6% (in the best case) and 10% (in the worst case) of ocean plastics through shipping waste overseas. The most likely figure probably falls somewhere in between.

Would a ban on plastic trade reduce the amount of plastic ending up in the ocean? Probably a bit. Would it fix the problem? Unfortunately not. Only a small fraction of the world's plastic waste is traded, and most of that waste ends up in countries that leak very little plastic into the oceans.

Still, there are other reasons to get strict on traded waste. It's outrageous that wealthy countries treat others as a dumping ground. For that reason alone, we should act on it. But if we're looking for a quick fix to the ocean plastic problem, or hoping that rich countries can fix this problem alone, this won't cut it.

What are the impacts of plastic pollution?

Every day there is a new headline about where plastic traces have been found. In our sewage systems, our food, our blood, even Antarctica.[22, 23, 24, 25] This sounds scary. But how worried should we be?

Let's start with ourselves. Most of us don't deliberately swallow big chunks of plastic, so it's the smaller pieces – the particles that are so small we're not even aware of them – that are the concern. We can ingest them through the water we drink, the fish or meat we eat, and we can inhale and swallow them through the air.[26]

What happens to them when they enter the human body? We don't know, but it's possible they don't hang around for very long.[27, 28] One piece of evidence we have for this comes from fish: studies suggest that microplastic particles don't stay around for long after they had been ingested. They pass through quickly. Most of the evidence – or maybe the *lack* of evidence – suggests that the plastic particles themselves are not a big concern for human health.

There is also a question about whether they become a vehicle for other pollutants. Plastic particles are sticky: other molecules cling to them easily. This means they might allow compounds such as polychlorinated biphenyl to get into our bodies. Industries also use additives in their plastics. I've yet to see any concrete evidence of this having an effect on human health, but it's too early to be sure. At the moment, I am not *very* worried about the impacts of plastics on human health, but I admit that the evidence is not clear enough to have a strong opinion either way. This is something I could easily change my mind on.

More worrying for me is the damage that plastic causes to wildlife. There are decades of research documenting this.[29] Animals can be exposed in a number of ways.

First, they can become entangled in plastics. Cases of entanglement have been documented for more than 340 different species, including most turtles, seals and whales.[30] The most common forms of entanglement come from ropes and fishing gear, which is why we need to get much stricter on the fishing industry. Second is the ingestion of plastics, either directly through the water that animals swallow or by eating organisms that have already ingested plastic. This is also prevalent; ingestion has been recorded in more than 230 different species.[31] It can have various impacts on the health of animals. An important one is that it reduces their stomach capacity and their drive to eat. They mistake a stomach full of plastic for one that is well nourished. Finally there are collisions or abrasions. Sharp pieces of plastic can cut fish or marine animals. And fishing gear can damage coral reefs.

Plastic also has the potential to upset the balance of whole ecosystems. Floating plastics can act as a life raft for different species, carrying them from their normal home to another ocean environment, which can find itself with a completely new 'invasive' species to deal with.[32]

The public would probably guess that plastic is one of the biggest threats to marine life. It's certainly on the list but it's not at the top. In the next chapter, we'll see that fish face much more urgent problems. Still, the pollution of our coastlines and oceans with plastic is, undoubtedly, a bad thing for wildlife. It's a negative impact that we can stamp out. Let's do something about it.

How do we stop plastic pollution in our oceans?

Of all the environmental problems in this book, stopping plastic pollution is the simplest. We know how to do it. We don't need to wait for new innovations or technological breakthroughs. With some basic investments, the world could solve this problem tomorrow.

To be clear, here I'm talking about plastic *pollution*: stopping plastic from leaking into our rivers and oceans where it harms wildlife. We don't want to eliminate plastic use completely. We should keep it for essential uses. For the rest, we can find alternatives or cut back.

Rich countries shouldn't be off the hook

It would be easy to lay the responsibility of ending plastic pollution at the door of the low- to middle-income countries, where most of it is entering the ocean.

But rich countries shouldn't be let off the hook so easily. They contribute to the plastic pollution problem in several ways. They should immediately stop sending plastics abroad, *unless* they commit to investing in good management practices in the country they're sending their waste to.

Even though ending plastic trade will not solve the pollution problem, it's a win that we could achieve very quickly. Not to mention, one of basic principle: poor countries are not a dumping ground for the rich.

The contribution of rich countries doesn't stop with traded waste. We also happily buy plastic products from poorer countries. Or export our own plastic-covered products there, knowing that they don't have the infrastructure to deal with the waste afterwards. Plastic pollution is a complex global problem, and to tackle it properly we need an integrated set of solutions. Countries – from rich to poor – can all play a role in fixing it.

Invest in more waste management

The biggest solution to ending plastic pollution is not a glamorous one. It's not a Tesla electric vehicle or a nuclear fusion breakthrough. It's the grimy but necessary investment in waste management. If every country had the waste-management systems that rich countries have, almost no plastic would end up in the ocean.

Countries need landfills that actually seal on top, so rubbish doesn't escape. They need good systems for collecting and storing the rubbish from thousands of streets across megacities. They need recycling systems and centres where plastics can be given another life.

There's no way to dress up waste management. It's just collecting rubbish. It's hard to make the case for investing in bins and landfills when countries have so many other priorities to grapple with. That's why we've ended up in this position in the first place. Living standards have increased quickly. People have moved to cities where they use many more consumables. They can now afford to use lots of plastic. That's a good thing; it's a sign that people are getting richer and can enjoy a better life. But waste management has remained low on the priority list.

The issue of waste is similar to that of air pollution in this sense. Eventually, people reach a stage of development where their priorities tip. In the early stages, people are willing to accept waste. It's not nice, but it's a trade-off they'll accept in return for having the benefits those materials bring. Then, further down the line, people realise they want waste-free rivers and shorelines. They expect local councils to have a plan to collect and manage the city's waste. When that transition happens, plastic stops leaking into the ocean. It's as simple as that.

Low- to middle-income countries can accelerate this transition by investing in waste management now. Rich countries can support them by financing this effort. If they're not willing to invest in waste management, then they're making their position clear: they want to look like they're doing something but choosing the easy way out.

Should we recycle our plastic waste?

Ask anyone what they're doing to 'save the planet' and they'll nearly always answer 'I recycle'. Recycling is the universal brand of a conscientious environmentalist. As seen in Chapter 3, people often think it has a massive impact on their carbon footprint. In reality, it's pretty tiny.

Why is it not quite as impactful as we imagine? Well, recycling doesn't magically happen on its own. It takes energy, and that energy comes at some cost. This is often a bit less than the energy it takes to make new plastic, so we are still saving something by recycling, but not as much as we would hope or expect. Our expectations of recycling are also too high. We think that our water bottle becomes another water bottle, and this reincarnation process happens over and over. It delays plastic going to the dump but doesn't stop it. Lastly, making stuff from plastic – especially single-use plastic – is just so efficient that it makes recycling old stuff much less attractive. Compared to other materials it's often a low-carbon way to make stuff.

I don't mean to be too down on recycling. I still tell my friends to do it. I still do it. But I don't delude myself that this is what's going to save the planet. My advice to you, then, is to recycle. It's a good thing to do. But if it's the *only* thing you do or one of the biggest things you do for the environment, then you need to up your game.

Expect more cooperation and innovation from industry

One of the reasons that global recycling rates are so low is that it's often not that cost-effective for countries to do it. Our recycling collections often take a mishmash of different types of plastic. Some can be recycled; some can't. Recycling streams get contaminated, and it's expensive to clean up the mess.

Industry – the ones that produce the plastics and the products that use them – aren't helping much. They throw plastic at us in large volumes, mixing a bunch of different types. It's then up to 'us' – and by that I mean individuals, local communities and councils – to build the infrastructure and systems to handle it. Governments need to put more pressure, and set stronger regulations, on industrial producers. Industry needs to streamline the plastics they use. They need to be recyclable. They need to invest in chemical recycling solutions that help us close the loop on plastics. And, in the meantime, they need to support local communities to build the infrastructure they need to handle the waste they generate.

Strict policies on plastics in the fishing industry

We've seen that most of the plastic in the ocean comes from land. But in certain parts of the ocean, most of the plastic comes from marine sources. When Charles Moore sailed through the Great Pacific Garbage Patch he probably saw many more fishing nets and ropes than plastic straws and Coca-Cola bottles.

Solving this problem could be quite simple. The world's oceans are not a free-for-all – at least not legally. In most countries, commercial fishing vessels need a permit. They often have quotas controlling how much fish they are allowed to catch (more on this in the next chapter). We can monitor their movements and sailing patterns using basic GPS technology. The solution, then, is straightforward: someone checks how much equipment a vessel has when it goes out to sea, and this is cross-checked with how much it has on its return. If ropes, nets and lines have been lost or abandoned in severe weather, or intentionally dumped overboard, fishermen get a hefty fine, a temporary ban or their licence taken away from them. We'd need some contingency for them accidentally losing small pieces of gear – if a massive fish rips a line right out of their hands it seems harsh to punish them for that.

Or we could use the 'carrot' approach. Fishermen could be incentivised to bring plastic waste back to land. Not only their own, but any rubbish they come across on their voyage.

The fishing industry relies on healthy marine ecosystems for a living. It is crazy that we're in a position where some treat the ocean like a rubbish dump.

The Interceptor

So far so boring: trade policies, more landfills and recycling centres, and someone who counts the number of nets on fishing vessels. Isn't there something a bit jazzier, a little more high tech, that we can nerd out on here?

It's clear that it will take several years at least to build the infrastructure the world needs to stop plastic pollution in our oceans. We could just sit – with our heads in our hands – watching all the plastic spewing out in the meantime. Or we could put in a temporary bath plug to stop the flow. A high-tech, shiny bath plug.

Let me introduce the Interceptor Original, a technology developed by Boyan Slat's Ocean Cleanup project. It's a solar-powered technological device – picture a small vessel with a long line of inflatable tubes around it – that is deployed at the outlet of rivers.[fn7] It can intercept the floating debris that comes out of rivers, trapping any plastic before gathering and processing it, and transporting it to a proper waste-management site. If you can trap plastic at the beginning of its ocean journey – right at the entrance – you catch it before it disperses. So far, the project has deployed eight Interceptor Originals in Indonesia, Malaysia, Vietnam, the Dominican Republic and Jamaica.

The Ocean Cleanup is just one project trying to turn this vision into a reality. There are many others. Some use 'river booms' – long curved barriers – that try to block and capture plastic. The Seabin Project – which started in Australia but has branched out globally – deploys bin-like structures that move with the tides and suck in any plastic floating around. Baltimore's Mr. Trash Wheel is a trendy machine with big comical eyes that chomps on plastic river rubbish as it moves on through. It's not unlike the game

Hungry Hippos. The Great Bubble Barrier, designed in the Netherlands, works by laying a tube along the full width of the river, on the riverbed. This tube then blows bubbles up towards the surface, creating a barrier that blocks plastics from moving forward. They can't move *past* the barrier and are pushed up to the surface instead, where they can be scooped up by a collection system.

It's too early to say how effective and how scalable these solutions are, but they seem worth a shot. Every day more plastics are escaping into our rivers and oceans, breaking down into smaller and smaller fragments. These will be even harder to remove from the environment in the future. We can stand around in despair, waiting for someone else to turn the tap off. Or we can do our best in the meantime: hold our hands out, ready to catch what falls through the cracks.

Cleaning up our beaches and shorelines

Most of the world's ocean plastic goes through cycles of getting stuck along coastlines – maybe even buried in the sediment – then shaken loose again into the waves. This process of burial and resurfacing of plastics can happen many times over.[33] This is good news. Scooping plastic out of the *middle* of the ocean is really difficult. But most of our plastic is not in the middle of the ocean – it's much closer to home, where we can reach it. Across the world you'll find people doing the thankless work of beach clean-ups. Except it's not thankless. If you live near a beach or coastline and can do your bit to clean it up, you can have a direct impact on stopping plastic from leaking into the ocean.

We have millions of tonnes of plastic already in the ocean. How do we get it out?

Up to this point we've focused on what we can do to stop plastic going into the ocean. But what are we doing with the plastic that's already in there? Should we just leave it, or can we get it out?

There's good news and bad news here. First, the bad news: there's plastic in the ocean that we won't be able to get out. We've all heard the statistics on how long plastics hang around in the environment – decades, if not centuries. This is partly true. Some compounds will take a long time to degrade. But some plastics break down much faster, creating microplastics.[34] The problem with microplastics is that they are now pretty much everywhere, and we can't get rid of them.

However, I'm more optimistic about the larger pieces – the debris Captain Charles Moore saw. I wasn't always so optimistic – you can find some of my scepticism in the internet archives. The internet is always there to unearth your old, embarrassing opinions.

The YouTube channel Kurzgesagt publishes some of the best videos on the internet. They explain science in an incredibly accessible way. The narrator has one of the world's most soothing voices, which plays over a backdrop of beautifully crafted animations. Millions watch every video. I've been lucky enough to work with Kurzgesagt on the scripts and research for some of these videos.

A few years ago we did one on the plastic pollution problem. It was a big hit. I did the research and wrote the script. I was asked if I'd participate as an expert on the topic for an 'Ask Me Anything' (AMA) on Reddit afterwards. These AMA sessions looked stressful, so I was reluctant. But Kurzgesagt had two other experts on board to help me, including someone from the UN's environment programme. Fantastic: I would be in good company.

As it turns out, I had no company. The other two experts didn't show up. It was one of the most frantic days of my life. Thousands of people arrived online to ask questions and get involved in the discussion. All of the questions were excellent: considered, nuanced, and asked with genuine interest to learn. They deserved a good and thorough answer.

The original video was centred on how we stop plastic pollution going *into* the ocean. That was the part of the problem I'd studied to death – I knew the data like the back of my hand. I had barely thought about the plastic that was already out there. I guess I had just assumed it was a lost cause.

Inevitably, people started asking me about it. Dammit. I was supposed to be the expert, and I had no idea. Embarrassingly, I turned to Google. *'How do we remove plastic from the ocean?'* I searched. The Ocean Cleanup project was the first result.

I had a look. I must have taken five minutes at most, but every minute spent was another question piling up in the backlog on Reddit. To be honest, when I looked at the Ocean Cleanup project back then, I thought their plan was nonsense. But I took the diplomatic approach: explained the problem, pointed people to the project, and said that it was too early to tell. 'Watch this space,' I concluded, which was a perfect non-committal cop-out.

After finishing my marathon AMA session, I stopped thinking about plastics for a while. But a year or two later I looped back round to see if there were any updates. I took another look at the Ocean Cleanup project – a proper deep dive this time – and saw it with fresh eyes. It's not that I suddenly saw it as some obvious, ideal solution. I still had a healthy dose of scepticism. What had changed was my appreciation for people – often incredibly smart people – really trying to *do* something. Just like Boyan Slat. Rather than simply wringing his hands and complaining about it, he set out to tackle the problem of the ocean being full of plastic. He was, by the way, just 18 years old when he founded the project. So if you think you're too young to really make a difference, you're mistaken.

There's always space for lone entrepreneurs to take a problem and run with it. But this is particularly true for these big, global problems like ocean plastics. Who is

responsible for the plastics floating around in the middle of the Pacific? Which government gets the bill for that? No country owns the open seas. It would be costly for any government to make it their mission to solve it. That means no country does. If we want to change things, it's up to brave individuals and private companies.

Boyan Slat and his team have focused on cleaning up the plastic in the big ocean garbage patches. They monitor and track where the high concentrations of plastic end up. That's the target zone. They then deploy their clean-up devices (which are different from the Interceptor): floating barriers – think of the long floating buoys you get at swimming pools – which collect and trap the plastic in a large pen. Once the pen is full, the plastic can be scooped up and taken on board a boat. It's then transported away for sorting and recycling.

