ACHIEVING NET ZERO

A REPORT FROM A PUTATIVE DELIVERY AGENCY

Michael Kelly

With a foreword by Sir Iain Duncan Smith MP

The Global Warming Policy Foundation
Note 30

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About the author

Michael Kelly ended his academic career as the inaugural Prince Philip Professor of Technology at the University of Cambridge. His main research focus was in new semiconductor physics and technology for ultra-high-speed electronic devices and the manufacturability of semiconductor structures at the nanoscale. He is a trustee of the GWPF. He is a Fellow of the Royal Society and of the Royal Academy of Engineering.

Foreword by Sir Iain Duncan Smith

Professor Michael Kelly's paper makes interesting reading, particularly as the UK is bound on an accelerated course to Net Zero by 2050. It is a clear examination of statements that are presented as fact, which are often repeated but rarely explained.

His paper points out the growing concern about the absence of a proper cost-benefit analysis which stands up to scrutiny. To that end, he asks important questions about why there has not been full transparency about the methodology behind the figures used by modellers, which in turn drive the Net Zero target. Professor Kelly makes the interesting point that ministers have been presented with only one possible path, instead of a range of possibilities and actions, as would be normal in most other areas of Government business.

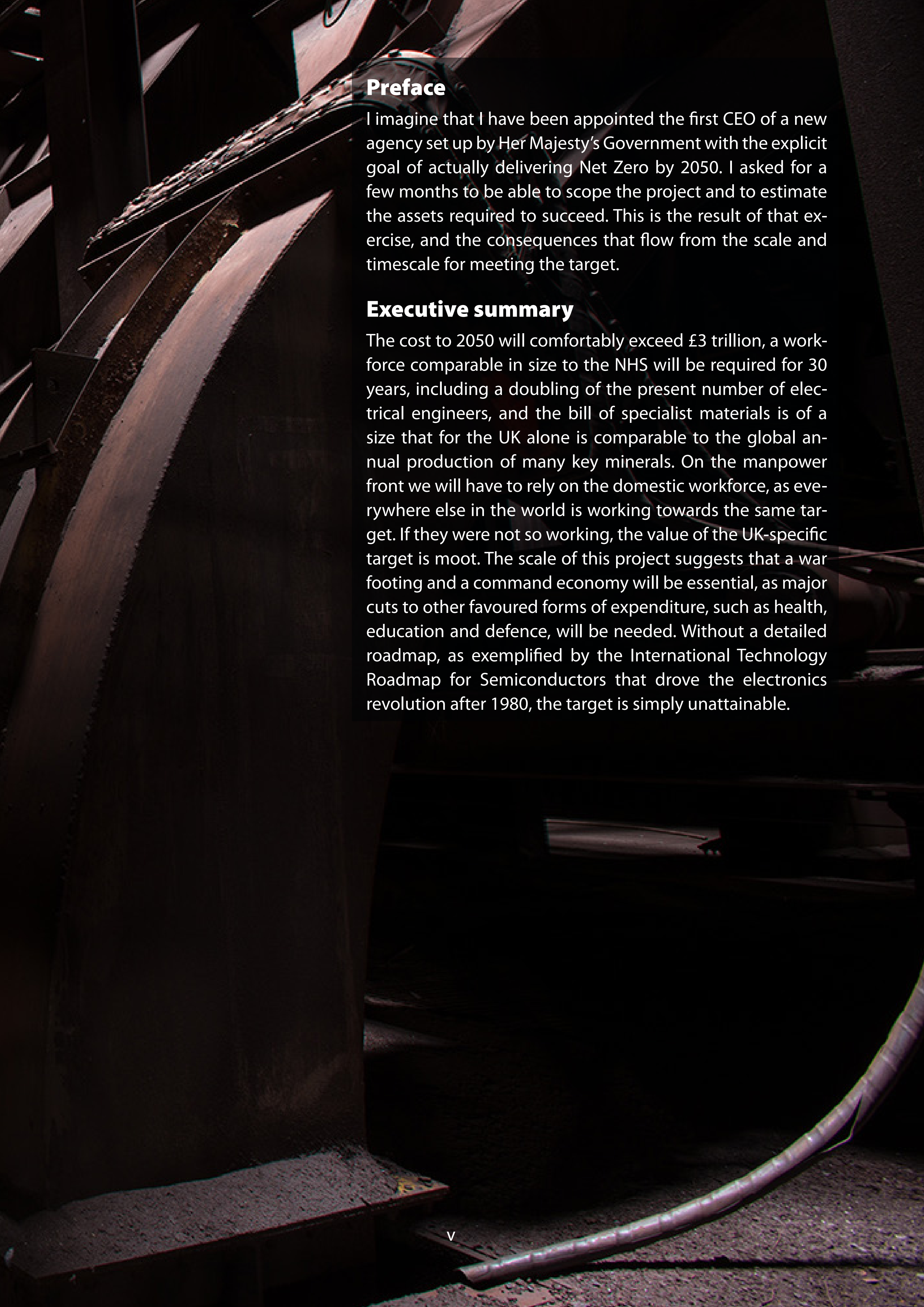
In this paper, Professor Kelly explains clearly that a critical study of what would be the biggest engineering project ever undertaken is missing. He makes the point that the need for materials, the required workforce, and the scale of the costs should be considered in the most robust manner, but this does not appear to have happened to date.

