SCOPING NET ZERO

Gautam Kalghatgi

The Global Warming Policy Foundation

Briefing 55

Scoping Net Zero
Gautam Kalghatgi

Contents

About the author

Gautam Kalghatgi is a fellow of the Royal Academy of Engineering, the Institute of Mechanical Engineers and the Society of Automotive Engineers. He has been a visiting professor at Oxford University, Imperial College, Sheffield University, KTH Stockholm and TU Eindhoven. He has 39 years of experience in combustion, fuels, engine and energy research; 31 years with Shell and 8 years with Saudi Aramco.

Summary

- The scale of the effort needed to meet net zero greenhouse gas (GHG) targets is extremely large and appears impossible to achieve on a reasonable timescale. All alternatives to current energy systems start from relatively very low bases, and face serious, and perhaps insurmountable, environmental, economic and materials-availability barriers. The debate over net zero needs much more honesty, a sense of realism, and an appreciation of broader global developmental, economic and environmental needs.
- Even if 40% of the UK's fossil fuel use could be eliminated through efficiency improvements, 120 GW of new, continuous CO_2-free energy generation capacity – equivalent to 40 nuclear power plants of Hinkley Point C size or 300 GW of new offshore wind – would be required to replace the remaining 60%. The capital cost would be over £1 trillion, even without the necessary back-up. Storage costs and operating costs would also be very high.
- The UK government has announced a new target of reducing GHG emissions to 22% of 1990 levels by 2035. The equivalent of 24 new Hinckley Point Cs will have to be built in the next 14 years to meet this target.
- Battery electric vehicles (BEVs) are *not* zero emission. Battery manufacture is both energy intensive and greenhouse gas intensive. On a lifecycle basis, including vehicle manufacture, use and disposal, BEVs with large batteries could have worse emissions than comparable conventional vehicles, although smaller BEVs in areas with low-carbon electricity supplies will have lower but non-zero emissions than comparable conventional cars.
- The very serious health issues associated with mining for metals are simply exported away from where the BEV is used. Particulate emissions can be almost eliminated in modern engines. That being the case, tyre wear will soon become the dominant source of particulates, and will be much higher for BEVs because of their greater weight.
- Even if BEV numbers in the UK increase to ten million by 2030, when the proposed ban on the sale of new cars with internal combustion engines (ICEs) comes into force, around 80% of all transport and 70% of cars and vans will still run on fossil fuels. The ban will simply exclude UK customers from access to any further improvements in ICE technology. If enough people do not buy BEVs because of high up-front costs and charging anxiety, the UK automotive industry will be destroyed.
- To replace just cars and vans with BEVs will require total battery capacity to increase by a factor of well over 200.
- As zero-carbon technologies such as BEVs and wind turbines become more widespread, the huge requirement for materials, and the environmental problems that result from their mining, will come increasingly to the fore, constraining their rapid growth.

- In addition to the huge transition away from fossil fuels, still greater efforts will be needed to transform society and dismantle the existing energy infrastructure. For instance, 26 million gas boilers will have to be replaced in the UK; electricity generation and distribution systems will have to be rebuilt, particularly to account for the intermittency of wind and solar; large investments in battery charging infrastructure will be needed for BEVs; the aviation, steel and cement industries, livestock farming, oil and gas production and distribution, and oil refining will all have to be dismantled.
- It is virtually certain that net-zero emissions will not be attained globally by 2050; large countries with increasing energy demand, such as China and India, are unlikely to reduce their fossil fuel use even if they are expanding their wind and solar capacity. Many developing countries are focusing on economic growth, which requires affordable fossil fuels. It is also inconceivable that major oil and gas producers such as Saudi Arabia and Russia are going to give up their main sources of income over the next few decades.
- The UK accounts for around 1.3% of global fossil fuel use and 1.1% of global greenhouse gas emissions. So, if most of the rest of the world does not follow the UK's 'lead', its efforts to reduce emissions will have little or no effect.
- Perhaps the 'existential crisis' that demands rapid decarbonisation is not really imminent or severe. All measures of human well-being – absolute poverty levels, undernourishment, education, child mortality, life expectancy, world food production (and per capita food consumption, productivity per acre, daily supply of calories) – have been improving significantly and consistently, particularly in poorer countries, over recent decades. Humanity should be able to cope with any consequences of future warming, just as it has did with the warming over the past century.
- In any case, if it is impossible, in the real world, to go to net zero emissions by 2050, humanity will have no choice but to adapt to the consequences of any future warming. In fact, even if net-zero were to be achieved, there would still be natural disasters and weather extremes.
- This reality needs to be recognised, and greater emphasis put on 'no regrets' adaptation policies, which make societies more resilient to possible consequences of future climate change.
- All available technologies including wind, solar, hydrogen, novel fuels, BEVs, and fuel cells need to be deployed and continuously improved to tackle environmental problems, while ensuring that global poverty and developmental goals are also tackled.
- All technologies need to be assessed on an honest lifecycle basis to ensure that they do indeed provide the emissions benefit they promise and do not have unintended consequences.

1. Introduction

Current energy policies in affluent western countries are based on the unquestioning assumption that climate change poses an imminent 'existential threat'. The term 'climate change' covers the impacts of global warming caused by the increase in greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane and nitrous oxides. Evolving knowledge on climate change is provided by the Intergovernmental Panel on Climate Change (IPCC) through its assessment reports.[1] It is now accepted that the Earth has warmed by about 1.1°C since 1900, and the IPCC says it is 'extremely likely' that the dominant contribution to global warming between 1951 and 2010 was from human activity. Carbon dioxide from human activities results from the burning of fossil fuels – coal, oil and natural gas – which supply most of the primary energy used worldwide, although natural processes are far more important in the global CO_2 cycle. Methane increases come primarily from agriculture and other land uses, as well as leakages from natural gas infrastructure.

Many governments perceive GHGs to be an 'existential threat' and are introducing policies to 'eliminate' them. For instance, the UK has committed, in law, to go to 'net zero' GHGs by 2050,[2] while the Green New Deal in the US,[3] which appears to be mostly accepted by the Biden administration, has similar ambitions. In fact, pressure groups, such as Extinction Rebellion, demand that the net-zero target be met by 2025.[4] Many major corporate entities, including oil majors, have announced their own net zero plans, although it remains unclear what these might mean in practice.

'Net' zero means that any remaining GHG emissions are balanced by removals, through processes such as carbon capture and storage (CCS), although these technologies are not yet ready for deployment at scale and often have huge requirements for land and energy.[5] Removals could also be achieved through natural sinks, such as the oceans and forests. In the last resort, emissions will have to be 'offset' by buying carbon credits from entities that have reduced their emissions by more than they need or are committed to. In practice, an almost complete elimination of GHG emissions is required to meet net-zero targets.

There appears to be a desire in many quarters to run the entire economy on electricity, with the assumption that this will be produced from CO_2-free sources; in other words, renewables. However, this approach would make society much more vulnerable to extreme weather. For instance, there would have been many more casualties of the unexpected cold weather in Texas in February 2021 if the natural gas system had been dismantled.

The scale of the net zero transformation, the complex interactions between demographic, environmental, economic, resource, technical and societal issues that determine energy systems appear not to be appreciated sufficiently. Similarly, environmental and other barriers to the deployment of alternative energy sources, such as wind and solar, seem to be mostly ignored. There often appears to be a lack of realism – or even of honesty – in the proposals and discussions on these matters.

In the discussion below, the focus is often on the UK, but the arguments are equally valid for other regions.