The technology might not yet be perfect, but there are signs that it works. With each attempt, you can see heaps of plastics being lifted out of the ocean. One of the problems the project has is making sure it only collects waste and not wildlife with it. The most recent numbers suggest that around 0.1% of the mass they catch is 'by-catch' – wildlife that sadly gets caught up in the barriers. This is small by ocean standards for fishing-type activities, but with improvements to the technology, the hope is that this can be almost completely eliminated.

I still don't know whether this technology will make a dent in the amount of plastic already in the ocean. I hope it does. Not least to celebrate the fact that a small group of individuals had the guts to tackle a problem that most assumed was unsolvable.

Things to stress less about

Plastic straws really don't matter

Paper and water don't go together. Paper is made of a compound called cellulose, which dissolves in water. Why anyone would think it's a good idea to make drinking straws out of paper is beyond me. They really are useless. Yet 'paper straws' have become the sustainability badge for restaurants and bars across the world.

I'm not an advocate for plastic straws. I don't really care about them. But I do care about ineffective policies, especially if they take the place of ones that could really make a difference. Plastic straws are just not a big deal in the scale of the world's plastic pollution. Especially in rich countries, the odds that your plastic straws will end up in the ocean are pretty small. Even if they're not recycled, they're probably being sent to landfill. We don't know exactly how many plastic straws end up in the ocean, but they're probably around 0.02% of ocean plastics. If we want to get strict on single-use plastic straws, fine. But it can't be a government's leading policy for tackling plastic pollution.

Some people with disabilities do need a straw, and banning them would have a significant impact. Most of us don't need a straw, but know that it's not a big deal, and

you don't need to feel guilty about using one on special occasions. My one request is that we quickly move past the paper straw phase.

The occasional plastic carrier bag is fine

A single-use plastic bag: the sin of any environmentalist. Many of us know the agonising pain of turning up at the supermarket, then realising you've left your reusable shopping bags at home. The next 10 minutes is a comedy show, seeing how many items you can stuff into your pockets, clutch in your arms, and even grip between your teeth. You will not let the team down by asking for a plastic bag.

I do the same. Even though I know better: the data shows us that the occasional plastic carrier bag is not that big a deal. In fact, in many ways, a single-use plastic bag is better than some alternatives. At least when it comes to the carbon footprint, it's much lower than the rest. You'd need to use a paper bag several times, and a cotton one tens to hundreds of times to 'break even' with the plastic carrier.[35, 36] This is also true for other environmental impacts such as water use, acidification, and the pollution of water with nutrients such as nitrogen. This doesn't mean you should switch back to using single-use carrier bags: it just means you should make sure you're reusing the other types of bags a lot. If you're buying a new organic tote bag every second visit, you're really making things worse. And as seen in previous chapters, you should be focusing much more on what you put *in* the bag than the bag itself. It will have a much bigger environmental impact.

The problem with plastic bags, then, is that they can pollute our waterways. But, like any other form of waste, only if we don't manage it properly. In rich countries, unless you're littering near a river or coastline, they're probably not going to end up in the ocean. Even sending it to landfill is not a big deal. This *is* a problem in low- to middle-income countries where the use of plastic bags is on the rise but the infrastructure to deal with the waste is not. That's where tight rules on single-use plastic bags, and the availability of alternatives, *really* make a difference.

So, be conscious of how much you're using. Take a rucksack or a sturdy bag and reuse it again and again. But you don't need to stress out if you reach the supermarket till and realise you've left it at home.

Landfills are often not as bad as they seem

I often feel guilty about sending things to landfill. It seems like a failure: I've produced waste that won't be recycled or used again. But one of the solutions I've repeated over and over in this chapter is the need for more and better landfills. That might make you shudder (it makes me flinch too), but they're not always as bad as they seem.

Landfills *can* be bad if they're not managed properly, and plenty in the world are not. Open dumps or surface landfills are not a good solution. Plastic and other waste can

blow away, pollution can leak out of the bottom, and strong greenhouse gases are emitted into the atmosphere.

But a well-managed landfill, deep in the ground, can be a very effective environmental solution. Many people think the world is running out of space to host landfills, but this isn't true. I did some calculations to see how much space we would need to store *all* of the 9.5 billion tonnes of plastic we've produced to date. That's taking all the world's plastic and burying it underground.

Let's imagine we have a buried landfill, around 30 metres underground. This is the depth of many existing landfills – the Puente Hills landfill in Los Angeles reaches a whopping 150 metres below the surface. Our landfill is going to extend 10 metres deep. How big an area would this take up? Around 1,800 square kilometres. That's an area the size of London, which might sound pretty huge but is just 0.001% of global land area. If this landfill was closer to the surface, it might take up a bit more space. If it was deeper or taller, you'd need less. But regardless of which dimensions you choose, the amount of area is small: the size of a city or two. No one wants a landfill in their backyard, but we have enough space so they don't have to.

Most people think landfills are awful, but they could be effective storage sites for carbon, reducing the impacts of waste on climate change. When trash decomposes it emits CO_2 and methane, an even stronger greenhouse gas. This is obviously bad for the climate. Well-managed landfills can slow or even halt this decomposition process by cutting off the oxygen supply. This stops CO_2 or methane from being emitted: the carbon stays in the landfilled material instead. This applies to other products such as paper and wood too. Think about it in terms of trees. When we burn wood or leave it to decompose, it emits CO_2. If we bury it instead, this carbon is 'locked in' and we have taken some CO_2 out of the atmosphere. This is called a 'carbon sink'.

Some decomposition still happens in landfills, but mostly from organic matter such as food waste and paper.[37] Well-managed landfills can capture any methane that escapes so it's not emitted into the atmosphere. Similarly, any leaking of polluted water into surrounding ecosystems can be stopped by landfills having secure linings underneath them. Not every landfill does this securely, and these linings can degrade over decades. But this is a fixable problem.

Landfills are not aesthetically pleasing; we need to be careful about where we put them. And if they're poorly managed they can be an environmental travesty. But in the fight against plastic pollution good landfills are an essential part of our toolkit. Let's not let our stress and guilt get in the way of using them.

8

Overfishing

Pillaging the oceans

‘We will see virtually empty oceans by 2048’

– *Seaspiracy*, 2021

In 2021, the Netflix documentary *Seaspiracy* took the world by storm. It was one of the most-watched programmes of the year, and set the media alight. I heard people around me repeat its headline claim over and over: ‘There will be no fish left by the middle of the century!’ We will have pillaged our seas of every last fish, our nets and lines coming up with nothing. There will be no life left on the sea floor. The beautiful corals that once housed vast marine ecosystems will crumble, with no life to sustain them. Earth is the blue planet, but its oceans will be barren.

Most marine scientists were torn. Finally, the dangers of overfishing and the state of our oceans were getting the attention they deserved. And yet the whole documentary was riddled with falsehoods.

Where did this claim come from? In 2006, Boris Worm and his co-authors published a paper in *Science*.[1] Worm, now a professor at Dalhousie University in Canada, is one of the world’s most renowned marine ecologists. His *Science* paper looked at the state of biodiversity in our oceans. At the time, there was great concern about the state of the world’s fish stocks. Bluefin tuna populations were in serious trouble, cod and haddock were in decline, and many people were avoiding salmon based on warnings from NGOs around the world.

The study didn’t paint a rosy picture. Yet the core results of the paper got very little attention at all. The media, instead, homed in on a single statistic, a number that appeared only once, in the conclusion:

> Our data highlight the societal consequences of an ongoing erosion of diversity that appears to be accelerating on a global scale. This trend is of serious concern because it projects the global collapse of all taxa currently fished by the

mid-21st century (based on the extrapolation of regression to 100% in the year 2048).

I can see why many would read this conclusion and be alarmed. I can also see why a journalist, hungry for a dramatic story, would grab on to it. Sure enough, the *New York Times* ran the story: 'Study sees "Global Collapse" of Fish Species'.[2] Other media concluded that the world's fish would be gone by 2048. The coverage snowballed from there.

There are two key problems with the framing of this story. The first is that when marine ecologists talk about a 'global collapse', they're talking in a different language from most of us. We might assume that a 'collapse' means there are no fish left. That a collapsed population is one that has disappeared. That's how the story seemed to jump from 'global collapse by 2048' to 'empty oceans by 2048'. But this is not what scientists mean.

There are many definitions of 'collapse' in fisheries science. The one that Boris Worm was using was when the amount of fish we *catch* falls to 10% of the highest recorded levels of catch in history. So if the maximum amount of Atlantic bluefin tuna we have caught in any year was 1 million, we would say it had 'collapsed' if our catch in any year fell below 100,000. It's quite weird that we would define this based on fish *catch* rather than the *number* of actual fish that are left. But we didn't have much data on the abundance of fish in the ocean at the time of Worm's paper. To understand how well fish populations were doing, we'd measure how easy it was to catch some. It's easy to catch fish when there are loads of them around. It gets harder and harder as their populations shrink.

When Boris Worm said that the trend pointed towards 'global collapse by the mid-21st century', he didn't mean there would be no fish left. Even if his projection of a collapse *did* come true, the oceans wouldn't be empty. Obviously, this would still be a terrible position to be in, whether you care about the fish or the people that catch them, but it wouldn't mean an empty ocean.

Now, the second big problem: how Worm got to a projection of global collapse by the middle of the century. He estimated the state of the world's fish stocks based on what data was available (which wasn't very much). Despite the lack of data this was important work: scientists have to try to understand where we are and where we're headed based on the best data they can get their hands on. He estimated that in 2003, almost 30% of the world's fish stocks were defined as 'collapsed'. What he then did was simply extend that trend line out until it reached 100%. He assumed that fish stocks would just continue to collapse, one after another, until they all had in 2048.

It's a somewhat innocent extrapolation. For a scientist it's an interesting thought experiment: 'If things carry on as they have in the past, when would this reach 100%?' I often do these calculations myself. They're fun. But this approach highlights a fundamental problem that we've seen over and over in this book. It's one that feeds into

the doomsday mentality that we've locked ourselves into. We extrapolate exploding population numbers and panic that they will never stop growing. At least, until they crash. We see rising CO_2 emissions and assume that they'll just keep rising. Fertilisers, coal, pesticides, air pollution: we'll just produce more and more. If you're sceptical that things can change, then this is a natural position to fall into. But there's no scientific basis for this assumption. In fact, for most of our environmental problems, there are clear signs that it *isn't* that way any more. We can, and are, course-correcting.

So, there were two big red flags about how this study was picked up by the media. First, 'global collapse of fish' does not mean an 'ocean empty of fish'. Second, just drawing a straight line until it reaches 100% is, well, not that scientific. It's hard to lay serious blame on the journalists at the time. But there's no excuse for getting this wrong today – more than 15 years later. That's because this controversy sparked a revolution of fisheries data. This data shows us that we've veered far away from the pessimistic scenario that first hit the headlines.

Many marine scientists were ecstatic that fish had made headlines in the *New York Times*, *Washington Post* and on the BBC. But others were struggling to make sense of it, even after they'd got to the bottom of the misinterpretation that a 'global collapse' meant an 'empty ocean'. These gloomy prospects didn't tally with what they were seeing on the ground – or, rather, in the sea. Sure, some of the world's fish stocks were doing poorly. But others were not close to collapse. In fact, the sustainability of some was *improving*. If anything, it looked like there would be *more* fish in 2048, not less. Shortly after Worm's study appeared, *Science* published several scientific rebuttals from other fisheries experts.

One of the study's fiercest critics was Ray Hilborn, another giant in the field, who was working as a fisheries scientist at the University of Washington. He had been a researcher for decades, and had been winning prizes for his academic work since the 1970s. He also had a slightly more optimistic take on the prospects of the world's fish.

In interviews, Hilborn called the work 'incredibly sloppy' and the projections 'mind-bogglingly stupid'. In the same month as Worm's paper came out, Hilborn responded with a paper in the journal *Fisheries*, titled 'Faith-based Fisheries'.[3] In it, he took a swing not only at the marine science community but also at the world's top scientific journals. They were favouring front-page news over evidence-based science.

Worm and Hilborn saw the problem differently, perhaps because they came at it from different world views. Boris Worm was a marine ecologist and Ray Hilborn was a fisheries scientist. A simplistic view of marine ecologists might be that they want ecosystems to turn back towards a pristine state before humans came along. Fisheries scientists focus on how we can maintain healthy ecosystems while catching as much fish as possible.

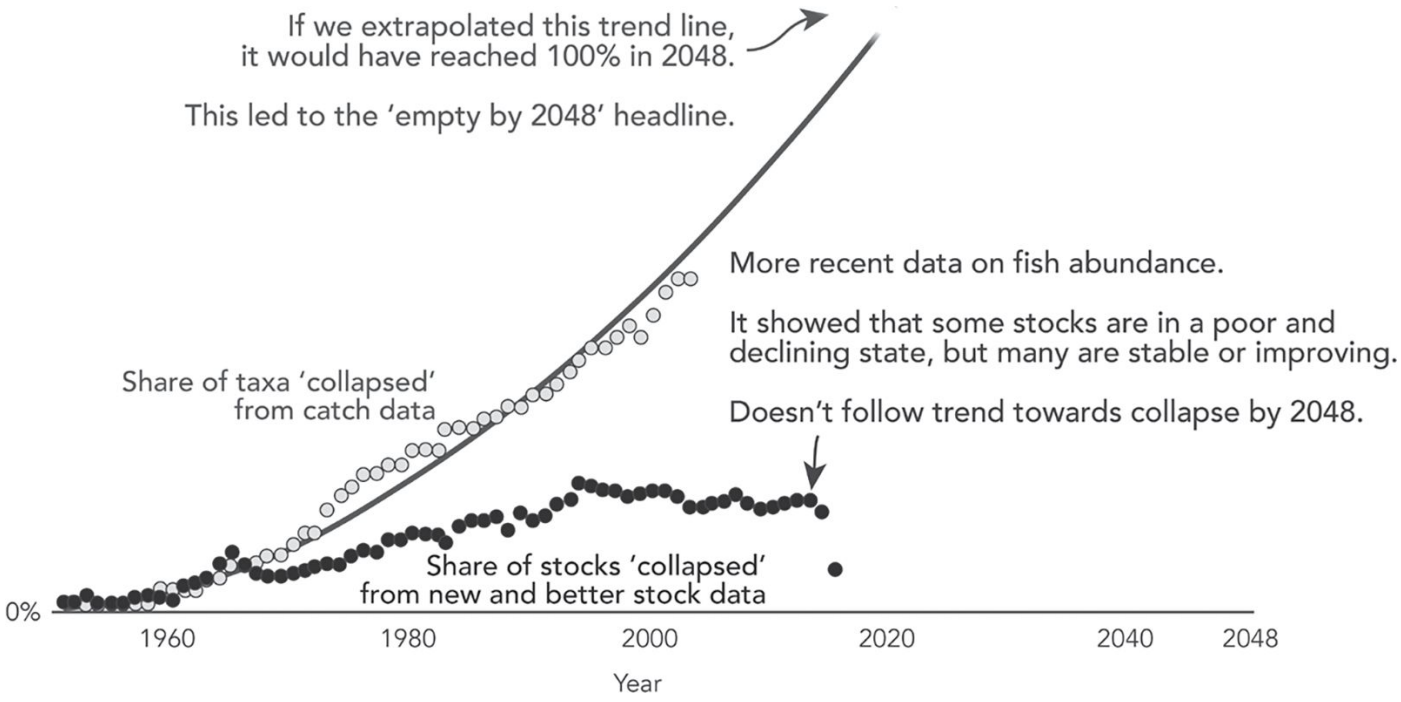
They were both invited to talk it out live on US National Public Radio. The hosts were probably hoping for a juicy, nerdy battle, but it turned out to be more amicable

than expected. Hilborn and Worm shared a lot of common ground, and mutual respect for one another. So much so that they continued to discuss it over email in the weeks that followed.