This is particularly important when as we see, the country is already feeling the growing cost of our progress towards Net Zero, and we have barely begun the process. In everything else we propose, Government plans receive the toughest scrutiny and even then, costs almost always end up higher than planned. One only need look at the HS2 railway programme to see how costs there have spiralled as an illustration of how often the cost of Government outstrips expectations.

The important point that comes out in this paper is that change on this scale needs to carry the public through open debate. The proposals and actions that are required to meet our current Net Zero commitments in the promised time frame will not be sustained if based only on fear.

We owe it to the citizens of the UK to take a long hard look at the path to be taken. Policymakers must be honest and open with the British public about how much all this will cost them, and how much change to our everyday lives may be required. The recent aggressive action by President Putin of Russia to invade Ukraine has highlighted our lack of energy security, and Western Europe's enormous reliance on Russia for supplies of gas and oil.

Sir Iain Duncan Smith is Member of Parliament for Chingford and Woodford Green, and a former leader of the Conservative Party. He was Secretary of State for Work and Pensions and is the founder of the Centre for Social Justice (CSJ).



Preface

I imagine that I have been appointed the first CEO of a new agency set up by Her Majesty's Government with the explicit goal of actually delivering Net Zero by 2050. I asked for a few months to be able to scope the project and to estimate the assets required to succeed. This is the result of that exercise, and the consequences that flow from the scale and timescale for meeting the target.

Executive summary

The cost to 2050 will comfortably exceed £3 trillion, a workforce comparable in size to the NHS will be required for 30 years, including a doubling of the present number of electrical engineers, and the bill of specialist materials is of a size that for the UK alone is comparable to the global annual production of many key minerals. On the manpower front we will have to rely on the domestic workforce, as everywhere else in the world is working towards the same target. If they were not so working, the value of the UK-specific target is moot. The scale of this project suggests that a war footing and a command economy will be essential, as major cuts to other favoured forms of expenditure, such as health, education and defence, will be needed. Without a detailed roadmap, as exemplified by the International Technology Roadmap for Semiconductors that drove the electronics revolution after 1980, the target is simply unattainable.

Introduction

Imagine we have a net-zero emissions economy in the UK by 2050. Three very large multidisciplinary engineering projects will have been completed:

- Transport will have been electrified.
- Industrial and domestic heat will have been electrified.
- The electricity sector – generation, transmission and distribution – will have been greatly expanded in order to cope with the first two projects.

A fourth project is to secure the buy-in of the public for what will be 30 years of social disruption, diminished living standards, and living under a command economy.

The successful completion of these projects is necessary to meet the high-level target, but they are not sufficient, as I have not dealt explicitly with agriculture and other matters.

Current UK energy consumption

The data in Figure 1 give an indication of the energy used over the years 2014–17 for transport, heat and electricity in the UK.[1] This was presented by the then Chief Scientific Advisor at BEIS to a Royal Society Conference in 2018.

Throughout the year, the use of transport fuel is fairly constant, whereas heating varies strongly. Electricity use peaks in winter and is lower than average in summer. In converting transport energy and heat – currently mostly derived from fossil fuels – to electricity, we will use today's data, assuming that the growth in demand from population growth will be offset by energy efficiency savings, both at about 10% over the next 30 years. This approximation would have to be revisited in a more detailed analysis than is given here.