2. Challenges of meeting net-zero targets

2.1 The size of the challenge

Global energy demand is very large. Table 1 shows the sources of primary energy for the World, China, USA, India, and the UK.[6] Fossil fuels supplied 84% of the total, with wind and solar accounting for just over 1%, although this share is higher in some countries; in the UK it is 3.5%. Table 1 also shows the installed solar and wind capacities for 2019, and the total electricity generated.

Table 2 lists the average *daily* demand during 2019 for liquid fuels for transport and other oil products.[7] The demand for transport fuels is also large – the world uses, on average, over 11 billion litres of gasoline, diesel and jet fuel every day. There are around 1.3 billion light-duty vehicles, cars and vans, and 380 million heavy-duty commercial vehicles in the world, and these numbers are expected to increase, mostly in non-OECD countries such as China and India.[8]

Decarbonising primary energy use

Decarbonising energy use will be hard. Let us assume that the UK will need to replace only 60% of its current fossil fuel energy use (6.21 EJ; see Table 1) with CO_2-free energy, the rest coming from efficiency improvements, lifestyle changes and carbon offsetting. This figure is extremely ambitious, because all the initiatives needed for the energy transition, such as building alternative generating capacity, upgrading the building stock and dismantling existing infrastructure, will actually require a lot of fossil-fuel energy.

Table 1: Primary energy and renewables capacity, 2019

Energy source	Units	World	China	USA	India	UK
Oil	EJ	193.0	27.9	37.0	10.2	3.1
Natural gas	EJ	141.4	11.1	30.5	2.2	2.8
Coal	EJ	158.0	81.7	11.3	18.6	0.3
Total fossil fuel	EJ	492.4	120.7	78.8	31.0	6.2
Actual delivered wind	EJ	5.1	1.5	1.1	0.2	0.2
Actual delivered solar	EJ	2.6	0.8	0.4	0.2	0.0
Nuclear	EJ	24.9	3.1	7.6	0.4	0.5
Hydro	EJ	37.7	11.3	2.4	1.4	0.1
Other*	EJ	21.3	4.3	4.4	0.8	0.8
Total primary energy	EJ	584.0	141.7	94.7	34.0	7.8
Installed wind capacity	GW	622.7	210.5	103.6	37.5	24.1
Installed solar capacity	GW	586.4	205.5	62.3	35.1	13.4
Total electricity generated	EJ	97.2	27.0	15.8	5.6	1.2

*Includes bioenergy, geothermal etc. EJ, exajoules, is 10^{18} joules.

Table 2: Daily average demand for liquid transport fuels, 2019.

	Energy content		Volume
	MBOE	EJ	M litres
Gasoline	26	0.16	5.0
Diesel/gasoil	28	0.18	4.9
Jet/kerosene	8	0.05	1.4
Residual fuel oil	6	0.04	1.0
Other*	30	0.19	
Total	100	0.61	

*Other includes energy used in refinery, petrochemicals etc. MBOE – million barrels of oil equivalent. 1 EJ equals 277.8 TWh or 163.4 MBOE.

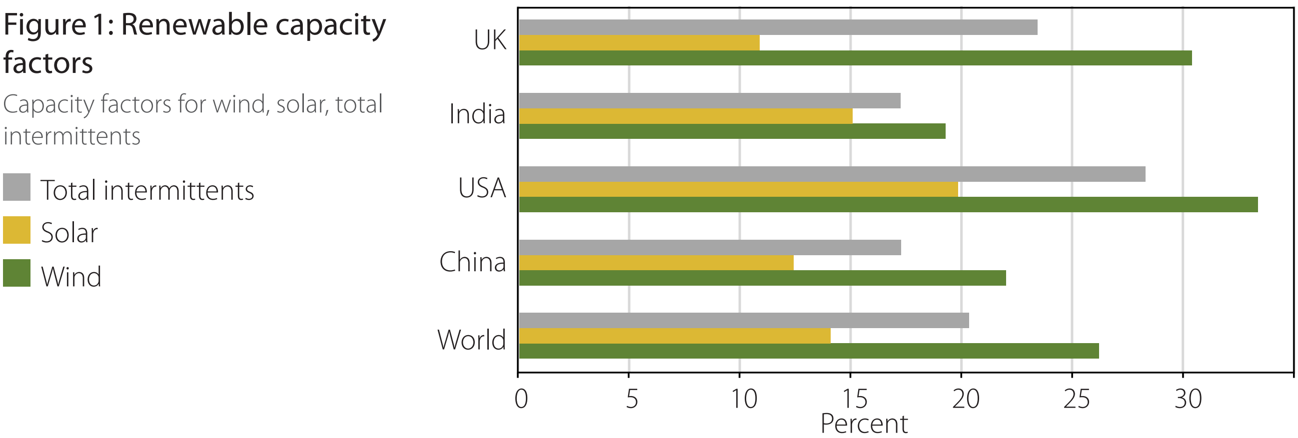
Building energy infrastructure on the required scale – no matter what the technology – would face fierce public resistance. Major hydroelectric projects, which require large areas of land and displace established communities, face significant opposition, and the scope for expanding these in the UK is limited anyway. Geothermal and tidal power are either limited in scope or not ready for large scale deployment. There is strong resistance to new nuclear power.

In reality, therefore, most of the additional decarbonised energy supply would have to come from wind or solar power. However, these are intermittent sources, and hence the installed capacity needs to be relatively large. The 'capacity factor' is the ratio of the actual energy supplied by a generator to the theoretical output if it operated continuously at full capacity. Figure 1 shows the capacity factors for wind and solar and total intermittents. Thus, on average across the world, in 2019, wind supplied only 26% of the electricity that would be expected if it operated continuously at full capacity. Similarly, intermittents together supplied only 23% of UK electricity in 2019, although in theory there was enough capacity to supply all of the national demand.[9]

So even with the an optimistic assumption that we can reduce energy demand by 40%, the UK will still need to build

Figure 1: Renewable capacity factors

Capacity factors for wind, solar, total intermittents



approximately 120 GW of continuous CO_2-free electricity generation capacity, equivalent to around 40 nuclear power plants the size of Hinkley Point C, or around 300 GW of new wind capacity, even assuming a much-improved average capacity factor of 40%. Under the same assumptions, the world and the USA would respectively need to build 24 TW and 3.8 TW of new wind capacity. Incidentally, the interim target announced by the UK government to reduce GHGs by 2035 to 22% of the level in 1990 amounts to a 60% reduction in GHG emissions compared to 2019. This would require new CO_2-free capacity of 72 GW, equivalent to 24 Hinckley Point Cs. Of course, the reduction in energy use might be lower than 40% and the capacity factor of future wind farms might be higher than 40%. In other words, the figures shown here are approximate and are used to give an idea of the scale of the problem.

Offshore wind would require huge amounts of material

Offshore wind represents the best chance for new CO_2-free energy in the UK. However, the material requirements are very significant. Table 3 shows what would be needed if the UK were to build 300 GW of wind turbines: the capacity it would need to replace 60% of its fossil energy use.[10] Large amounts of fossil fuel energy would also be needed as backup.[11]

Offshore wind would be expensive

However, the capital cost of offshore wind, the most likely technology for expansion in the UK, is estimated to be around £4 million per MW.[12] The capital requirement to install the 300 GW of offshore wind required would therefore be of the order of £1.2 trillion. The real operating costs of offshore wind are also very high.[12]

In order to prevent blackouts when wind and solar fail, there has to be sufficient backup – from nuclear, hydro, gas or coal – or enough storage capacity. The scale is again large. For instance, the biggest battery facility planned for the UK has a storage capacity of 640 MWh and will cost £200 million.[13] It will cover London's peak electricity demand of 8 GW for less than five minutes. Backup on the required scale would therefore add significantly to the costs.