It became clear that the data set needed to really understand what was going on hadn't been built yet. They decided to team up and construct it. As Boris Worm recalled: 'Ray and I realized independently this [public disagreement] was not going to make the science any better, because you have the danger of being blind in one eye.'[4] They applied for – and got – a grant to assemble a group of twenty scientists. The mission was to gather and aggregate data on fish *abundance* – the number of fish in the ocean rather than the amount of fish being caught.

By 2009, they had the data they needed. Their co-authored study – titled 'Rebuilding Global Fisheries' – appeared in *Science*,[5] with the journal introducing the paper as an end to the war over fish: 'after a controversial projection that wild-caught fish would disappear, top researchers buried the hatchet to examine the status of fisheries – and what to do about it'.

What their results showed was that, on average, there was no decline in these fish stocks. But they did find different results across different regions. Some stocks were doing well, and were in fact increasing. Others were struggling and were a cause for concern. This is why, on average, there was no clear change; the good news was cancelling out the bad news. But one thing was very clear: there was no indication of a 'global collapse' by mid-century. If you drew a new extrapolation based on these figures, it would actually never reach 100%. Not even in the year 3000.



The oceans will not be 'empty by 2048'
Following the publication of a paper in 2006, many headlines have made the claim that the 'oceans will be empty by 2048'. This chart shows where this claim came from, and more recent evidence that refutes it.

This was a crucial update to our understanding of the world's fisheries. But 'not getting much better, not getting much worse' is not quite as catchy as 'global fish stocks will soon collapse'. Negative news sells. Positive news can occasionally sell. Neutral news rarely does.

Science is full of head-to-head clashes, quarrelling academics, political divisions, ideological barriers. It can be hard to set differences aside and make progress together. Worm and Hilborn showed us how it's done. When the evidence wasn't there to settle their differences, they worked together to build it.

Unfortunately, not everyone updates their position when the evidence changes. That's why the 'empty oceans by 2048' falsehood was repeated in 2021 in *Seaspiracy*.

Of course, this does not mean that the state of the world's fish is perfect and that we have nothing to worry about. But I hope that – if you did believe *Seaspiracy* – some of your worst concerns have been tamed a little. Now that we've addressed the worst panic, we can take a deeper look at the history of our treatment of the oceans, where we are today, and what we need to do to make them healthy again.

How we got to now

The rise and fall of whaling

We might show our dominance today by overpowering some of the ocean's smaller creatures. But in the past, it was the big ones we went for. Weighing in at over 150 tonnes, blue whales are the largest animal to have ever lived on Earth. You might think their size would have protected them from human exploitation. But, in fact, it made their fate even worse. As seen in Chapter 6, humans have always been drawn to the big guys. Whales made for an incredibly valuable source of oil, meat and blubber.

When we imagine early whaling perhaps we think of Herman Melville's 1851 story of *Moby-Dick*. But our battle with whales goes back much further. In the early 2000s, researchers were exploring Bangudae, a site in South Korea, which dates back to 6000 BC.[6] There they found many breathtaking carvings of whales in the rocks. The whales are not alone in these sketches; beside them are boats of men with harpoons. These petroglyphs might be the first window we have into the beginning of whaling.

Whale hunting dates back *at least* several thousand years. It became increasingly popular across Europe during the medieval period – from around AD 500 to 1600 – when elite Londoners, Scots and the Dutch would carve whale bones into lamps and ornaments, and make a banquet out of the precious meat.[7, 8] But hunting tools were not very effective at the time. This all changed in the 18th and 19th centuries, especially when whaling hit the United States, where it became a key industry. Although the uses of whale oil later diversified, Americans mainly used it for lighting.

Today it seems crazy to think that we would kill something so majestic just to light a candle. But it's a perfect illustration of how limited the supplies of our ancestors were.

They weren't killing whales out of malice. They were trying to find a source of energy, and as it turned out, whale oil was one of the best they had.

Over the first half of the 19th century, US production of whale and sperm oil continued to climb. In 1800 it was producing tens of thousands of barrels a year. By the mid-1840s it was more than half a million. But like so many trends we've seen so far: what goes up inevitably comes down. It hit its peak in the 1840s and production fell just as fast as it increased. Plot the trend of whale oil production in the US over the 19th century and we get an almost perfect upside-down U.

What caused whale oil production to peak and then fall? Partly, fossil fuels. Around this time, petroleum oil was discovered, and kerosene began to replace whale oil in lighting because it was cheaper. Whale hunting became increasingly unprofitable.[9] As whaling began to die in the US, the boom was just getting started in other parts of the world. Towards the end of the 19th century, new technologies were being developed that could catch whales in much larger numbers. Rather than the classic sail- or oar-powered boats that the Americans had been using, the Norwegians had mechanised, steam-powered vessels with cannons and harpoons. This made whaling much more efficient. Not only could we catch more, it also allowed us to catch whale species that were too fast for our old technologies. When large whales are killed they usually sink. In the 1880s a way was found to stop this: pumping air into the dead whale to keep it afloat.

This was the start of the 'modern' whaling era, from the turn of the 20th century, which didn't only bring innovations on how to track and hunt whales, but also advances on how we could use their oils, blubber and bone. Whale oils were initially used for lighting as a fuel and machinery as lubricant. Advances in cosmetics and food chemistry meant that its by-products were soon used for soaps, textiles and even margarine. Ambergris – a substance found in the intestine of sperm whales – was, and still is, used to make perfume. You will find it in Chanel No.5, for example. Whales made it into the fashion industry too. Instead of teeth, baleen whales have long strips of keratin (a protein found in human nails and hair) which hang from their mouths – these strips were used in everything from skirts and women's corsets, to umbrellas, parasols, fishing poles and crossbows.[10]

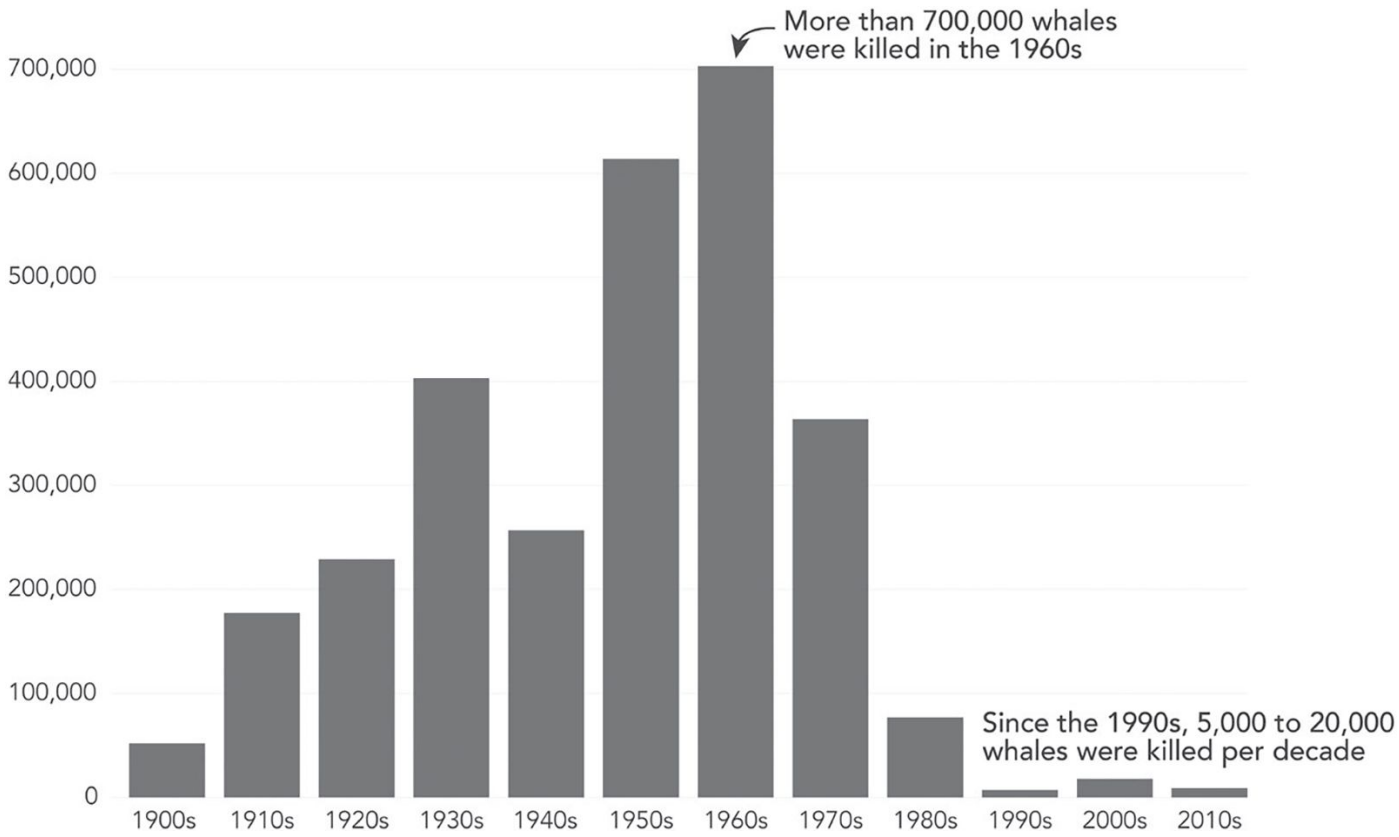
We were, suddenly, much better at hunting whales and had a growing market. Year after year we killed more. From only a few thousand each year to 10,000, then 20,000, until the 1960s, when we were killing 80,000. The only brief period of reprieve was the Second World War, when humans turned their hunting boats on each other. Once the fighting was over, whales became the target again.

Whaling rose steeply over the first half of the century. But, remarkably, it has become something of a conservation success story. It fell dramatically in the 1970s then plunged to low levels in the 80s, 90s and the 00s. We hunt very few whales today – and almost none for commercial reasons. How did the world manage to turn things around? There

were a number of factors at play. By the 1960s, whale populations had become increasingly depleted; this scarcity made it expensive to hunt them, because they were hard to find and catch. Whale oil and bones were losing their competitive advantage. There were now cheaper and more accessible alternatives for the cosmetic, food and textile industries. Fossil fuels had started to replace whale oils.

Political action took this one step further. In 1946, noticing that whaling was becoming unsustainable, a number of countries had formed the International Whaling Commission (IWC). After many decades of failed quota agreements, in 1987 the IWC agreed to a global moratorium. This made commercial whaling illegal, with only a few exceptions.[fn1]

Human dominance in the 20th century still had a profound impact on their numbers. Just before the start of the 20th century there were around 2.6 million whales in our oceans.[11, 12] A century later, there were only 880,000 left. The number of whales fell by two-thirds, with some species particularly badly affected. I'm sure you've guessed the pattern by now. The largest whales were prime targets. The minke whale saw a fall of 'just' 20%. The blue whale was almost plundered to extinction. Its populations fell from 340,000 to just 5,000, a reduction of 98.5%.



Whaling is just a fraction of what it was in the past
The global number of whales hunted and killed per decade.

It will take a long time for whale populations to recover. But the world acted just in time to allow them to do so. The story could have ended very differently. Many species

were hurtling towards extinction and we pulled on the handbrake, just in time.

The history of fishing

The remains of one of the earliest modern humans show that he was a fish eater. Bone fragments of the 'Tianyuan man' were found in the Tianyuan Cave near Beijing, and suggest that he was alive around 40,000 years ago. Isotope analysis shows that he ate plenty of freshwater fish.

We also know from cave paintings, discarded fish bones and makeshift hooks that our history of fishing goes back tens of thousands of years. For most of that time our tools were fairly limited. The tech innovators might have had a hook and line, or a spear. Many just had simple baskets woven from reeds. But this started to change in the 15th century, when the first large fishing boats arrived on the scene in Europe. These boats would put out long 'gillnets', which would form a wall or curtain of mesh to catch fish in. These were much more effective at catching large amounts of fish, including unwanted marine life too. Expeditions would often last weeks at a time, and fishermen would come back with a healthy supply.

Large-scale fishing efforts escalated from there and expanded across the world. Not only were nets and methods more sophisticated, but boats became bigger and faster. They were later bolstered by an engine; fishermen could set the net, move at speed to stop fish from escaping, and catch more as they went.

A crash in fish stocks became the reality for many rich countries. Looking at the catch of North Atlantic cod from Newfoundland and Labrador in Eastern Canada, we can see that it started to ramp up from the 17th century. In the 18th we were catching around 100,000 tonnes a year. By the 20th this was around 250,000 tonnes. It eventually peaked in 1968, before a collapse in stocks led to a dramatic decline. Fisheries were forced to close completely in the early 1990s.

Another innovation that opened up a whole new world of fishing was steam trawlers, which appeared in the UK in the 1880s. Vessels could go further offshore, they could stay out at sea for longer periods of time, and they had better gear to reach deep into the ocean. Fish catch rose steeply over the first half of the 20th century,[13] despite being interrupted by two world wars.[14]

Bottom trawling spread across the world, but without tight monitoring of fish populations, stocks started to decline. Bottom trawling in the UK – and other rich countries – fell a lot in the late 20th and early 21st centuries.

As we'll see, many countries have learned how to manage their fish stocks much more sustainably. Endangered fish stocks have made a comeback. But unmonitored and unregulated fishing techniques – where large amounts of fish are caught indiscriminately – are increasing across some parts of the world. We need to make sure they don't follow the same destructive path that many fisheries did in the past.

Where we are today

How much of the world's fish are sustainably managed?

How unsustainable have our fishing habits really become? That sounds like a simple question but racks up a whole lot of controversy. To answer it, we need to agree on what 'sustainable fishing' actually means. Not everyone does.

We can fight it out over technical details and numbers: how much fish we catch, how many fish are left or whether populations are being depleted. But this is often not where the real disagreement lies. It lies one step earlier, with the ethical conflict of how we view fish. You can see already that we don't discuss fish in the same way that we discuss other wild animals. In the biodiversity chapter, our goal was to protect them at all costs. Some view fish in the same way, but most don't: they think about them as animals to catch. And when people view fish through different lenses, these debates don't get very far. They don't even reach the stage where they can discuss the numbers.

There are two main schools of thought when it comes to fish. One school – often adopted by environmentalists, ecologists and animal welfare advocates – views fish as animals in their own right. This is how we view most other wild animals, like elephants or monkeys. Here, our goal is to restore wild animal populations back to their pre-human levels. The same would apply to fish: we should allow populations to increase back to their historical levels, before we started fishing them. Here, sustainability would mean catching very few fish, if any.

The other school views fish as a resource. Most of us eat fish, and hundreds of millions rely on it for their income. We can't let fish return to their pre-fishing levels *and* catch lots of fish at the same time. So 'sustainability' according to this view means catching as much fish as possible, year after year, without depleting fish populations *any further*. This meets the classic Brundtland definition of sustainability: we catch as much fish as possible to meet the needs of people alive today, but don't take so much that it would sacrifice catch for future generations.

Scientists can calculate this magical 'sweet spot': the exact point where we can catch as much fish as possible without depleting their populations below their most productive levels. It's called the 'maximum sustainable yield'. If you get greedy and catch more than this, then you deplete fish populations for future generations. If you catch too little, then you're sacrificing food and income for the current generation. This is what most fisheries are aiming for: catching not too much, not too little, just right.