Even though the cost of wind and solar is alleged to be falling rapidly, domestic electricity prices are generally higher in countries with more installed wind and solar capacity,[9] primarily because they do not supply electricity when it is actually needed.

Table 3: Material requirements for the 300 GW capacity of offshore wind needed to replace 60% of UK fossil fuel energy use in 2019.

Material	Million tonnes
Steel	32
Concrete	150
Copper	0.9
Rare earths	0.014
Fibreglass	2.1
Other plastics and aluminium	2.8

Looming environmental problems

The environmental costs of renewables are also very serious. Wind turbines are now considered apex predators, killing rare birds of prey, such as eagles and falcons, as well as other birds and bats. They may also degrade habitat for a variety of wildlife.[14,15,16] These problems can have a ripple effect on the entire ecosystem.[15]

Decommissioning of wind turbines at the end of their 20-year lives – particularly of the blades, which are made from unrecyclable plastic – will be a growing problem. Similarly, the disposal of toxic materials, such as cadmium and lead, at the end of solar panels' 25-year lives looks set to cause great difficulties.[16,17,18]

2.2 Further examples of wishful thinking

There are many other examples of decarbonisation plans being put forward, where the scale of the problem was not appreciated, or perhaps not honestly assessed.

Synthetic fuels and hydrogen

There is talk of replacing aviation fuel with synthetic fuels made from hydrogen and CO_2. However, making them is very inefficient – only 44% of the input energy is left in the fuel.[19,20] To replace current global aviation fuel demand of about 8 MBOE per day (Table 2) with e-fuels – synthetic fuels made from renewable energy – would require the world to build around 1300 GW of new, continuous CO_2-free energy generation capacity. Similar arguments can be made about hydrogen (with additional concerns about distribution, storage and safety).[8]

Of course, as the intermittents' share of electricity generation increases, occasional electricity surpluses can in theory be used to make e-fuels or hydrogen, but the quantities will be negligible for a very long time to come. 'Storing' electricity in this way, rather than using batteries, may enable the spread of intermittents, but is not a way to decarbonise transport.[8,21]

Similarly, biofuels are also not strictly suitable for aviation, even if sufficient quantities can be manufactured in a carbon-neutral way.[8] If they are oxygenated, their gravimetric energy density is around 16% lower than that of aviation fuel, and either payload or range will be compromised.

Carbon offsetting by planting trees

Rough calculations can also be performed to assess the idea of offsetting CO_2 emissions by growing trees, so-called 'carbon offsetting'. Six trees will fix around 1 tonne of CO_2.[22] A barrel of oil produces 431 kg of CO_2,[23] and the annual demand for aviation fuel is 2929 million barrels of oil equivalent (from Table 2). This implies that global aviation produces 1.3 billion tonnes of CO_2 annually, and to 'offset' this will need 7.6 billion trees to be planted. One million trees will occupy roughly 20,000 acres, or 80 km^2,[24] so to offset the CO_2 emissions from aviation alone will require around 600,000 km^2 of forest – an area the size of France – to be planted *every year*. Indeed, for all practical purposes, decarbonisation of the aviation industry requires it to be shut down.

Domestic heat

In addition to replacing fossil fuels with CO_2-free electricity, the existing energy infrastructure will need to be safely dismantled, and the building stock will need to be improved to reduce energy consumption. For instance, in the UK, 22 million homes have gas central heating,[25] with at least 26 million gas boilers installed overall.[26] These are supposed to be converted to electric heating (heat pumps), although there might not be enough trained heating engineers and electricians in the country to achieve this by 2050. Heat pump systems are also very expensive, currently costing between £10,000 and £20,000 for the full installation, depending on the size and location of the property; many householders would not be able to afford them. In addition, utility is degraded – heat pumps cannot supply hot water almost instantly in the way that gas boilers can, and a storage tank with an electric immersion heater might be needed instead. The size of the radiators would have to be increased because of the lower water temperature from heat pumps and insulation might need to be enhanced to maintain adequate heating.

Will the rest of the world follow UK's leadership?

Many countries plan to decarbonise transport, usually by replacing internal combustion engine vehicles (ICEVs) with their electric equivalents. This is very unlikely to deliver significant reductions in CO_2, but will have huge environmental and economic consequences, as discussed in the next section. It will require rebuilding the electricity distribution network, at the micro level, at huge expense, as well as bringing many practical difficulties.[27]

Moreover, GHG emissions from agriculture must be reduced to zero. For instance, globally, livestock farming for meat and dairy contributes about 7 gigatons of CO_2-equivalent, or 14% of global GHG, including gases such as methane,[28,29] the same share as from all transport. Ultimately, the steel, aviation and cement industries, which are extremely difficult if not impossible to decarbonise, will need to be largely shut down;[30] oil and gas production and distribution and the refining industry will need to be safely dismantled. At a global level, Saudi Arabia, Russia and other oil and gas producers will have to be persuaded to give up their main source of income; India, with the highest number of livestock in the world,[31] and where cows are worshipped, will have to cull most of its cattle.

However, currently, most of the world seems to be focusing on energy security and economic development. For instance, India has vast reserves of coal, and also ambitious plans for wind and, particularly, solar. However, even as coal's share of the country's energy supply declines, its use is expected to increase in absolute terms, as energy demand grows.[32]

China's coal-fired fleet capacity rose by a net 29.8 GW in 2020, even as the rest of the world made cuts of 17.2 GW.[33] Most major oil producers have recently committed to sharply increase the pace of monetising their oil and gas reserves.[34] The US Energy Information Administration projects that demand for oil, gas and coal will grow until 2050, although renewables will have grown faster.[35] The IEA says that the world is still far from adopting the kinds of energy policies and investments that would put global emissions on the path to deliver net zero by 2070 – let alone by 2050.[36]

It is virtually certain that most of the rest of the world will not follow the UK's 'leadership', and go to net-zero GHGs by 2050. And even in the UK, with its deeper commitment to decarbonisation, the net-zero target does not seem achievable; the costs are too high, and concrete plans are lacking. Of course, the UK accounts for only 1.3% (Table 1) of global fossil fuel use and 1.1% of global GHG emissions, so even successful carbonisation here would have little effect.

3. Decarbonisation of transport

3.1 Approaches

Currently, 99.8% of global transport is powered by internal combustion engines and 95% of global transport energy comes from petroleum-based fuels.[8] The total annual energy content of gasoline, diesel and jet fuel is 142 EJ, 24% of global primary energy consumption. This demand will increase as demand for transport grows in non-OECD countries such as China and India.[8]

Several alternative approaches to decarbonising transport are being considered. Of these, two – fuel cells and e-fuels – seem somewhat implausible. Fuel cells, powered by hydrogen produced using renewable electricity, are not ready for the mass market. Moreover, there are great difficulties associated with the production, transport and storage of hydrogen, which make it unlikely to ever be a true alternative fuel for transport in the near future.[8] The costs would probably be prohibitive.

The energy efficiency of the process to make e-fuels from CO_2 and hydrogen is only around 44%.[19,20] So, for example, the world would need to provide an additional 41 exajoules of CO_2-free energy annually – over five times the amount currently supplied by wind and solar in 2019 (Table 1) – to meet the demand for jet fuel alone. This is the equivalent of around 1300 GW of additional continuous electricity generation or over 3250 GW of wind power (again assuming a generous capacity factor of 40% for wind).

The most likely way to decarbonise transport is therefore through electrification of vehicles. This can be done in different ways:

- battery electric vehicles (BEVs) get all their energy from the electricity grid;
- plug-in hybrid electric vehicles (PHEVs) have a small electric motor/battery and an internal combustion engine;
- conventional hybrid electric vehicles (HEVs), for example the Toyota Prius, are 'self-charging', and all their energy comes from the onboard fossil fuel.

Full electrification is not desirable for larger vehicles and is impossible for aviation because of the size of the batteries needed.[8] For instance, to electrify a medium-range jet such as the Airbus A320, giving it the same energy capacity as aviation fuel does currently, would necessitate a battery weighing around 19 times the maximum take-off weight of the aircraft.[8] Full electrification is therefore only relevant for light-duty vehicles (LDVs, i.e. cars and vans), which account for around 45% of global transport energy use.[8]

At the end of 2020, the number of BEVs in the world was around 6.5 million, mostly small cars. In the UK at the end of 2020, the number of LDVs was around 36 million,[37] and the number of BEVs was 206,000.[38] Therefore, BEV numbers have to grow by a factor of nearly 200 to replace even the current number of LDVs. The battery capacity needed would have to grow much more than 200-fold if bigger LDVs, with longer ranges, and therefore requiring bigger batteries, were also to be replaced with BEVs. At the same time there would be a need for more and more batteries to support wind and solar deployment. The demand for materials would be huge and the environmental impacts would be unsustainable, as discussed below.

The UK government has announced a ban on the sale of any new ICEVs from 2030, and even HEVs and PHEVs by 2035.[38] From the latter date, only BEVs and vehicles equipped with fuel cells and running on hydrogen will be permitted. Other countries have announced similar plans.

3.2 Infrastructure and other costs

The cost of electrification of the UK LDV fleet is significant. For example:

- Only 22% of cars in the UK have access to garages.[37] Analysis by the Society of Motor Manufacturers and Traders shows that we will need 1.7 million public charge points by the end of the decade and 2.8 million by 2035.[39]
- BEVs are much more expensive than ICEVs. For instance, the cheapest Nissan Leaf, a BEV, costs £29,000, while the cheapest Nissan Micra, comparable in size, is £14,000. A recent study by Toyota concluded that BEVs would not reach purchase price parity with ICEVs by 2030,[40] even under the most optimistic assumptions. Subsidies will continue to be needed to encourage people to buy BEVs until their up-front costs come down sufficiently – a regressive transfer of money to the rich, who can afford expensive BEVs.
- BEVs are much less practical: the Nissan Micra has a long range and can be refuelled in about 5 minutes using existing infrastructure. The Nissan Leaf, with a 40 kWh battery, takes nearly 6 hours to charge, even on a 7-kW fast charger. The time wasted waiting for vehicles to refuel at public charging points may be significant, and will therefore carry a significant cost to consumers.

- At present, the government receives around £40 billion in taxes on transport fuels. If it is successful in bringing about a complete shift to BEVs, it will lose this income, and will inevitably need to recoup it, most likely by charges for road use, making BEVs more expensive still.
- There are very challenging problems – both at the micro and macro level – associated with providing electric power to a large number of BEVs.[27,41] The electricity distribution network, particularly the final connections to households, will need to be very significantly altered.

The demand for batteries – both for BEVs and for grid-scale energy storage – will become enormous, and the availability of the materials will be of increasing concern. One study estimated that to replace all LDVs with BEVs, the UK would require twice the current global cobalt production, nearly all neodymium production, three quarters of lithium production and at least half of copper production.[42] There is much faith in the 'circular economy', but it is very unlikely that lithium-ion batteries will be fully recyclable in the near future,[42] because it is so difficult and energy intensive to recover critical metals from them.[43,44]

3.3 BEVs are not 'zero emissions' vehicles

BEVs do not offer a very significant benefit over ICEVs in terms of CO_2 emissions, unless they are manufactured and powered by electricity that is CO_2-free. Manufacturing a battery takes much more energy than making an ICE.[8,45] The CO_2 impact of a BEV during use depends on the carbon intensity of the electricity grid, which will be very high if coal is a dominant source of generation, as it is in, say, India and China. And even if renewables are dominant, the extra demand from BEVs has to be met with marginal (backup) generation, which can quickly respond to changing demand.[8,45] Marginal generation usually means fossil fuels, especially if nuclear power is not in favour, and it has a very much higher carbon intensity than the average value.

There have been many life cycle assessments of the emissions of BEVs and ICEVs, but the results depend on the assumptions made. For instance, the GHG emissions embedded in a battery depends on the CO_2 intensities of:

- mining and processing the materials
- manufacturing and assembly of the batteries.

Currently most of these activities take place in countries that use high-carbon energy. A very recent estimate for battery manufacture from China, where over 70% of EV batteries are made,[46] is 125 kgCO_2eq per kilowatt hour of battery capacity.[47] A BEV with a 60 kWh battery will therefore start with a deficit of 7500 kgCO_2eq before it has driven a single kilometre.

In the UK, the CO_2 impact of a small BEV will be lower than for a comparable ICEV on a life-cycle basis, but it will not be zero. As battery size increases, to enable longer range and/or bigger vehicles, BEVs could in fact have a larger lifecycle CO_2 footprint than an equivalent ICEV, even as the electricity used to run them becomes increasingly CO_2-free.[45]

A recent IEA study suggests that in Europe, lifecycle GHG emissions for a mid-sized car are on average around 25% lower for a BEV than its conventional equivalent.[48] But the 36 million LDVs account for only about 70% of transport energy use in the UK.[49] This means that even if all of them were replaced with BEVs – at very great environmental and economic cost – GHG emissions would fall by only 15–20% (0.7 × 25%).

Even then, converting all 36 million LDVs to battery power by 2030, when the ban on the sale of new ICEVs is supposed to come into force, is implausible. Let us instead assume that the number of BEVs increases from the current 0.2 million to an improbable 10 million by 2030 in the UK – around 28% of current LDV numbers. The overall reduction in GHG emissions would be around 4.9%, and over 70% of LDVs would still be using ICEs.

But now consider an alternative – and very plausible – scenario, in which a reduction in fuel consumption of ICEVs of 5% was achieved across all transport sectors.[21] This would result in a similar reduction in GHGs, but without incurring any of the costs noted in Section 3.1.