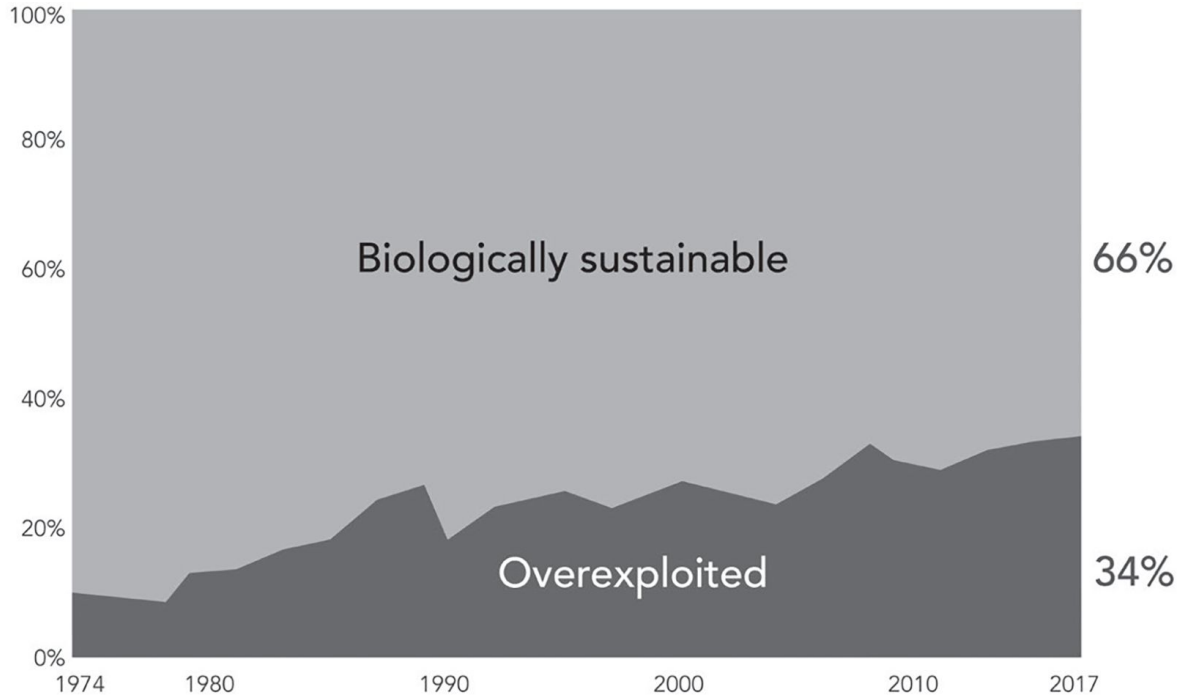
The tension between these schools of thought is obvious. The definition of 'sustainability' is completely different. So, too, is the end goal. When a fish stock is at its 'maximum sustainable yield' it's around half of its original, pre-fishing level.[15] So, what is sustainable to the second school is only half of what the first school considers sustainable. It's a hard deadlock to break. I can see both positions. We do tend to view fish differently from wild animals on land, and that seems odd to me. At the same time,

it seems unrealistic that the world will stop fishing overnight. If people are going to keep fishing we need to make sure we are monitoring and managing wild fish stocks as best we can. That means catching fish in a way that doesn't overexploit stocks, and keeps them in a healthy balance. Which essentially brings us to the second camp.

The UN's Food and Agriculture Organization has a division dedicated to fisheries research and reporting. Each year it produces estimates of how sustainable the world's fishing activities are.[16] The 1980s and 90s were scary times. In the early 1970s, close to 90% of the world's fish stocks were being managed sustainably. But from there, things went downhill rapidly. Global demand for fish continued to increase. The number of fish stocks that were pushed beyond their limits seemed to increase year after year. You'd be forgiven for thinking that this trend would just continue to rise, just as Boris Worm did at the beginning of this chapter.

By the early 2000s, around one-quarter of the world's fish stocks were overexploited. By 2008, this had climbed to one-third. But the increase has slowed. Since then, the share of stocks that are exploited has stayed at around one-third. That means two-thirds of global fish stocks are managed sustainably.[fn2]

Of course, that's not really worthy of celebration. We're no longer on the steep rise we saw in the 1980s and 90s, but we have, at least, slowed or stalled this increase. We've done enough to buy some time to work out *what* is going right, and apply it elsewhere.

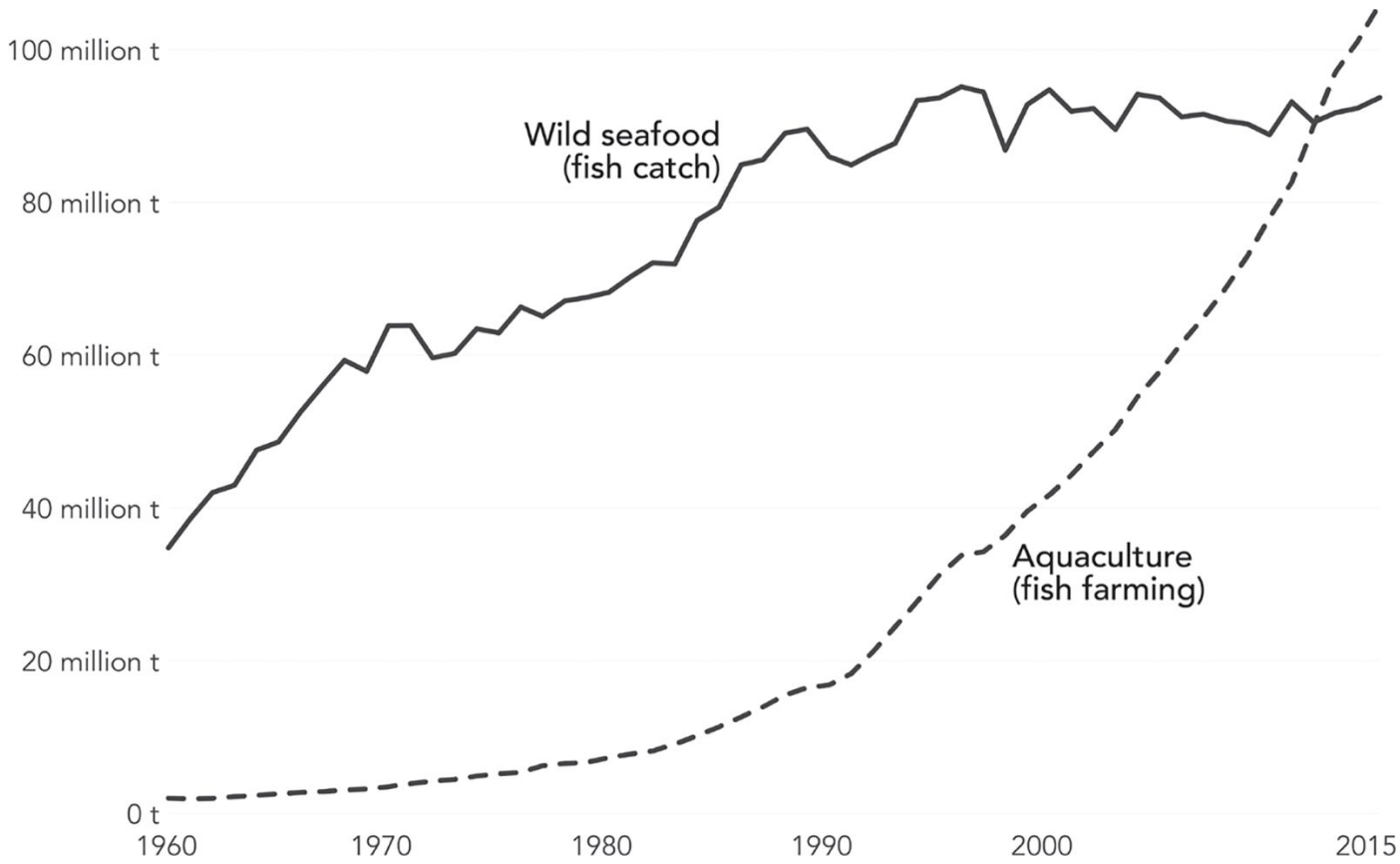


One-third of the world's fish stocks are overexploited
Fish stocks are overexploited when fish catch exceeds the maximum sustainable yield – the rate at which fish populations can regenerate.

We now farm more fish than we catch

Something doesn't quite add up here. We've managed to put a pause on the number of fish populations that are being overexploited. But since 1990, global seafood production has more than doubled. How did this happen? Rather than catching more fish, we started to *grow* them. This is called 'fish farming', or 'aquaculture', and we can think about it in a similar way to raising cows, pigs and chickens on land. Rather than relying on populations of wild fish (the equivalent on land would be relying on wild birds or deer), we can breed our own. Farmers feed and breed fish under controlled conditions – either in caged enclosures in the sea or rivers or in artificial facilities on land – before killing them to sell.

Fish farming is a relatively new industry, one that has skyrocketed since the 1990s. In 1990, the world was producing just 20 million tonnes of seafood from fish farming. By the year 2000, this had doubled. By 2010 it had doubled again. And today, we produce well over 100 million tonnes of seafood from it. The world now produces more seafood from fish farming than it does from wild catch in the ocean. Wild fish catch has barely changed since 1990. Fish farming has made up for all of the extra demand. If we had tried to meet it through wild catch alone, our oceans could be in a terrible state.



The world now produces more seafood from fish farming than wild catch
Most of the growth in seafood production in recent decades has come from aquaculture. This is good for the protection of wild fish stocks.

The saving grace of aquaculture is not too dissimilar from the transition to crop and livestock farming. Imagine if we'd tried to feed a large and growing population from

wild mammals alone. They'd be gone in an instant (and so would we). Our ability to grow our own food and produce our own livestock allowed us to feed more people without putting much more pressure on wild mammals. The same is true in the oceans.

Fish farming hasn't always provided this safety net. In its infancy, it was really inefficient. Many farmed fish are fed on other lower-quality wild fish. Some need a lot of it. This is the 'fish in: fish out' ratio: how much fish you need to get one fish back in return. As late as 1997, this ratio across the world's fish species was two.[17, 18] That obviously makes no sense, and means putting even more pressure on wild fish populations.

Thankfully, the process has become far more efficient since then. We've become much better at farming and have developed plant-based feeds that can be used instead. For many fish, the ratio is now 0.3. Some species do even better. Some need no fish inputs at all. That means the total payback is even higher than three. Around 11% of the 90 million tonnes of wild fish that we catch each year is used as feed for aquaculture. Aquaculture then gives us about 100 million tonnes of seafood. Not a bad deal. Unless, of course, you are a fish. Just like our hierarchy of farm animals – from smallest to largest – earlier in the book, the efficiency of fish means that we kill a lot of them. Trillions every year. And welfare standards in fish farms are often very poor.

I was worried that with the aquaculture boom, demand for wild fish for farming would become unsustainable. This hasn't happened. In fact, we use *fewer* wild fish for feed than we did a few decades ago, and produce more than five times as much from aquaculture.

Fish farming is an innovation that has saved many fish populations across the world. But it's not the only thing we've got right.

Many iconic fish species are now healthy and sustainably managed

When I was a kid, the big fish dilemma was whether to eat tuna. I kept hearing that the world's tuna was in deep trouble. I didn't know *why* tuna was the one fish that was being plundered more than the rest. I just assumed it was because everyone loved it as much as I did.

I didn't check back in on how the world's tuna was doing until recently. Terribly, no doubt, because tuna was as popular as ever. But, in fact, this should have told me the opposite. It's hard for a fish species to be popular – and affordable – for decades if its populations are on the brink of collapse.

My lifetime has been one of the great tuna turnaround. In the 1930s there were more than 8.5 million southern bluefin tuna. By the 1970s this had halved to 4 million, and by the millennium this had fallen below 1 million. Stocks had fallen by almost 90%.[fn3] Populations of the Atlantic yellowfin tuna had also been slashed by 75%. But things are looking much brighter in the 21st century. The steep decline of many tuna populations has reversed. With better monitoring technologies, and stricter regulations on where,

when and how much fishermen can catch, countries can make sure they're managing their populations sustainably. Albacore tunas and yellowfin tunas have both been moved from 'Near threatened' to 'Least concern'. The southern bluefin tunas have been moved from 'Critically endangered' to 'Endangered'. They're obviously still in a bad state, but things are moving in the right direction.

To most people, saying 'wild tuna populations have been cut in half' makes them gasp. But remember the 'maximum sustainable yield' – the point where we can catch as much fish as possible without depleting their populations – for most fish species is about 50% of their pre-fishing levels. So, if we want a sustainable supply of seafood, we'd expect tuna populations to be just half of what they were in the past.

Many tuna populations are now being managed responsibly; the world still has a steady supply for food, but we're not taking so much that populations are falling. It's not all good news though. Tunas in the Indian Ocean are in a worrying state. We're simply taking too much too quickly. As we'll see, the hope is that we can pull off another great turnaround before stocks hit rock bottom.

Tuna populations are not the only ones to stage a comeback. Cod populations fell off a cliff through the 1980s and 90s. Atlantic cod fell from 8 million tonnes in 1980 down to less than 3 million tonnes in 2000. But the world got its act together. Within a decade, populations had more than doubled again.

Tuna, cod, haddock and salmon from across Europe and North America are closely monitored: we catch them at the 'Goldilocks' spot: catching as much as possible but not so much that their populations shrink.

Fish stocks across Asia, Africa and South America

'You can't manage what you don't measure' is a quote often attributed to the business management thinker, Peter Drucker. What is relevant in business also applies to environmental conservation.

The bounce-back of iconic fish species across Europe and North America was only possible because we monitored them closely.

Unfortunately, not every country invests in this level of monitoring. We have large data gaps across many parts of Asia, Africa and South America. Of course, a lack of data doesn't necessarily mean things are going bad. The fact that you don't wear a fancy watch that monitors your sleep doesn't mean you're not sleeping well. But in this case, the fact that countries are not monitoring fish stocks closely probably means that they're doing poorly. That's because it's very difficult to keep fish stocks in balance *without* this information. They need this data to know how much they can fish, and when. They need it to set quotas to make sure there is a fair distribution between fishermen.

Ignorance might be bliss in the short term, but not for long. There's actually a pretty selfish reason to monitor fish populations closely. Countries need to if they want to have a profitable fishing industry in the medium term. As we saw from examples in Canada

and the UK, they will have to work harder and harder to get a good catch. Fishing becomes less profitable. Short-term greed will come back to bite and sink them later.

There are other clues that fish in these regions are not doing well. We know fishing activity is very high. Bottom trawling is very common in countries such as China and India. Maintaining such high rates of fishing without monitoring it closely makes it unlikely that fish stocks are in a healthy state. We might not have large-scale surveys to draw on, but we do have a few smaller-scale studies from specific locations. All show a large reduction in fish stocks.[19]

The first step towards healthy fish across many countries is to start counting them. Until we do that, we are swimming in the dark.

The world's corals are getting bleached to death

Deciding what you want to do with your life is hard. I knew the rough trajectory of the path I wanted to take: I was passionate about science, and had always wanted to be a writer, so science journalism seemed like the right fit. But I had a choice to make: do a journalism and creative writing degree while keeping my science passions burning on the sidelines; or do the opposite, a science degree with some writing on the side. In the end, the science won. At least that's how I liked to rationalise my decision. In reality, something else might have swung the decision. The university programme I chose had a compulsory field trip to Jamaica. It's tough when you have to endure a scuba-diving trip to a tropical Caribbean island to pass your degree.

In between the beach parties and trips to the rainforest, we were diving in the waters of Discovery Bay on the north coast. We were there to do ecological surveys and sampling of the coral reefs. It was my first 'real-life' experience of environmental change. It hit me hard. I had spent several years reading papers, writing essays and looking at sections of corals under the microscope. I still wasn't prepared for the reality.

I had expected that diving among the coral reefs would be like something from Pixar's *Finding Nemo*. The corals we see in films are these beautiful structures: pinks, reds, oranges and blues. They're alive. They're surrounded by marine life and fish. Clownfish like Nemo and surgeonfish like Dory duck in and out of the maze. I thought that's what I'd see when I dived into the water on that Jamaica trip.