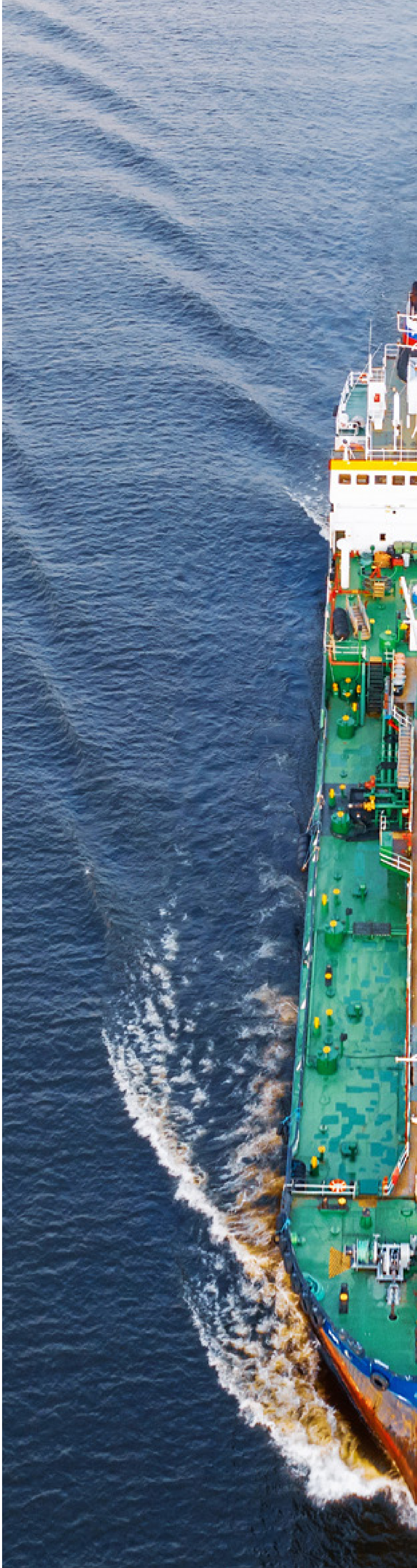
Mining also requires moving large quantities of earth and rock – on average 500 times the weight of the battery.[50] This will have its own environmental consequences as the demand for battery materials increases.

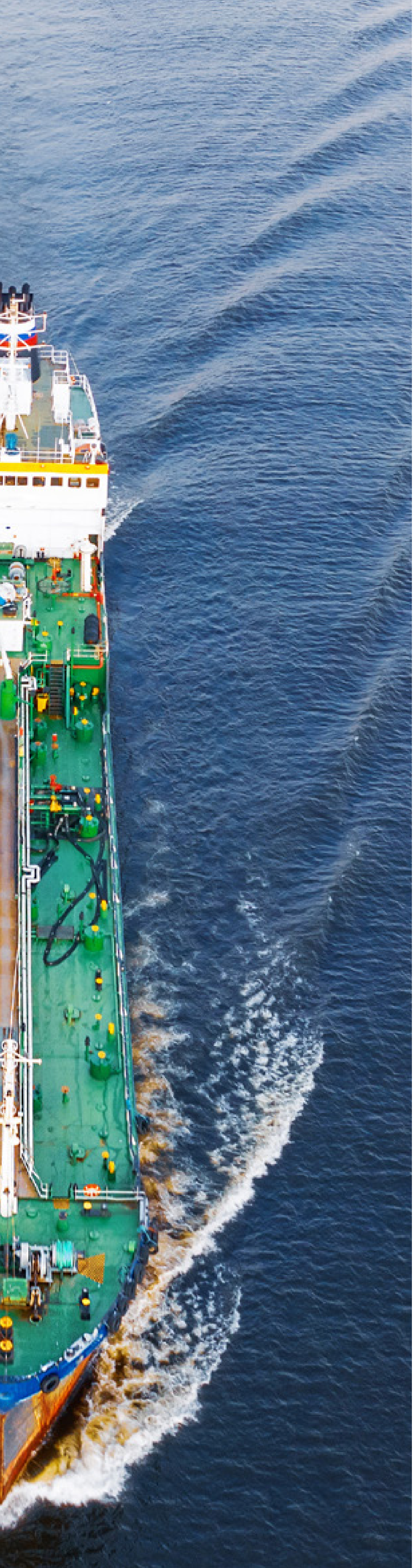
The lesson is clear. Sustainability of transport can only be ensured by improving the efficiency and exhaust emissions of ICEVs, since these will remain the backbone of the transport system in the medium term.[21,51] The technology to do so already exists: partial electrification via HEVs can readily deliver a reduction in fuel consumption and hence CO_2 emissions of about 20%, and – the point is worth reiterating – without requiring any new infrastructure.

3.4 BEVs, ICEVs and human health

The impacts on human health of the mining of metals needed for BEV batteries are very significant. Human toxicity potential is estimated to be three to five times worse for BEVs than for exhaust pollutants from ICEVs.[52,53,54] There are water and eco-toxicity effects too. These health and environmental impacts are experienced in the countries where the mining takes place and materials are processed. The bigger the battery, the worse the impact.

Closer to home, ICEVs produce a range of exhaust





pollutants, such as particulates, unburned hydrocarbons and nitrogen oxides (NOx), all of which can affect human health. However, emissions standards are now very stringent: modern (Euro VI) diesels can comfortably beat the most stringent NOx requirements,[21] and once the vehicles have warmed up, their exhaust gases may have lower particulate levels than the ambient air in cities. Similarly, with ultra-low emissions petrol engines, levels of unburned hydrocarbons may be lower in the exhaust than in the intake in some areas.[21]

This being the case, other sources of particulates – notably tyre wear – are becoming more important. However, here BEVs are more of a problem, because they weigh 25–30% more than comparable ICEVs, a function of the weight of their batteries, which leads to greater tyre wear.[55,56] As BEV numbers increase, their impact on air quality will need to be reassessed.

3.5 Impact of the proposed ban on the sales of ICEVs

Even if the UK government wishes to promote BEVs, banning the sale of new ICEVs does not make sense. As noted above, even under the most optimistic assumptions, ICEVs will be the backbone of the transport system for decades to come. But the ban will ensure that all these vehicles have, at best, 2030s' ICE technology; any subsequent improvements will not be available to customers.

Well before the ban is in place, all UK research and development on ICEVs will stop, laying waste to quite a strong scientific capability, and throwing many young and talented scientists and technologists out of work. If people are not persuaded to buy BEVs in large numbers by 2030, because of charging anxiety, lack of utility and high up-front costs, and car manufacturers are not allowed to sell ICEVs, the UK auto industry will be destroyed, with all the implications that has for employment.

The number of BEVs will certainly rise very rapidly and they have an important role to play in the future. However, batteries cannot and, to avoid environmental and economic catastrophe, must not become the sole source of power for transport. All available technologies, including ICEVs, BEVs, fuel cell vehicles and alternative fuels should be deployed and continuously improved. However, all these technologies need to be assessed on an honest lifecycle basis to ensure that they really deliver what they promise. So many policies instituted on the basis of environmental arguments have and do not have unintended consequences, biomass energy and biofuels being the obvious examples.

4. The 'existential crisis' and the need to adapt

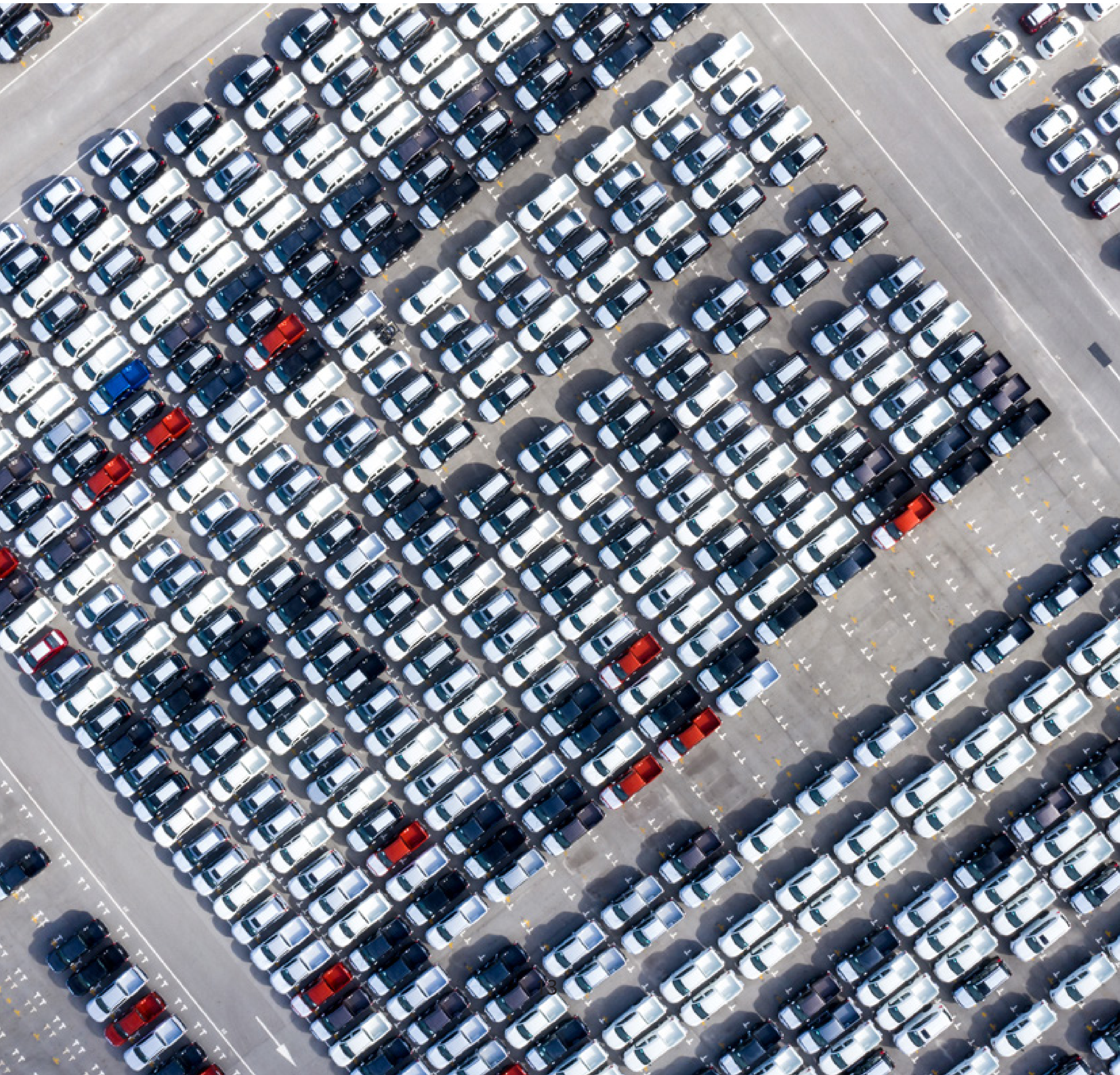
The pace at which decarbonisation is to be pursued clearly depends on how serious and imminent the 'existential crisis' of climate change is believed to be. It is worth noting that many climate scientists[57,58,59] have criticised the apocalyptic predictions of groups such as Extinction Rebellion. There will be clearly some impacts of climate change in the future. However, there is little sign that we are currently in any kind of 'climate emergency' – empirical evidence of worsening floods and droughts, storms, area burned by wild forest fires and the rate of sea level rise, is hard to come by.[18,60,61,62,63] And although the economic damage from extreme weather events has increased, this is because of growing wealth; there is simply more valuable property to be destroyed.[63] The earth has been 'greening' over the last 35 years, largely due to rising levels of CO_2, an effect which is expected to mitigate global warming by increasing the carbon sink on land and altering other processes.[64] Meanwhile, deaths from drought, floods, extreme weather, extreme temperature, landslides, wildfires, volcanic activity and earthquakes have declined by more than 95% over the past century.[18,61,63,64,65] This is because we are now much better able to cope with anything the climate throws at us. We can predict extreme weather earlier and more accurately, and we have technologies to deal with it when it hits.

Growing wealth makes societies more resilient to the vagaries of the weather. If the world is really in some kind of crisis, it is hard to explain how, on almost every measure – absolute poverty, undernourishment, education, child mortality, life expectancy, world food production, per-capita food consumption, productivity per acre, and daily supply of calories – things have been improving significantly and consistently over the last century, particularly in poorer countries.[18,60,61,62,63,64]

Despite the clear evidence that humankind is coping well and that human wellbeing is improving, western governments base their policies on the notion of a climate emergency, with the result that they brush aside concerns over the scale of the decarbonisation task and the many insurmountable barriers to completing it, as outlined above. Poorer countries, with more pressing problems, such, as poverty, environmental degradation, disease and unequal distribution of resources, cannot afford the luxury of such shallow thinking, and are pressing on with developing their fossil fuel resources so as to lift their peoples out of poverty.

That unavoidable fact means that in spite of the decarbonisation efforts of western countries, global greenhouse gas levels are unlikely to fall significantly in the next several decades. There will be some consequences of this; IPCC projections say that extreme weather will become more likely and more intense in the future. However, since global GHG levels cannot be reduced significantly in the medium term, humanity has no choice but to cope with these consequences, just as it has successfully done with the warming of the last century. In any case, even if the world were to eliminate GHG emissions, there would still be extreme weather events, and societies would have to adapt and be resilient to them, regardless of climate change. As developing countries become wealthier they will be better able to do so.

Much more focus should be put on 'no regrets' adaptation policies. Worries about, say, extreme rainfall because of future climate change are far better addressed through building better flood defences than by setting unachievable targets to decarbonise the economy. Energy policy certainly needs to be informed by much more realism, honesty, and an appreciation of broader global developmental, economic and environmental needs.



Notes

1. The Intergovernmental Panel on Climate Change, https://www.ipcc.ch/, (accessed 25 April 2021).

2. https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law (accessed 25 April 2021).

3. https://berniesanders.com/issues/green-new-deal/ (accessed 28 April 2021).

4. Extinction Rebellion. https://extinctionrebellion.uk/the-truth/demands/ (accessed 18 April 2021).

5. The Royal Society, *Greenhouse Gas Removal*, 2018. https://royalsociety.org/-/media/policy/projects/greenhouse-gas-removal/royal-society-greenhouse-gas-removal-report-2018.pdf (accessed 1 May 2021).

6. *BP Statistical Review of World Energy 2020*. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf (accessed 1 May 2021).

7. IEA, *Oil Markets Report*, December 2019. https://www.iea.org/reports/oil-market-report-december-2019 (accessed 11 May 2021).

8. Kalghatgi, G, 'Is it really the end of internal combustion engines and petroleum in transport?', *Applied Energy* 2018; 225: 965–974.

9. Kalghatgi, G, 'Are domestic electricity prices higher in countries with higher installed capacity of wind and solar? (2019 data)', *Journal of Automotive Safety and Energy* 2021; 11: 79–83.

10. USGS, *2011 Wind Energy in the United States and Materials Required for the Land-Based Wind Turbine Industry From 2010 Through 2030*. 2011. Table 5 https://pubs.usgs.gov/sir/2011/5036/sir2011-5036.pdf (accessed 3 May 2021).

11. Smil, V, 'To get wind power you need oil'. IEE Spectrum, 2016. https://spectrum.ieee.org/energy/renewables/to-get-wind-power-you-need-oil (accessed 3 May 2021).

12. Hughes, G, *Wind Power Economics – Rhetoric and Reality*, 2020. https://www.ref.org.uk/attachments/article/365/Gordon%20Hughes%20-%20REF%20Wind%20Economics%20webinar.pdf (accessed 1 May 2021).