The reality couldn't have been more different. I plunged underneath the surface and couldn't find the coral. If I hadn't known it was there I would have missed it completely. It was just white rock and rubble. The reef was covered in algae. And there were no fish. The most exciting thing we saw in our sampling of the entire coastline was sea urchins. They were the only sign of life.

That was one of the first up-close moments where the reality of what we were doing to our planet hit me. I didn't talk to my classmates about my shock on that trip. I have no

idea if they felt the same. I kept quiet out of embarrassment. I had studied the theory to death. Why, then, had my expectations of those dives been so unrealistic?

Coral reefs – which are a collection of individual corals – are some of the most beautiful and diverse life forms on the planet. The fact that they live in our oceans means that, like much of the planet's marine life, only a tiny fraction of people will see one up close. Yet they provide immense value to communities across the world. More than 450 million people in more than 100 countries live close to coral reefs and rely on them for their livelihoods.[20] They're so valuable because they form the bedrock of diverse ecosystems. Corals only cover 0.5% of the ocean floor, yet they support almost 30% of the world's marine fish species.

That's why it's so tragic that many of the world's corals are dying. To understand *why* they're struggling, we need to understand a little bit about what corals are and how they stay alive.

Corals are animals that belong to the phylum of cnidarians – a group of more than 11,000 water-based animals. Most live in marine environments, and most shallow-water corals are found in the tropics.[fn4] They use the calcium carbonate in ocean waters to build a hard exoskeleton. But the key to their success is how they get their energy. Corals contain microscopic algae called zooxanthellae that are part of a symbiotic relationship. The algae photosynthesise for the corals, providing them with most of their energy. They wouldn't be able to survive without them. They can only do this by living close to the surface where light is abundant.

Coral reefs face several threats – some natural, some from humans. These threats – warming waters, ocean acidification, changes in ocean chemistry and the dynamics of ecosystems – are nothing new. Corals have experienced pressures to varying degrees throughout Earth's history.

In the very distant past some of these pressures were extreme. Each of the 'Big Five' mass extinctions (looked at in Chapter 6) involved huge changes in the global climate and the chemistry of the world's oceans. These events were devastating for corals. After every one, there were no living reefs for millions of years. Even in less extreme times, corals would still experience stresses. They would be hit by storms and cyclones. They would undergo bleaching events, particularly in warm El Niño years. And they would see changes in the dynamics of their ecosystems. Corals are put under massive strain, but they can usually recover in the years that follow.

What's changed is that human pressures are increasing the frequency and intensity of these events. We're piling multiple threats on top of one another. We're overfishing at the same time as we're pouring sewage and fertilisers into coastal waters. To add insult to injury, we're simultaneously ramping up the thermostat.

My biggest concern for the world's reefs is coral bleaching. Coral bleaching happens when corals expel the algae they rely on to harvest sunlight. This starves them of their energy source, and they can ultimately die. They do this when they're exposed to

extreme warming. It's called 'bleaching' because the corals lose most of their colour. They end up looking like white rubble – a mere shadow of the beautiful life forms they used to be.

In a world without humans and climate change, coral bleaching would still happen. It often hits corals in El Niño years. El Niño is a normal climatic cycle that happens every seven years or so, and leads to localised warming in specific parts of the ocean. When bleaching events are spread out, corals have time to recover. They just need some breathing space.

The problem is that, because of climate change, bleaching events are no longer reserved for warm El Niño years. They're happening every year, even in the 'cool' La Niña phase. This means that corals have almost no time to recover. They are also being hit with cyclones more often, or at a higher intensity. And the pressure of overfishing and algal blooms only adds to their distress. This is like an athlete in the gym training at a high intensity, multiple times per day, with no sleep, hydration or food. It's not long before the body breaks down.

There is an abundance of evidence that coral reefs are being hit by more frequent, and more severe, bleaching events. Satellite data allows us to track changes in water temperatures around reefs, and the level of thermal stress they are exposed to. The first study to do this at a global scale found that the percentage of global reefs impacted by bleaching tripled between 1985 and 2012.[21]

In a more recent study, published in *Science*, Terry Hughes, the eminent coral ecologist, and his colleagues tracked the frequency of coral bleaching events across 100 pantropical locations from 1980 to 2016. This included all of the key coral hotspots spanning 54 countries, from the West Pacific to the Atlantic, the Indian Ocean to the Great Barrier Reef in Australasia.

They looked at the total *number* of bleaching events, as well as their intensity. 'Moderate' bleaching events are those where less than 30% of the corals are affected, 'severe' when 30% or more are. They found that there had been an increase in the number of bleaching episodes across the 100 reefs. In the 1980s we might have expected a coral reef to be hit by a severe bleaching event once every 27 years. By 2016, this had fallen to once every six years.

These shorter recovery times mean it's much more likely that a coral reef will die off entirely. That's the big concern as the ocean continues to warm. We are pushing some of the world's most diverse, complex and beautiful ecosystems to their limits. And we continue to pile on the pressure year after year.

The most obvious way to protect our coral reefs is to limit global climate change. Many governments will prioritise other, cheaper, ways to promote reef conservation. Don't be fooled: the biggest threat to the world's coral reefs is a warming ocean. If countries are not reducing greenhouse gas emissions, they are trying to pull the wool over your eyes.

The evidence is clear: to save the world's coral reefs we need to stop climate change.

How do we stop pillaging the oceans?

Eat less fish

The gut reaction to documentaries like *Seaspiracy* is to give up fish completely. I have several friends who have made that decision. If you can and want to stop eating fish, that's a very legitimate choice. It lets you bypass the dilemma of animal ethics. If you are going plant-based, it's also a good choice for the environment. But many don't want to – or, in some cases, can't – give up fish completely. A more realistic future, at least in the short term, is that people should just eat less of it.

This is not a blanket recommendation. In earlier chapters, when I discussed eating less meat, I made the point that this was not suitable advice for everyone in the world. For some, especially in poorer countries, meat is one of the few protein- and micronutrient-rich foods available. With good substitutes and a diverse diet, we can meet our nutritional needs. But billions of people can't afford a nutritionally complete diet, and need to make the most of whatever is available.

The same is true of fish. Some communities rely on fish as an important source of their nutrition. And they often don't have protein-rich plant-based substitutes lining the supermarket shelves, or omega-3 supplements in the local pharmacy. Until these alternatives become affordable and accessible across the world, I won't recommend eating no or less meat or fish as a sustainable solution for everyone. But many consumers in rich countries could certainly eat less without noticing any difference.

Which fish should I eat?

Fish *can* be a climate-friendly protein source. Many of our favourite seafood dishes have a lower carbon footprint than chicken – the most climate-friendly kind of meat. Let's say I'm convinced that many fish are a climate-friendly protein source, and can avoid the ones that have a high carbon footprint. No lobsters for me. But I don't only care about the carbon footprint. I'm also concerned about the impact on biodiversity – how our food production affects other species. And, of course, its impact on fish stocks. I want to pick a fish from a population that is not overfished. How can I be sure?

Labelling is a good place to start, but be careful: it's easy to be fooled. I still remember the day I discovered the label 'fresh' on egg boxes did not mean that the eggs were free-range. In fact, it often meant the opposite – it was a 'nice' way of saying they came from caged chickens. Don't fall for the fish labels. On their own, messages like 'all natural', 'sustainably caught', 'sustainably harvested', and 'responsibly caught'

don't tell you much. They rarely have clear verification processes or independent evaluations.

It's better to look for fish with certification labels from organisations like the Marine Stewardship Council (MSC) or the Aquaculture Stewardship Council (ASC). These councils work with third parties to monitor and check the sustainability of fish against a list of standards such as the state of fish stocks, how management practices are implemented, and impacts on other marine life. They do a reasonable job of sorting the sustainable from the unsustainable. But even these are not perfect. Various conservation groups have criticised them for occasionally turning a blind eye or a lack of transparency. While most fish labelled as certified *will* be of a high standard, some not-so-great stuff might fall through the cracks. That points to one important solution: improve the traceability and certification standards of these labels.

What can consumers do in the meantime? There are a number of seafood guides that do a good job of giving recommendations. In the UK, the Marine Conservation Society's Good Fish Guide is my go-to.[22] In the US, the Monterey Bay Aquarium's Seafood Watch is the best.[23] Other countries have their own guides. These rate specific fish populations from 'best choice' to 'avoid', based on rigorous independent assessments. Most have websites and apps where you can look up any type of fish you're hungry for, finding out where it was sourced and the method of catch. The problem is that the consumer has to go looking for the information. *You* need to know this before you step into the supermarket.

Stop overfishing by implementing strict fishing quotas

We need to know the size of a fish population, and how fast it reproduces. Once we have the data we can work out how much we can sustainably catch. If it reproduces slowly, we need to catch less to stay in balance. If it reproduces very quickly then we can catch more. Bigger fish – and animals in general – tend to take longer to grow to maturity and then reproduce. That's why there has been so much concern about tuna.

Once we know how much we can fish, we need to be strict about monitoring and policing how much fishermen are catching. What makes this difficult is that there is rarely just one boat of fishermen in each area of the ocean. We need to work out how much we can catch in total, and find a way of divvying up that quota for each group. It sounds difficult, but it can be done.

One thing is clear: good management of fisheries can work. Populations can recover, and people still get some catch. Each boat gets a strict quota; its catch is counted when it comes back to land. Fines and penalties are dished out for overfishing.

The use of strict fishing quotas is more common in richer countries, but even in European countries, they can produce mixed results. When they're done correctly, they work. When scientists are ignored, or ambition is lacking, they don't. The European Union has a Common Fisheries Policy, where it sets rules for how to sustainably

manage its fish populations. Countries agree, collectively, on how to share these responsibilities. The EU has made a lot of progress. In 2007, when overfishing reached its peak, 78% of the region's fish stocks were overfished.[24] By 2020, just 30% were.[25]

This was both a success and a failure. Clearly things are a lot better, but in 2013 the EU agreed to end overfishing by 2020, so it missed this target by a long way. Why? Countries set many of their fishing quotas above the limits recommended by scientists. Some fish stocks improved a lot. Take the example of the European plaice – a group of flatfish. In the decade from the late 1980s to 1990s, the number of fish more than halved.[26] The EU got its act together in 2007, and the number of plaice has nearly tripled. Meanwhile, populations of other species have gone in the opposite direction: cod in the Baltic and Celtic seas were continually overfished.

This situation is a perfect reflection of the three-true-statements: things are awful (30% are still overfished, and the EU missed its target); things are much better (30% is much less than the 78% it used to be); things can be improved. We know how to put good, sustainable policies in place. If we can implement them across the board, an end to overfishing is well within our reach.

Strict regulations on by-catch and discards

We've seen the videos and the pictures. Large industrial fishing vessels drop a massive net and plough-like tool – called a trawl – onto the seabed and the net scoops up everything and anything in its path – the fish they want to catch, but also other fish, turtles, dolphins, rays and seals. They flounder around, trying to escape, but with no success.

Next, we see the fishermen hauling their catch up into the boat. They're sorting through it. The tuna, salmon or cod get thrown into storage crates. The rest gets thrown back into the water. If not dead already, most of it dies pretty soon after. It's painful to watch the animals struggle, but it's also such a waste. They are collateral damage. Even if you have no ethical dilemmas with killing animals to eat, maiming and killing them without *any* useful end seems really bad. No one wins when this happens.

The fish we catch unintentionally that get thrown back into the water are called *discards*. Globally, around 10% of the animals we catch are discarded.[27, 28] It's hard to get some perspective on whether 10% is a big or a small number. Obviously, it could be lower. Ideally, it would be zero. But 10% is also much lower than it used to be. If we go back to the 1950s and 60s, 20% of the fish we caught were thrown back overboard. So, things have got better. But we're also now catching more fish. Thankfully, the total amount is less than it used to be too. In the 1970s we were throwing around 14 million tonnes of fish away every year. We've since chopped that by a third. How did we manage to reduce this number, and how can we get it as close to zero as possible?

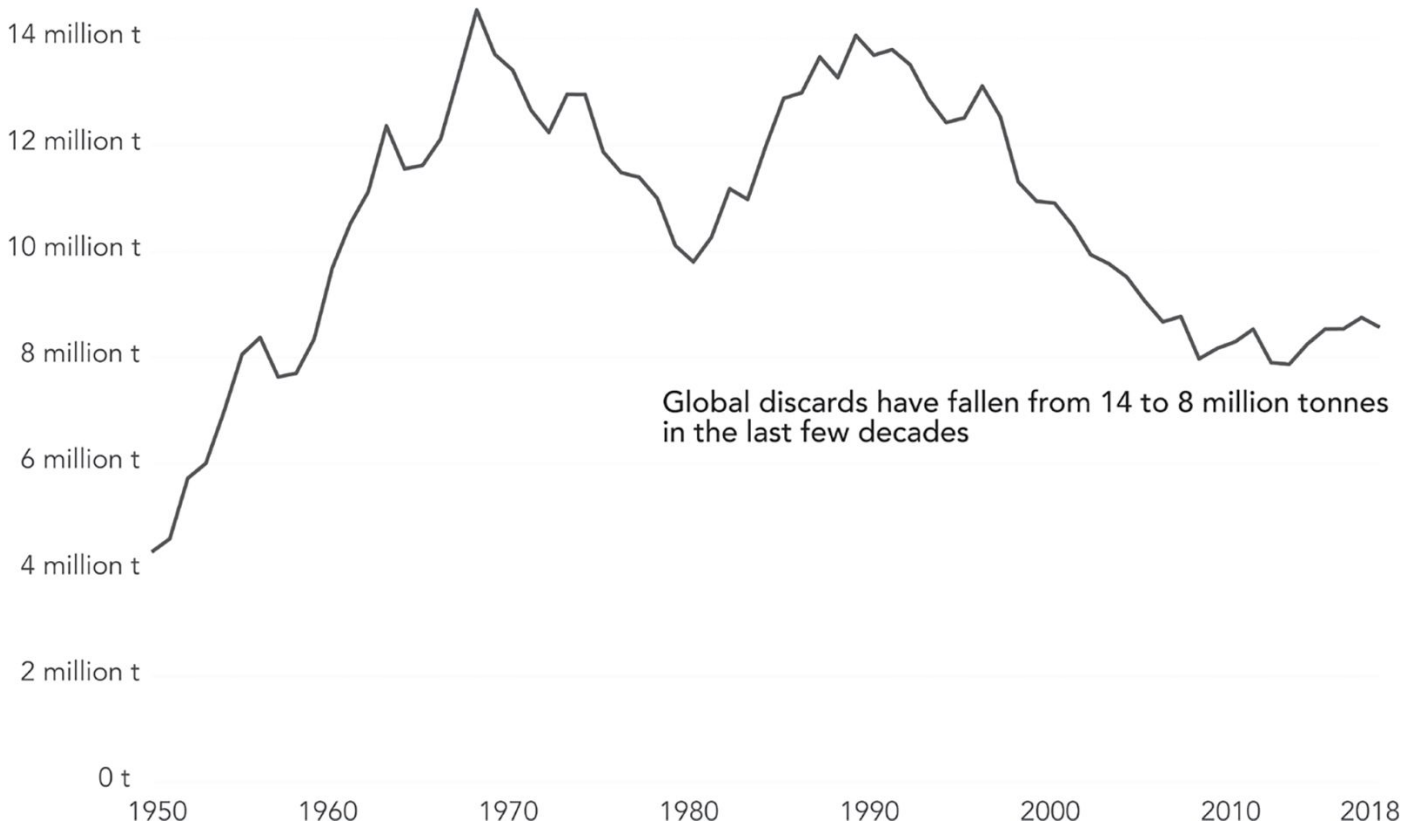
One reason is that the market value of fish has increased over time. In the past, if a fisherman accidentally caught a different fish, they might think they wouldn't be able to sell it. Or, if they did, it wouldn't be worth very much. Instead, they just tossed it away. Now, fishermen are more incentivised to bring any fish back to land because they know it will sell.