13. Lampriere, M. Energy Storage News, 2020, https://www.energy-storage.news/news/uks-largest-battery-storage-project-at-320mw-gets-go-ahead-from-government (accessed 1 May 2021).

14. Environmental impacts and siting of wind projects, 2019. https://www.energy.gov/eere/wind/environmental-impacts-and-siting-wind-projects (accessed 10 Feb 2021).

15. Thaker, M et al., 'Wind farms have cascading impacts on ecosystems across trophic levels', *Nature Ecology & Evolution* 2018; 2: 854–1858.

16. Tsoutsos, E et al., 'Environmental impacts from the solar energy technologies', *Energy Policy* 2005; 3: 289–296.

17. Shellenberger, M, 'If solar panels are so clean, why do they produce so much toxic waste?' 2018, http://borosilrenewables.com/pdf/2018/toxin-free/Research%20-%20poisoning%20of%20environment%20by%20solar%20modules%20-%20recycling%20challenges.pdf.

18. Shellenberger, M, *Apocalypse Never: Why environmental alarmism hurts us all*. HarperCollins, 2020.

19. Transport and Environment. https://www.transportenvironment.org/press/e-fuels-too-inefficient-and-expensive-cars-and-trucks-may-be-part-aviations-climate-solution-%E2%80%93 (accessed 11 May 2021).

20. Malins C. 'What role is there for electrofuel technologies in European transport's low carbon future?' 2017. https://www.transportenvironment.org/sites/te/files/publications/2017_11_Cerulogy_study_What_role_electrofuels_final_0.pdf (accessed 5 May 2021).

21. Leach, F et al., 'The scope for improving the efficiency and environmental impact of internal combustion engines', *Transportation Engineering* 2020; 1. https://doi.org/10.1016/j.treng.2020.100005.

22. CO_2 Living. https://co2living.com/reduce-your-carbon-footprint-by-planting-a-tree/ (accessed 5 May 2021).

23. EPA. Energy and Environment. https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references (accessed 5 May 2021).

24. The Environmentor. https://blog.tentree.com/this-is-the-impact-of-1-million-trees/ (accessed 5 May 2021).

25. Installer, 2019 was a record year for gas boiler sales, 2020. https://www.installeronline.co.uk/2019-record-year-gas-boiler-sales/ (accessed 5 May 2021).

26. PHAM News, 2017. https://www.phamnews.co.uk/global-gas-boiler-sales-revealed/ (accessed 5 May 2021).

27. Travers, M. *The Hidden Cost of Net-Zero: Rewiring the UK*, 2020. https://www.thegwpf.org/content/uploads/2020/07/Travers-Net-Zero-Distribution-Grid-Replacement.pdf (accessed 5 May 2021).

28. IPCC. Chapter 8: Transport IPCC WGIII Fifth Assessment Report. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter8.pdf (accessed 5 May 2021).

29. FAO. *Tackling climate change through livestock*, 2013. http://www.fao.org/news/story/en/item/197623/icode/ (accessed 5 May 2021).

30. UK Fires, Absolute Zero, 2019 https://www.icax.co.uk/Absolute_Zero_Report.html (accessed 5 May 2021).

31. Singh, A. *Livestock Production Statistics of India – 2018* https://www.vetextension.com/livestock-animal-production-statistics-of-india-2018/ (accessed 5 May 2021).

32. Pyper, J. How long will coal remain king in India?, 2021. https://www.greentechmedia.com/articles/read/coal-king-india (accessed 4 May 2021).

33. Reuters, *Study: China's New Coal Power Plant Capacity in 2020 More Than Three Times Rest of World's*, 2021. https://www.voanews.com/science-health/study-chinas-new-coal-power-plant-capacity-2020-more-3-times-rest-worlds (accessed 5 May 2021).

34. Doshi, T. 'The Middle East doubles down on oil and gas as the UN warns of 'climate emergency', 2021. https://www.forbes.com/sites/tilakdoshi/2021/12/29/the-middle-east-doubles-down-on-oil-and-gas-as-the-un-warns-of-climate-emergency/?sh=5586080c454e (accessed 4 May 2021).

35. US EIA, *International Energy Outlook 2020*. https://www.eia.gov/outlooks/ieo/pdf/ieo2020.pdf (accessed 5 May 2021).

36. IEA, *World Energy Outlook 2020*: Frequently Asked Questions. 2020 https://www.iea.org/articles/world-energy-outlook-2020-frequently-asked-questions (accessed 4 May 2021).

37. RAC 2020, 'Motoring FAQs', https://www.racfoundation.org/motoring-faqs/mobility#pagetop (accessed 4 May 2021).

38. Next Green Car, 'Electric Car Market Statistics'. https://www.nextgreencar.com/electric-cars/statistics/ (accessed 3 Aug 2021).

39. Department of Transport, https://www.gov.uk/government/news/government-takes-historic-step-towards-net-zero-with-end-of-sale-of-new-petrol-and-diesel-cars-by-2030 (accessed 2 August 2021).

40. Hamza, K, et al. 'On modeling the total cost of ownership of electric and plug-in hybrid vehicles', SAE Paper 2020-01-1435, 2020. https://doi.org/10.4271/2020-01-1435.

41. Muratori, M. 'Impact of uncoordinated plug-in electric vehicle charging on residential power demand'. *Nature Energy* 2018; 3: 193–201.

42. Herrington, R., 'Mining our green future'. *Nature Reviews Materials* 2021; 6, 456–458.

43. Olivetti, EA et al. 'Lithium-Ion battery supply chain considerations; analysis of potential bottlenecks', *Joule* 2017; 1: 229–243.
44. Gaines, L. 'The future of automotive lithium-ion battery recycling: Charting a sustainable course', *Sustainable Materials and Technologies* 2014; 1–2: 2–7.
45. Buchal, C and Sinn, H-W. 'Decarbonizing mobility: Thoughts on an unresolved challenge'. *European Physical Journal Plus* 2019; 134: 599.
46. Bloomberg NEF, 'China Dominates the lithium-ion battery supply chain, but Europe is on the rise', 2020. https://about.bnef.com/blog/china-dominates-the-lithium-ion-battery-supply-chain-but-europe-is-on-the-rise/ (Accessed 8 May 2021).
47. X. Sun et al. 'Life cycle assessment of lithium nickel cobalt manganese oxide (NCM) batteries for electric passenger vehicles'. *Journal of Cleaner Production*, 2020; 273.
48. IEA. *The Global EV Outlook 2020*. https://www.iea.org/reports/global-ev-outlook-2020 (accessed 8 May 2021).
49. *Digest of UK Energy Statistic (DUKES) 2020: Petroleum* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/904777/DUKES_2020_Chapter_3.pdf (accessed 18 Feb 2021).
50. Mark P. Mills, *Mines Minerals and 'Green' Energy: A Reality Check*, Manhattan Institute, 2020, https://media4.manhattan-institute.org/sites/default/files/mines-minerals-green-energy-reality-checkMM.pdf (accessed 8 May 2021).
51. Kalghatgi, G. 'Development of fuel/engine systems—the way forward to sustainable transport'. *Engineering* 2015; 5: 510–518.
52. Hawkins TR et al. 'Comparative environmental life cycle assessment of conventional and electric vehicles'. *Journal of Industrial Ecology* 2013; 17: 53–60.
53. Brennan, JW and Barder, TE. *Battery Electric Vehicles vs. Internal Combustion Engine Vehicles - A United States-Based Comprehensive Assessment*. 2016. https://www.adlittle.de/sites/default/files/viewpoints/ADL_BEVs_vs_ICEVs_FINAL_November_292016.pdf (accessed 8 May 2021).
54. EEA Report 13/2018. *Electric Vehicles from Life Cycle and Circular Economy Perspectives*, Ch. 6, 2018 https://www.emobility-svizzera.ch/pdf/TH-AL-18-012-EN-N%20TERM%202018.pdf (accessed 8 May 2021).
55. Timmers, ARJH and Achten, PAJ. 'Non-exhaust PM emissions from electric vehicles'. *Atmospheric Environment* 2016; 124: 10–17.
56. Emissions Analytics, 2020. https://www.emissionsanalytics.com/news/pollution-tyre-wear-worse-exhaust-emissions (accessed 8 May 2021).
57. Hulme, M. https://mikehulme.org/am-i-a-denier-a-human-extinction-denier/ (accessed 10 May 2021).
58. Betts, R and Hausfather, Z. https://www.theguardian.com/commentisfree/2020/aug/06/global-climate-crisis-doom-optimism-emergency (accessed 17 Feb 2021).
59. Allen, M. https://theconversation.com/why-protesters-should-be-wary-of-12-years-to-climate-breakdown-rhetoric-115489 (accessed 17 Feb 2021).
60. Lomborg, B. *False Alarm: How climate change panic costs us trillions, hurts the poor, and fails to fix the planet*, Hatchette, 2020.
61. Koonin SE. *Unsettled: What Climate Science Tells Us, What It Doesn't, and Why It Matters*, Benbella Books, 2021.
62. Goklany, IM. *Impacts of Climate Change: Perception and reality*, GWPF, 2021, https://www.thegwpf.org/content/uploads/2021/02/Goklany-EmpiricalTrends.pdf (accessed 10 May 2021).
63. Pielke, Jr RJ. *The Rightful Place of Science: Disasters & Climate Change.* Consortium for Science, Policy & Outcomes, 2014.