A more impressive move has been that some countries have implemented a ban on discards at sea. This is sometimes called a 'landing obligation', which means that fishermen must keep all their caught fish on board and declare it as 'landings'. This policy is implemented by the European Union, and was a core part of its Common Fisheries Policy reform in 2013. If fishermen have a quota or limit on how much fish they can catch, they have to be much more careful about by-catch – these unwanted fish will still count towards their quota for the day. These policies have been very effective. If other countries can replicate them, we could significantly reduce fish discards.

Finally, we can't talk about discards without talking about the type of fishing gear we use. You're going to scoop up much more marine life with a large mesh net than you are with a fishing rod. The large trawlers are the worst. They scoop up everything in their path. Around one-fifth of the catch from bottom trawlers are discarded. For particular types – such as shrimp trawls – this can be as much as 50%.

One way to reduce these discards is to cut back or stop bottom trawling entirely. Another way is to improve the gear we're using. Over time, we've engineered better equipment that is more selective – it only catches the fish we want it to. Some well-managed trawl fisheries have got discard rates down to less than 10%. We've done this in various ways: changing the size and shape of the mesh and hook; adding 'escape panels' to trap nets; using underwater lights and alarms.[28–30] These improvements have been really effective. Some countries, such as Belize, are leading the way and have banned the use of fishing gear that is not selective for specific fish.

Eliminating by-catch completely might be unrealistic. But the fact that discards have been falling means we can still do something about it. If every country was more like Belize, we could get pretty close to a world free of abandoned fish.



Global fish discards have been falling
Discards are animals thrown back (alive or dead) into the sea after being caught during fishing activities.

Marine protected areas might help a bit, but they're no silver bullet

One of the ways that we can make sure that certain parts of our oceans are not overexploited is to try to cut them off from human impacts entirely. On land we have heritage sites and national parks which are strictly policed. We have special sites of biodiversity that are closed off from disturbances.

Eight per cent of the world's oceans are defined as 'marine protected areas' (MPAs).[31] These are areas of oceans – which include the water column and sea floor – that have been reserved by law for protection. The regulations that are in place for MPAs vary from place to place, but include interventions such as no-fishing zones, restrictions on the type of gear that can be used, bans or restrictions on activities such as mining, and regulations on inputs to the ocean from rivers and industrial effluents.

As we saw in the biodiversity chapter, how effective MPAs are is not a settled science. In a perfect world, we would ban the exploitation of a particular part of the ocean, and that impact would disappear completely. The reality is a bit messier. Rather than vanishing, these activities often move to another – unprotected – part of the ocean. The total impact on our oceans is no different. In fact, in some cases it can be worse, if we move it somewhere with even poorer regulations or richer sites of biodiversity.

Simply increasing the amount of our ocean that is protected is no silver bullet. It all depends on how well we manage our MPAs, and if the rules are actually enforced.

MPAs with weak restrictions and enforcement will make little difference to the health of our oceans.[32] In fact, labelling an area as 'protected' without implementing it properly might even be worse – the illusion could make us complacent.

Despite the controversy about their effectiveness, the world has set bold targets to scale up the amount of ocean that our MPAs cover. We've already missed our first target of protecting 10% of the oceans by 2020 – in 2021, just 8% were protected. The next target to aim for is 30% by 2037, then half of the world's ocean by 2044. If we're to stand a chance of meeting these targets we need to get a move on.

Marine protected areas are just one spanner in our toolbox. Scale them up without the other solutions in this chapter and our grand targets won't help our oceans. They'll just make the water murky so we don't see the damage.

Things to stress less about

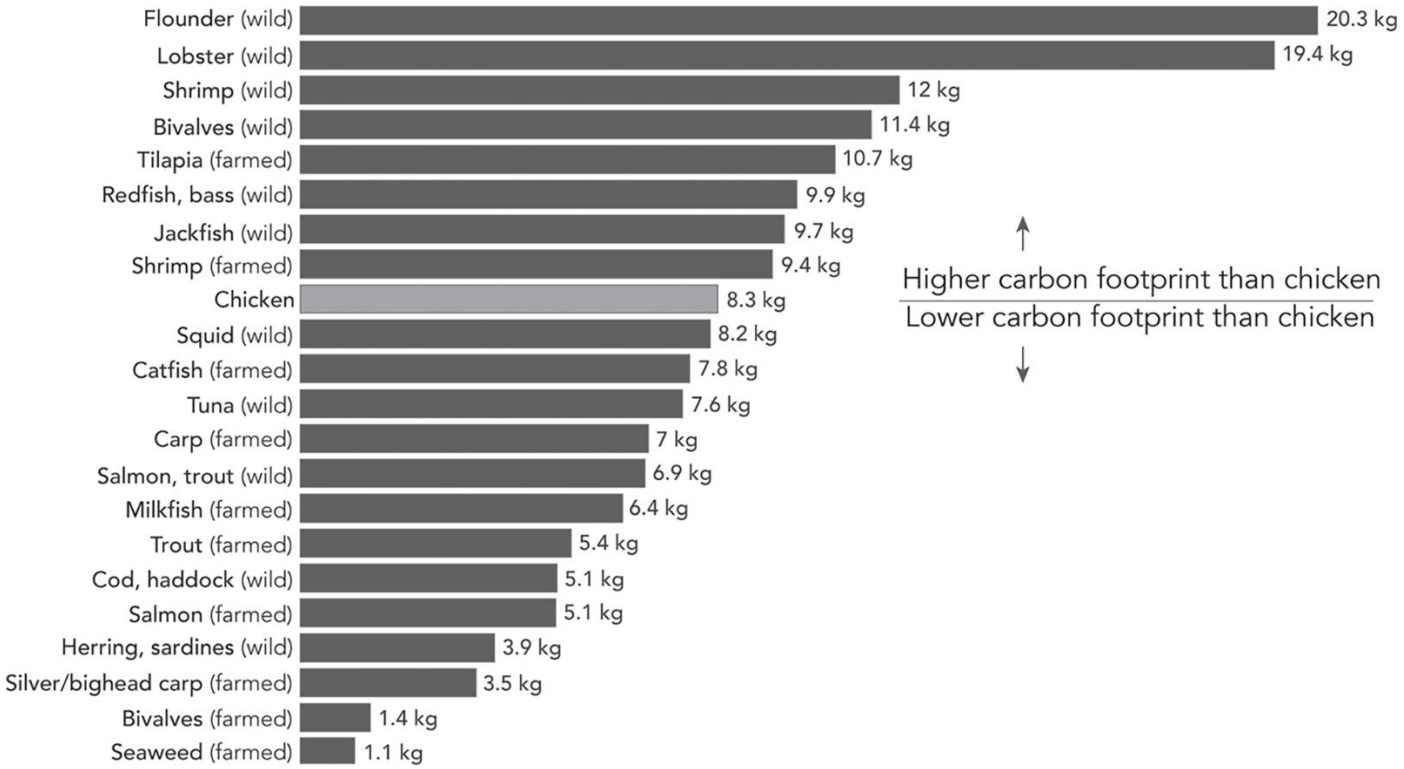
The carbon footprint of fish: fish can be an environmentally friendly source of protein – if we pick the right stuff

You don't need to lose sleep over the climate impact of most fish. Pick the right stuff, and we can eat fish and still have a pretty low-carbon footprint.

Producing fish *does* emit greenhouse gases – though not directly, like with burping cows. When it comes to wild fish, we burn fuel in boats to catch them; they need to be frozen or refrigerated to keep them fresh; we transport and package them. For aquaculture, there is a climate cost to producing the food we feed to fish, just like there is a climate cost to raising chickens, pigs or cows in the same way.

As seen in Chapter 5, things like transport and packaging tend to have small emissions. One large meta-analysis, published in *Nature*, looked at the environmental impact of fish from thousands of fish farms and wild fisheries.[33] They found that most of the popular fish we eat – tuna, salmon, cod, trout, herring – were the most climate-friendly types of meat. Fish are not quite as good as plant-based protein sources, but they can still be a fairly low-carbon choice. Most fish perform well on other environmental metrics too. They're nearly all better than chicken.

Be careful, though. There are a few delicacies where you could be hit with a high footprint, as well as a hefty price tag. Seafood such as flounder and lobster can have a very high footprint. If you want to eat seafood sustainably, I would avoid them. Good choices would be farmed bivalves – clams, oysters, cockles, mussels, scallops – and small wild fish such as herrings and sardines.



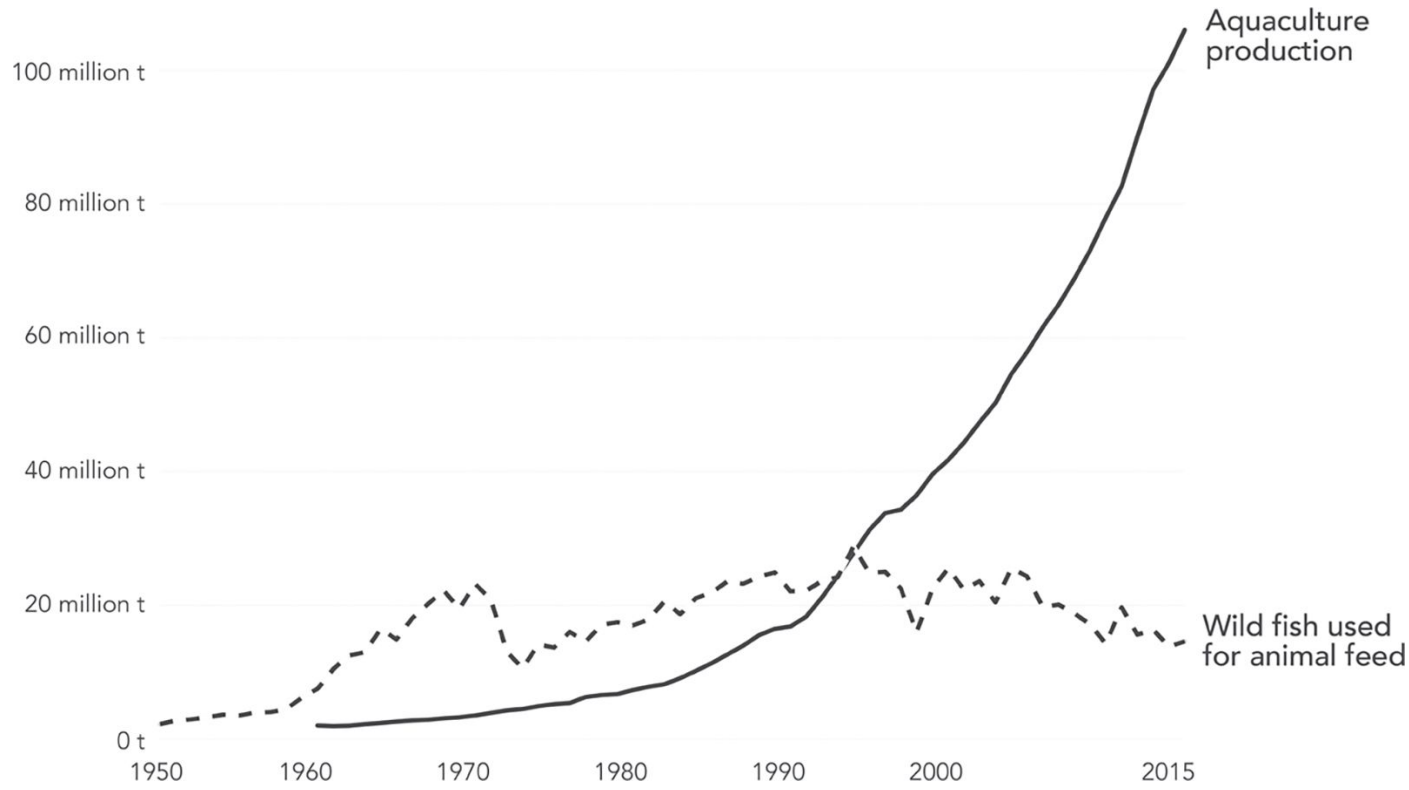
Many fish species can be a low-carbon source of protein
Greenhouse gas emissions per kilogram. Chicken is the meat product with the lowest carbon footprint. Many fish species have an even lower footprint.

Farmed fish, a solution that seems icky

Just when the world's wild fish stocks were hurtling towards oblivion, fish farming stepped in. Since the late 1980s, nearly all of the increase in fish production has come from aquaculture.

Yet many of us still feel a bit unsettled about eating farmed fish. Perhaps it comes back to the feeling that 'natural' is best. Eating wild-caught fish seems much more instinctual than fish from an environment that has been constructed by humans. But if the world wants to keep eating as much fish as we do (or more), consumers need to get comfortable with it.

People worry about the amount of wild fish used as fish feed. Why use fish as feed in the first place? Well, it gives farmed fish the nutrition they would normally get in the open ocean, where larger carnivorous fish typically feed on smaller fish, and they get a high-quality source of protein and amino acids, plus essential omega-3 fatty acids.



Aquaculture production has decoupled from the use of wild fish for feed
In the past, a lot of wild fish was used as feed for fish farming. A move to plant-based feeds and more efficient production means aquaculture production has increased a lot, while wild fish use has fallen.

The world is already moving away from wild fish feeds, thanks to increased efficiency in aquaculture, plus a move towards plant-based feeds that can provide all the nutrition that fishmeal and oils do. We can, for example, create more concentrated feeds from algae. Humans have, again, managed to solve this problem by engineering what would normally happen in the wild. A future where we can farm fish without any wild fish is a very real possibility. So, as a consumer, I wouldn't stress. As an innovator, policymaker or funder, you could help us get there even faster.

Conclusion

Sustainability is humanity's North Star. Make sure current generations have opportunities for a good life, shrink our environmental impact so that future generations have the same (or better) opportunities, and let wildlife flourish alongside us. That's the dream. And I hope I've shown over the course of the book why it's one I believe we can achieve in our lifetimes.

No generation has done this before. As seen in Chapter 1, 'sustainability' has two halves. Our ancestors were never sustainable because they never achieved the first half – meeting the needs of the current generation. Half of all children died, preventable disease was common and nutrition was often poor.

Over the last century the world has made unprecedented progress in improving living standards across the world. In some places progress has been slower, but *every* country has improved in health, education, nutrition and other important indicators of well-being. Of course, we're not done. The world is still terrible in many ways: children and mothers die from preventable diseases, nearly one in ten go hungry, and not every child gets the opportunity to go to school. We've got serious work to do. But many of the solutions are at our fingertips – we know what to do, and many countries have done it already. It's possible to achieve this everywhere over the next few decades if we commit to it.

This book has focused on the second half: making sure we leave the environment in a much better state than we found it. We've travelled through seven big problems, looking at where we are, how we got here, and what we need to do next. For every one of them, we're either at the turning point to a lower impact, or have already passed it.

Air pollution kills millions of people every year, but it doesn't have to be this way. We know how to get levels of air pollution very low. I am breathing the UK's cleanest air for centuries, if not millennia. The solution is simple: stop burning stuff. Make sure that people have access to electricity for cooking and heating, stop burning crops and fossil fuels, regulate industrial plants, and focus on clean public transport networks. These changes can be fast: China nearly halved its air pollution in just seven years. Other countries might not be as fast, but a dramatic reduction in air pollution is achievable in the next few decades. This will only get easier as clean energy gets cheaper; poorer countries can skip straight to the good stuff without burning fossil fuels along the way.