64. NASA. https://earthobservatory.nasa.gov/images/146296/global-green-up-slows-warming (accessed 10 May 2021).
65. Our World in Data, Oxford Martin School, https://ourworldindata.org/ (accessed 5 Aug 2021).

Review process

GWPF publishes papers in a number of different formats, with a different review process pertaining to each.

- Our flagship long-form GWPF Reports, are all reviewed by our Academic Advisory Panel.
- GWPF Briefings and Notes are shorter documents and are reviewed internally and/or externally as required.

Part of the function of the review process is to ensure that any materials published by the GWPF are of a proper academic standard, and will serve the GWPF's educational purpose. As a charity, we recognise that educational material should provide any reader the opportunity to understand, and explore different perspectives on a subject.

This means that, for most publications, we also invite an external review from a party who we would expect to take a different view to the publication's author. We offer to publish any substantive comments alongside the main paper, provided we are satisfied they will enhance the educational experience of the reader. In this way, we hope to encourage open and active debate on the important areas in which we work.

This enhanced review process for GWPF papers is intended to take the content and analysis beyond a typical review for an academic journal:

- More potential reviewers can be involved
- The number of substantive comments will typically exceeds journal peer review, and
- The identity of the author is known to the potential reviewers.

As an organisation whose publications are sometimes the subject of assertive or careless criticism, this review process is intended to enhance the educational experience for all readers, allowing points to be made and considered in context and observing the standards required for an informed and informative debate. We therefore expect all parties involved to treat the reviews with the utmost seriousness.

Final responsibility for publication rests with the Chairman of the Trustees and the GWPF Director. But In every case, the views expressed are those of the author. GWPF has never had any corporate position beyond that dictated by its educational objectives.

About the Global Warming Policy Foundation

The Global Warming Policy Foundation is an all-party and non-party think tank and a registered educational charity which, while openminded on the contested science of global warming, is deeply concerned about the costs and other implications of many of the policies currently being advocated.

Our main focus is to analyse global warming policies and their economic and other implications. Our aim is to provide the most robust and reliable economic analysis and advice. Above all we seek to inform the media, politicians and the public, in a newsworthy way, on the subject in general and on the misinformation to which they are all too frequently being subjected at the present time.

The key to the success of the GWPF is the trust and credibility that we have earned in the eyes of a growing number of policy makers, journalists and the interested public. The GWPF is funded overwhelmingly by voluntary donations from a number of private individuals and charitable trusts. In order to make clear its complete independence, it does not accept gifts from either energy companies or anyone with a significant interest in an energy company.

Views expressed in the publications of the Global Warming Policy Foundation are those of the authors, not those of the GWPF, its trustees, its Academic Advisory Council members or its directors.

RECENT GWPF BRIEFINGS

19	Indur Goklany	The Papal Academies' Broken Moral Compass
20	Donoughue and Forster	The Papal Encyclical: a Critical Christian Response
21	Andrew Montford	Parched Earth Policy: Drought, Heatwave and Conflict
22	David Campbell	The Paris Agreement and the Fifth Carbon Budget
23	Various	The Stern Review: Ten Years of Harm
24	Judith Curry	Climate Models for the Layman
25	Fritz Vahrenholt	Germany's Energiewende: a Disaster in the Making
26	Hughes, Aris, Constable	Offshore Wind Strike Prices
27	Michael Miersch	Truly Green?
28	Susan Crockford	20 Good Reasons not to Worry About Polar Bears: Update
29	Mikko Paunio	Sacrificing the Poor: The Lancet on 'pollution'
30	Mikko Paunio	Kicking Away the Energy Ladder
31	Bill Gray	Flaws in Applying Greenhouse Warming to Climate Variability
32	Mikko Paunio	Save the Oceans: Stop Recycling Plastic
33	Andy Dawson	Small Modular Nuclear: Crushed at Birth
34	Andrew Montford	Quakes, Pollution and Flaming Faucets
35	Paul Homewood	DEFRA vs Met Office: Factchecking the State of the UK Climate
36	J. Ray Bates	Deficiencies in the IPCC's Special Report on 1.5 Degrees
37	Paul Homewood	Tropical Hurricanes in the Age of Global Warming
38	Mikko Paunio	The Health Benefits of Ignoring the IPCC
39	Jack Ponton	Grid-scale Storage: Can it Solve the Intermittency Problem?
40	Robert Lyman	Carbon Taxation: The Canadian Experience
41	Rémy Prud'homme	La Transition Énergétique: Useless, Costly, Unfair
42	Judith Curry	Recovery, Resilience, Readiness: Contending with Natural Disasters
43	Paul Homewood	Plus Ça Change: The UK Climate in 2018
44	David Whitehouse	Cold Water: The Oceans and Climate Change
45	Crockford and Laframboise	The Defenestration of Dr Crockford
46	Paul Homewood	Britain's Weather in 2019: More of the Same, Again
47	John Constable	The Brink of Darkness: Britain's Fragile Grid
48	Mike Travers	The Hidden Cost of Net Zero: Rewiring the UK
49	Martin Livermore	Greenhouse Gas Emissions: The Global Picture
50	Paul Homewood	The US Climate in 2019
51	Patricia Adams	The Red and the Green: China's Useful Idiots
52	Andrew Montford	Offshore Wind: Cost Predictions and Cost Outcomes
53	Tim Worstall	A Saviour Spurned: How Fracking Saved us from Global Warming
54	Jun Arima	Eco-fundamentalism as Grist for China's Mill
55	Gautam Kalghatgi	Scoping Net Zero

For further information about the Global Warming Policy Foundation, please visit our website at www.thegwpf.org.

The GWPF is a registered charity, number 1131448.