Leapfrogging a long fossil-fuel-powered development path will also be essential if we're to tackle climate change. Rich countries built their wealth on economies run on fossil fuels. It brought countless benefits to human well-being. But it obviously came at a climate cost. Moving forward, we need to make sure that everyone can move through this pathway to prosperity, but on a low-carbon energy source. This option was never there for our ancestors. It was wood, fossil fuels or nothing. That's not the case today. The price of renewable energy has plummeted, and the same goes for batteries and electric vehicles. Soon the low-carbon pathway will be the cheap one. There used to be a trade-off: burn fossil fuels or stay poor. We'll be the first generations that don't have to face this dilemma. Things are already changing and will seem unrecognisable by the middle of the century.

The trade-off for energy was also true for forests. First, for firewood and building materials, then to clear land for agriculture. You either cut down the forest or run out of land to grow food. Crop yields have increased three-, four-, five-fold in the last century, breaking this deadlock. We can grow more food without using more land. Global deforestation peaked in the 1980s, has now also peaked in our most precious forests such as the Amazon, and many emerging economies have committed to ending deforestation by 2030. In the next few decades, deforestation will hit zero if we continue to invest in productive crops and make better decisions on what food to eat. We've lost one-third of the world's forest over the last 10,000 years. This loss is slowing and can be stopped, and then we'll see more of the world's forgotten forests return.

We won't solve climate change, stop deforestation or protect biodiversity without changes to how we eat. Hunger rates have fallen quickly over the last 50 years, but one in 10 people still don't get enough food to eat. It's not because we can't grow enough food. It's because we feed it to livestock, put it into cars, or in the bin where it gets wasted. That's good news: it means the power to reshape the food system is in our hands. Technologies are changing the way we make food. We can produce products just like meat, without the environmental impact or the animal slaughter. That would save an incredible amount of resources and help alleviate global malnutrition at the same time. We just need to make these products nutritious, tasty and cheap enough for the global stage. In 50 years, we won't be using half of the world's land to grow food, or raising and slaughtering billions of animals every year to feed ourselves. Everyone in the world can be well fed on a planet that isn't eating itself alive.

Humans have always been at war with other life on the planet. We were either hunting them or fighting them for space. What's changed is that wildlife now faces a diverse list of threats: not just hunting but also climate change, deforestation, nutrient pollution from farming, competition with livestock, plastics, ocean acidification and overfishing. It really is 'death by a thousand cuts'. Tackling biodiversity loss on its own might seem impossible, but we won't tackle it in isolation; we'll get most of the way there by fixing the other problems. Do this in the next few decades and we'll see a great

wildlife turnaround. Thousands of years of humans versus other species will end, and both will be able to flourish at the same time.

Plastic pollution is the most tractable problem in this book. That is, stopping plastic leaking into the environment and 1 million tonnes flowing into the ocean every year. Invest in waste-management systems and we could stop this. The biggest barrier is money. Most of the world's plastic pollution now comes from low- and middle-income countries. Rich countries have a responsibility as manufacturers and trade partners to help other countries make landfills and recycling centres a priority. Work together, and plastic pollution will be solved in the next few decades. If it was higher on the agenda, it's one problem we could solve in just a fraction of that time.

Our final problem is overfishing. Overfishing is almost inevitable in seas with many fishermen and no way to monitor the health of fish populations below the surface. Knowing how many fish there are, and how this is changing, is essential to knowing how much we can sustainably catch. We weren't fishing beyond our means when our societies were small, but we've become experts in plundering the oceans. However, we are getting a grip on the problem: rates of overfishing have slowed, fish farms allow us to produce more fish with less pressure, and in some regions our iconic species of fish are making a recovery. It only took a decade or two for these species to stage their comeback. We can do it at this pace – or faster – everywhere.

The problems we're facing are tightly interconnected. The worry is that this gives us impossible trade-offs; we'll be forced to prioritise one problem at the expense of another. But it isn't the case; instead, these interdependencies mean we can solve a lot in one go. Move to renewable or nuclear energy to improve air pollution and climate change; eat less beef to improve climate, deforestation, land use, biodiversity and water pollution. Improve crop yields to benefit the climate and humans.

The other commonality between our environmental problems is that their historical arc is the same. We've told ourselves that all of our environmental problems are recent. We believe they've been created in the last few decades through an exploding population and greed. In reality, nearly all of them have a long history. Humanity's environmental impacts date back hundreds of thousands of years. This damage was not deliberate – our ancestors often had no other option. But their actions had consequences for the environment and the species we shared it with.

What these problems also have in common is that progress is happening, and it's happening quickly. Not as fast as we would like, but, nevertheless, attitudes, investments and attention have shifted dramatically. Sustainable solutions are becoming the cheapest option. People are demanding action from political leaders, who can no longer ignore these calls.

There is a real opportunity to solve all of these problems in the next 50 years. All going well, that should be in my lifetime. I'll be old but still pushing for change, right to the finish line.

Three things to bear in mind

(1)

Being an effective environmentalist might make you feel like a 'bad' one

Some of the 'solutions' in this book might have made you uncomfortable. They don't sit quite right. For years I've battled with this personal dilemma: being an effective environmentalist has often made me feel like a fraud. My take on 'cooking' looks like an environmental disaster. I always use the microwave. I try to cook as quickly as possible. It nearly always comes from a packet. My avocados are shipped over from Mexico, and my bananas are from Angola. My food is rarely produced locally. If it is, I don't check the label enough to notice.

Ask people what a 'sustainable meal' looks like, and they'd describe the opposite of my eating habits. An 'environmentally friendly meal' is one that's sourced from the local market, produced on an organic farm without nasty chemicals, and brought home in a paper bag, not a plastic wrapper. Forget the processed junk: it's meat and vegetables, as fresh as they come. We should set aside time to cook them properly, in the oven.

But I know that my way of eating is low-carbon. Microwaves are the most efficient way to cook, local food is often no better than food shipped from continents away, organic food often has a higher carbon footprint, and packaging is a tiny fraction of a food's environmental footprint while often lengthening its shelf life.

But it still *feels* wrong. I know I'm making effective choices for the environment, but there's still a part of me that feels like a traitor. I can see the confusion on people's faces when they hear about some of my decisions. I worry that they might think I'm a 'bad' environmentalist.

This probably comes back to the good old 'natural fallacy': things that seem more grounded in 'natural' properties must be better for us, where natural equals good, and unnatural equals bad. We're sceptical of synthetic stuff that comes out of a factory. It's easy to mock this 'natural is best' type of thinking. In the past I'd brand it as 'unscientific' because it *is* unscientific. But ridicule has never been an effective way to drive change, and it'd make me a hypocrite because I haven't totally rid myself of these feelings either. I still get the instinctual pull towards 'natural' solutions. Working against it takes repeated, and sometimes uncomfortable, effort.

Yet it's something that we need to overcome. The fact that our intuitions are so 'off' is a problem. At a time when the world needs to eat less meat, we've seen a pushback against meat-substitute products because they're 'processed'. When we need to be using less land for agriculture we've seen a recent resurgence in organic, but more land-hungry, farming. When more of us need to be living in dense cities I hear more people dreaming of a romantic life in the countryside with a self-sufficient garden plot.

If what we need to do is at odds with what feels right, then that's a problem. That means that the societal image of sustainability needs to change. Lab-grown meat, dense cities and nuclear energy need a rebrand. These need to be some of the new emblems of a sustainable path forward. I hope this book can play a small role in changing that narrative. It's only then – when the image of 'environmentally friendly' behaviours line up with the effective ones – that being a good environmentalist might stop feeling so bad.

(2)
Systemic change is the key

The reality is that we will not fix our environmental problems through individual behaviour change alone. This became obvious during the coronavirus pandemic. The world spent most of 2020 at home, at a huge cost to the quality of life for millions of people. Our lives were stripped back to the bare minimum. There were hardly any cars on the roads or planes in the sky. Shopping malls and entertainment venues were shut. Economies across the world tanked. There was a dramatic and almost-universal change in how all of us lived. What happened to global CO_2 emissions? They fell by around 5%.

That's a hard pill to swallow. We want to believe in 'people power' – that if we all just pull together and act a bit more responsibly then we'll get there. Unfortunately, to make real and lasting progress we need large-scale systemic and technological change. We need to change political and economic incentives.

That doesn't mean we can't contribute as individuals. As we've seen throughout this book, there are some key and specific behaviours that can make a difference. But there are three really big things we can do that underpin it all. These are things that provide the vital shove for systemic change.

The first is to get involved in political action and vote for leaders who support sustainable actions. One positive policy change can almost immediately trump the individual efforts of millions of people. In the 1970s, President Nixon set up the now pivotal Environmental Protection Agency, and signed the Clean Air Act and the Clean Water Act to clean up the US's polluted air and rivers. These policies have transformed the natural environment and saved many lives from toxic pollution. Incremental behaviour changes across the population would never have achieved the same – at least not as quickly.

We need to make sure environmental action has a seat at the table in government. Leaders need to know the public cares. Nixon has gone down as one of the 'greenest' leaders in history, but in fact he was quite apathetic about the environment.[1] It wasn't a priority for him, personally. He had to pretend to care because the public did. If politicians don't match their priorities with the public, they won't get elected.

The second thing we can do is vote with our wallets. Every time we buy something we're sending a clear signal to the market – and those who bring products to the shelves – that this is what we care about. Every time we buy an electric vehicle, a solar grid connection or a plant-based burger, we're telling innovators across the world that there is demand, shouting 'We're over here, come and serve us'.

These products are all new technologies, and most technologies cost more when they first start out. They follow a learning curve, where the more we produce the more we learn about how to do it efficiently. The price starts to fall the more we buy. Richer consumers can play a key role in being the early adopters that pull the price down. This might, initially, be at a personal cost to them. But the point is that they can act as the early signallers to show that there is a growing market for these goods. Innovators – sensing an opportunity – start to move in like vultures. This competition pushes the whole market forward. Before we know it, we have amazing products battling it out for the lowest prices. In the 1990s, an electric car battery would have cost as much as $1 million. Now it costs just $5,000 to $12,000, and the market is flooded with competition to produce the cheapest.

Another way to use your money well is to donate it to effective causes. This isn't something that everyone can afford to do. But those who can could have a positive impact that extends far beyond themselves. A few years ago, I took the 'Giving what we can' pledge, where I committed to donating at least 10% of my income each year to effective causes. *Where* we donate our money matters just as much as how much we give, if not more. A dollar can go hundreds, thousands, even millions of times further for some causes compared to others. We can give to environmentally focused charities, but charities focused on other areas such as health, education or poverty alleviation also help on our path to sustainability.[fn1] Remember, sustainability is about achieving a good standard of living for everyone alive today, as well as those that come after us. One of the biggest tragedies of our environmental damage is that it is the poorest in the world that are most vulnerable to its impacts. Pulling people out of poverty has to be central to our goal. If you're looking for evidence-based recommendations on where your donations can do the most good, the charity evaluator GiveWell is my most trusted reference.[2]

The final thing you can do is to think about how you spend your time. The problems in this book won't solve themselves. It will take the creative, determined effort of people spanning a range of roles. We'll need innovators and entrepreneurs to create new technologies and improve our current ones. We'll need funders to give them the money to do so. We'll need policymakers that support environmental action and make good decisions on what to do about it.

The average person will spend around 80,000 hours at work throughout their lifetime.[fn2] Pick a great career where you can really make a difference and your impact

could be thousands, or millions, of times greater than your individual efforts to reduce your carbon footprint.

(3)

Stick with others pulling in the same direction

To make the solutions in this book a reality, we need to work with those who also want to move us forward.

Step into any environmental space and you will find a range of opinions on how we should proceed. Nuclear or renewables. Cycling or electric vehicles. Strict vegan or flexitarian. What's odd and counterproductive is that people assume that solutions need to be all or nothing. One against the other. You must pick a 'team', and you must berate the other side. But this isn't going to move us forward. As far as I'm concerned, most of us are on the same team.

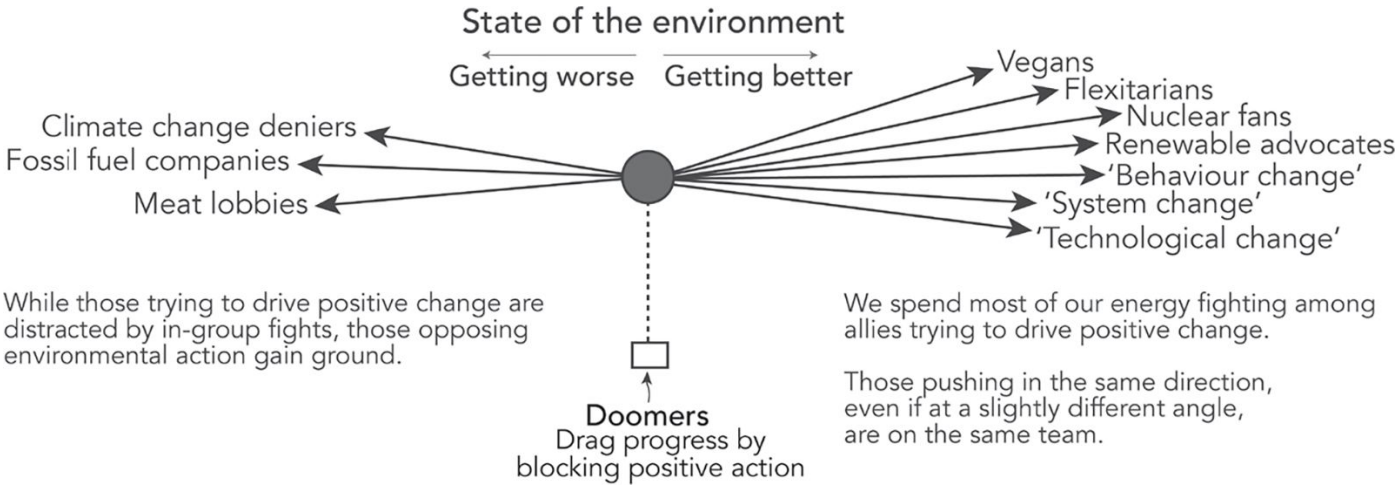
That's how all of us should see ourselves as we try to build solutions. I can't claim credit for the following analogy, but I think it captures this tension brilliantly.[fn3] Imagine you are an arrow, and you're pushing in the direction of where you think we should be headed. Let's say you're really supportive of nuclear energy. Others around you are equally passionate about building low-carbon energy infrastructure, but they hate nuclear and love renewables. Their arrow is pushing at a slightly different angle to you – maybe 10 degrees off to your left or right. But the most important point is that both you and the other arrow are pushing pretty much in the same direction: both want to build low-carbon energy as fast as possible. You are teammates, whether you see it or not.

The problem is that we spend most of our time fighting with the arrows closest to us. We squabble over nuclear versus solar energy, or solar versus wind. We argue over whether people should be eating processed soy-based burgers or lentils. We fight about whether we should focus on reducing emissions from food or from energy. The point is that, at the most basic level, all the people in these fights are trying to push in the same direction.

While we fight among ourselves, the arrows pointing in the opposite direction pull against us. The fossil fuel companies, the meat lobbies and those that oppose environmental action get a free ride. To counteract our weight, they don't have to do that much at all. We're too distracted fighting internally to put up any resistance to the real opponents to progress. A good principle, then, is to be wary of attacking others that we're broadly aligned with. That doesn't mean we can't debate their ideas – we absolutely need this critique to make sure we're picking effective solutions – but we should be constructive and generous in these discussions.

The arrows pointing in the same direction as me are those that are focused on building solutions that move us forward. Doomsayers are *not* interested in solutions. They have already given up. They often try to stand in the way of them. At best, they are

just counterweight to progress. At worst, they're actively pulling the other way; just as damaging as deniers.



Stick with others pushing in the same direction
We might have slightly different opinions on how we solve our environmental problems, but we are on the same team.

Time to become the First Generation

If you are living today, you are in a truly unique position to achieve something that was unthinkable for our ancestors: to deliver a sustainable future. I believe that we can be the generation that meets the needs of everyone while leaving the environment in a better state than we found it.

What makes us different from our ancestors is that economic and technological changes mean we have *options*. We're not stuck with the default of whale oil, coal or cutting down trees. We've developed alternatives that allow us to do the same thing in a much better way. That optionality comes with responsibility. We can make responsible choices that move us forward. But we can also stick with the status quo. A sustainable future is not guaranteed – if we want it, we need to create it. Being *the first generation* is an opportunity, but it's not inevitable.

What makes me most optimistic is the number of people I meet who are all pushing for this. Surround yourself with those people. Be inspired by them. Ignore those who say that we are doomed. We are not doomed. We can build a better future for everyone. Let's turn that opportunity into reality.

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Conclusion

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Index

The page references in this index correspond to the print edition from which this ebook was created, and clicking on them will take you to the location in the ebook where the equivalent print page would begin. To find a specific word or phrase from the index, please use the search feature of your ebook reader.

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Footnotes

Introduction

fn1 Paul R. Ehrlich is an American biologist. He's not to be confused with Paul Ehrlich, the German physician who won the Nobel Prize for his contributions to immunology. The latter invented the cure for syphilis in the early 20th century, and saved many lives as a result. The same cannot be said for Paul R. Ehrlich.

Chapter 1

fn1 I'm using data from the United Kingdom here. These national averages don't directly reflect personal risk to my mother, and the women that came before her, but it gives us a decent proxy for the chances.

fn2 Here it's useful to clarify what 'life expectancy' means. It refers to the number of years a person can expect to live. There are two common ways of measuring life expectancy. *Cohort life expectancy* is the average life length of a cohort – a group of individuals born in a given year. When we can track a group of people born in a particular year and track the exact date on which each one of them died then we can calculate this cohort's life expectancy: it's the average of the ages of all members when they died. This is quite hard to do: we need to follow an entire group of individuals through to the end of their life. Instead, a more common measure is *period life expectancy*. This estimates the average length of life for a cohort of people if they were exposed, from birth to death, to the mortality rates observed in any given year. Period life expectancy doesn't take future changes in life expectancy into account. When we report life expectancy here, we're talking about period life expectancy.

fn3 Of course, this is not the only metric on education that we're interested in. It's not just the *time* in school that matters, but the quality of teaching and learning. Here, the data is more concerning. We see that many – if not most – children in the poorest countries in the world leave school without being able to read and write (https://ourworldindata.org/better-learning).

They might be at school, but this doesn't mean they're learning a lot. This is not a problem exclusive to girls: it's across the board. Having access to a basic education, then, is just a starting point. Kids need to be in school first. Then we need to find a way of making sure that they receive the high-quality education they deserve.

fn4 To be clear: here we're focusing on the international poverty line – the poverty line that is reflective of the poorest countries in the world. There is no single definition of poverty. Our understanding of the extent of poverty and how it is changing depends on which definition we have in mind. Obviously, richer and poorer countries set very different poverty lines in order to measure poverty in a way that is informative and relevant to the level of income of their citizens. For instance, while in the United States a person is considered poor if they live on less than $22.50 per day, in Ethiopia the poverty line is set more than 10 times lower – at $1.75 per day.

fn5 If you think this global development is just about the reduction in poverty in China, you're wrong there too. Even when we take China out of the picture, rates of extreme poverty have fallen dramatically.

fn6 Here we're talking about children under the age of five. But even if we take the population of children under 15 years old, the world has passed the peak. According to the UN's medium projections, the global population of under-15s peaked in 2021.

fn7 If your gut reaction to this is 'Yes, but they've only managed this because they've shipped all their environmental damage overseas to poorer countries', then you're not alone. But while it's true that some countries *have* exported some of their impacts elsewhere, even when we account for this, the footprint of rich countries is still falling.

Chapter 2

fn1 It's important to note that this was not a just or seamless transition. In the first winter, many households had their coal boilers taken away, but did not yet have gas replacements. Many families were left without heating for the year.

fn2 Seneca, technically named Seneca the Younger, was born in Hispania, part of modern-day Spain. But he spent most of his life in Rome.

fn3 We don't know exactly when early humans discovered fire. There is archaeological evidence of widespread use of fire hundreds of thousands of years ago. However, there are also more localised pieces of evidence that its discovery might be as early as 1.5 to 2 million years ago.

fn4 We're focusing on the Kuznets Curve of *environmental* problems here, but this theory of things getting worse before they get better is not just applicable to the environment. In fact, the original Kuznets Curve was about income inequality: Simon Kuznets hypothesised that inequality got worse as a country industrialised, but then fell again as the country got much richer.

fn5 Globally, around 15,000 people die from disasters each year. This figure can vary from year to year, usually depending on whether there have been any large earthquakes, which are the deadliest disaster events today. They are the hardest to predict and prepare for.

Chapter 3

fn1 Here we're looking at emissions from fossil fuels and industry, which account for over 90% of CO_2 emissions. Emissions from land-use change is not included, because the changes from year to year can be quite noisy.

fn2 This figure is adjusted for inflation.

fn3 This relationship between the deployment of technologies and falling prices is commonly referred to as 'Moore's Law'. We see it across many technologies.

fn4 You can find the latest commitments, which are being followed and documented by the Net Zero Tracker: https://zerotracker.net/.

fn5 To make these balance, the actual chemical formula for this reaction would be: $2\ H_2O + \text{energy} = 2H_2 + O_2$.

fn6 We make the key part of cement – clinker – by heating up limestone ($CaCO_3$) to temperatures as high as 900°C. From this process, we get lime (CaO) and, unfortunately, carbon dioxide.

fn7 The data shown in the chart overleaf combines estimates of emissions reductions from Wynes and Nicholas (2017) and survey data from Ipsos (2021). All figures on emissions reductions come from Wynes and Nicholas, except estimates for the adoption of a plant-based diet. This has been updated with data from Poore and Nemecek (2018) – it includes the emissions savings from dietary change, as well as sequestered carbon from the reduction in agricultural land use (i.e. carbon opportunity costs of land).

One action – having one less child – has been excluded from the chart shown here. This is because the underlying data didn't take account of changes in the carbon footprint of people over time. It's fair to say that my child will not have the same footprint as me: in the coming decades as we

rapidly decarbonise, the emissions of a 'person' will hopefully decline significantly and eventually reach close to zero.

Chapter 4

fn1 Iceland is a supermarket chain in the UK.

fn2 All oils contain some combination of polyunsaturated, monounsaturated and saturated fats. The reason some people think seed oils are bad for us is that they contain lots of omega-6, a type of polyunsaturated fat. One type of omega-6 is called 'linoleic acid', which people claim causes chronic inflammation. It's not actually the linoleic acid itself that's inflammatory, but the body converts it to 'arachidonic acid', a building block for inflammatory compounds.

It is unlikely to have this effect in humans. Only a small amount of linoleic acid – 0.2% – turns into arachidonic acid. And not all of this causes inflammation. And arachidonic acid is a complicated compound: it also has *anti*-inflammatory effects. Some animal studies in rats have suggested that linoleic acid causes inflammation, but the opposite effect has been found in humans: it may lower inflammation, protecting against disease.

Linoleic acid is an essential amino acid, which means that the human body doesn't produce it. We need to eat it. It's important for several reasons, including the production of cell membranes and skin health. The argument that we should cut seed oils – and linoleic acid – out of our diets completely is not supported by the evidence, so far.

fn3 This is based on oil production and land use data from the UN's Food and Agriculture Organisation, affected by how much of these crops are used for oil versus other co-products (e.g. seeds or coconuts). I've seen some other estimates over 3.5 tonnes for palm, and 0.7 tonnes for coconut. So, yields could be higher if crops were grown primarily for oil, but none come close to palm yields.

fn4 We can calculate this as 40% (rich countries' contribution) of 29% (the share of deforestation that comes from traded goods). This is 12%.

Chapter 5

fn1 Food is not just about calories. Calories are a measure of energy and so they maintain our body weight, give us energy and stop us feeling physical hunger. But health is about much more than that – we need proteins, fats and micronutrients such as vitamins and minerals. We need a diverse diet, not just

one that hits a calorie target. You might be sceptical that the world produces enough of all of these other nutrients. Thankfully we do. I know this because I crunched all the numbers on it for my PhD. In fact, one of the key motivations for my PhD was to move beyond calories to take a more holistic look at our food system. The conclusion was that we can feed everyone a complete, nutritious diet if we want to.

fn2 He does mention that this would probably be unfeasible politically, and seems disappointed (almost annoyed) by that fact.

fn3 For brevity, when I say 'calories' I mean 'kilocalories'.

fn4 In 2019, the USA allocated 121 million tonnes of maize to industrial uses (nearly all of which is biofuels). The entire African continent produced 82 million tonnes. Brazil produced a similar amount.

fn5 The one caveat to this figure – that three-quarters of soy is fed to livestock – is that this is based on *mass*. How the 350 million tonnes of soy we produce every year is distributed. When we break this down based on economic value – how many dollars we make from selling these products – soybean oils also play a big role. Animal feed and soybean oils are often co-products of the same process: we take soybeans, extract the oil, and the protein-rich solids are fed to animals. Soybean oil is used as a cooking oil, and as an ingredient in a range of processed foods such as snacks, confectionary, baked goods, sauces and dressings.

There is something of a chicken-and-egg debate when it comes to working out which of these products is the 'driver' of soy production. Are we greedy for soybean oil, and simply use the solids left behind for animal feed? Or are our animals greedy for protein, and we have to do something with the oil? As usual, it's probably both. In terms of economic value between oils and animal feed, there's a roughly 50–50 split. Perhaps there is no clear driver, and the two work perfectly together in tandem. What's also true is that if we weren't producing this animal feed from soy, we would have to produce it from somewhere else. Globally we eat a lot of meat, and we need something to feed the animals.

fn6 Despite being a little smaller than pigs, sheep tend to be slightly 'less efficient' than pigs because they move more, have lower-quality feed, and use energy in producing co-products such as wool.

fn7 The efficiency of meat and dairy production can vary depending on things such as the quality of feed, feed scheduling and the use of supplements. Here I'm giving global average figures of efficiency for each meat, but they can vary across the world.

fn8 In the chart I've shown this in terms of food production in monetary terms. This is adjusted for inflation. This is not just true in dollar terms: when we look at it in physical units of tonnes (the total stuff that we produce), this is still true.

fn9 Eutrophication occurs when nutrients run off farmland into water systems such as rivers, estuaries, lakes, or into the ocean. These nutrients can come from synthetic fertilisers, or organic inputs such as manure. The excess nutrients in water systems then disrupt the ecosystems there. You often see large 'algal blooms' where algae flourish and take over the ecosystem, starving the other life of oxygen.

fn10 That's 40 million km^2 – so a bit smaller than the 50 million km^2 that I referenced earlier in the book. That's because here we're only looking at the agricultural land used to produce food products. That doesn't include the land used to produce biofuels, textiles or other non-food crops.

fn11 At the time of writing it is still, sadly, not available in the UK.

fn12 This includes not only the *emissions* of producing the products, but also the carbon opportunity costs of the land that we would free up. Releasing this land from livestock production would allow it to revegetate and suck carbon out of the atmosphere.

fn13 You might notice that the total numbers here are slightly different to the carbon footprint of foods shown earlier in the book. This is because one is given as the mean, and the other the median. For some foods these values can be quite different. Ideally, I'd be able to show the breakdown across the supply chain using exactly the same metric as shown earlier. Unfortunately, this data is not available in the underlying scientific literature. While the precise values might differ, the overall rankings and takeaways are the same.

fn14 By 'conventional' here I mean non-organic farming with some synthetic inputs. Some people protest to the fact that the addition of synthetic inputs is seen as the 'conventional' way of farming and not the other way round. But they have become the terms that most people use to distinguish them.

Chapter 6

fn1 Whenever I share these numbers, there's always someone who asks why I haven't included chickens. They are then embarrassed when I reveal that chickens are birds, not mammals.

fn2 When measured across all life forms – including plants, fungi, bacteria and animals – and presented in terms of biomass.

fn3 This figure is for multi-celled organisms. It doesn't include single-celled organisms, a group called 'prokaryotes'. Prokaryotes include bacteria and viruses.

fn4 We can actually see a 75% reduction in species in two ways: high extinction rates, or very low speciation rates. If speciation – the creation of new species – slows down a lot, the extinction rate does not need to be as high as we would expect in order to deplete species numbers by 75%. These events are sometimes called 'mass depletions' but treated in the same way as mass extinctions.

Chapter 7

fn1 I say 'hopefully' here, because in some lower-income countries the plastic is simply burned and not converted into energy.

fn2 There is some uncertainty on exactly how much plastic enters the oceans each year. Most studies come out in the range of 1 to 8 million tonnes. That's 0.3% to 2% of our plastic waste that enters the ocean. The point is the same: a small fraction of our waste pollutes the ocean. Certainly much less than the third or two-thirds that many people think.

fn3 Previous studies estimated that around 60% of plastic in the Great Pacific Garbage Patch came from fishing activities. This was closer to the 'more than half' statistic that was quoted in *Seaspiracy*.

fn4 The exception to this is if there is an extreme event such as a hurricane or flood. We saw, for example, that during the Tohoku earthquake and tsunami in Japan in 2011, large amounts of plastic were swept out to sea.

fn5 Previous studies had estimated that the concentration was even greater than this. One study estimated that the largest five rivers were responsible for 80% of ocean plastics! Another estimated it was the largest 162 rivers. These modelling studies were much lower-resolution than the recent update. They assumed a too simplistic relationship that it was mainly just the size of the river and the size of the population with poor waste management around it that determined plastic emissions. This meant that they were completely dominated by the big rivers like the Yangtze, Xi and Huangpu rivers in China, the Ganges in India, Cross in Nigeria and the Amazon in Brazil. As it turns out, the dynamics of river plastics is a bit more complex than that.

fn6 One of the reasons that plastic trade is such a small percentage of the world's waste is that recycling rates across the world are so low. It is mostly recycled

plastics that are traded. Therefore, the upper limit on how much plastic will be traded, is the total amount of waste that is recycled.

fn7 There used to be just one 'Interceptor'. But since then the charity has built a portfolio of different technologies. Hence the Interceptor became the Interceptor Original.

Chapter 8

fn1 The moratorium only applies to commercial whaling, so whaling classified for scientific research purposes and aboriginal-subsistence provisions is still allowed.

fn2 When we look at the percentage of fish *catch* that is managed sustainably, the number is more than 80%. This is because some fish stocks – fish populations in particular locations – are bigger than others. Rather than calculating the percentage of stocks that are managed sustainably, we can weigh this by the quantity of fish we catch. By this measure, 83% of catch came from sustainable sources.

fn3 There have been some claims that the populations of all tuna species fell by 90%. These claims have been proven to be incorrect. In this case, the 90% fall is for the southern bluefin tuna, but not all tuna stocks across the Atlantic and Pacific.

fn4 There are two main types of corals: shallow, warm-water corals; and cold, deep-water corals. The obvious difference between the two is that warm-water corals live close to the sea surface – usually in coastal waters – whereas cold-water reefs can extend to depths of 3,000 metres below the surface. Here we're focusing on warm-water corals.

Conclusion

fn1 I mostly give my monthly donations to global health and poverty alleviation charities. I have given the most to the Against Malaria Foundation, and also support nutritional supplements for children in low-income countries. These two causes are some of the most cost-effective in improving and saving lives.

fn2 There is a great organisation, founded by the philosopher Will MacAskill, called '80,000 hours' for this reason. The charity gives evidence-based advice on how people can create the largest positive impact by picking a career where they can contribute.

fn3 Credit to Andrew Dressler and Ken Caldeira, who I heard this metaphor from.