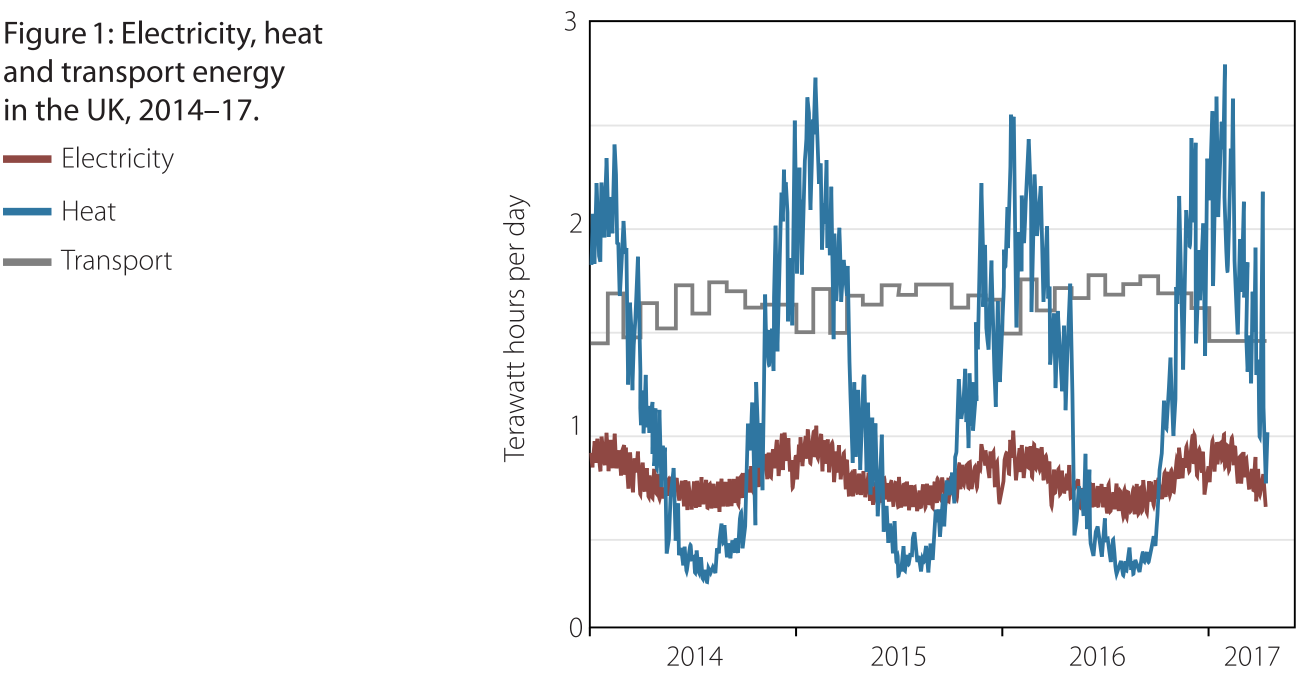


Figure 1: Electricity, heat and transport energy in the UK, 2014–17.

Decarbonising the economy

Transport

Transport energy consumption is twice that of electricity. Because an internal combustion engine converts the energy stored in its fuel into transport motion with an efficiency of about 30%, while electric motors are over 90% efficient at using energy stored in a battery, we will need to increase the electricity supply by about 67% in order to maintain transport in the UK at today's level in 2050. A small part of this transport energy is used for aviation and shipping, the electrification of which is much less advanced than the electrification of ground transport, and will, in the end, be more expensive per journey than implied by the use of aviation fuel and bunker oil today. At present, the amount of battery storage needed to contain the energy for a jumbo jet crossing the Atlantic weighs six times the maximum cargo that such a jet can carry today. Since the total world effort in battery research has improved the energy density of storage by a factor of six since 1970, it would take another 50 years of equally successful research progress, at an historic pace, before a large electric jet could take off even without passengers and cargo! Kerosene will therefore still be essential to maintain air transport in 2050. The extra cost of alternatives to aviation fuel and bunker oil is not examined here in detail, and this omission allows us to insist that the estimates below are a lower bound on the total cost of delivering Net Zero. The additional electricity infrastructure required is considered in the third engineering project.

Heat

We note from Figure 1 that in winter, we use three times as much heat as electricity. If this heat was provided by radiant heaters, we would need a grid four times the size of today's just to keep homes and businesses warm. If we use air-source and ground-source heat pumps, with a coefficient of performance of 3:1 – optimistic given the poor quality of the thermal envelope of UK houses – then the grid would need only to be double the size, for the heat element alone.

Combining this result with the figures for transport in the last section, the grid in 2050 will *prime facie* need to be 2.7 times its present size. We return to this later. However, it may be possible to reduce the amount of electricity required by insulating buildings.

The building stock in the UK is made up of 26 million houses and 5.5 million other buildings; most were built when the cost of heating fuel was not very high. If the UK stock had been built in Sweden or Spain, the thermal envelope would have been much more effective for keeping energy in during winter, or out during summer.

In 2009, as Chief Scientific Advisor to the then Department for Communities and Local Government, I briefed Lord Drayson, the then Science Minister, about the challenge of retrofitting all existing buildings to reduce the energy consumption and hence emissions of carbon dioxide. I suggested a detailed pilot programme be put in train. This became a £17 million expenditure programme called

'Retrofit for the Future', a series of projects in which over 100 social houses (i.e. smaller than the average) were subject to various measures. One group of 45 houses received complete makeovers – double and treble glazing, external cladding, extra loft and underfloor insulation, and new energy-efficient appliances. Detailed studies of emissions before and after for this group[2] showed that for an average expenditure of £85,000, the average emissions reduction achieved was 60%, with only three dwellings achieving the 80% emissions reduction target, and another three not even reaching 30%. Linearly scaling the result to the whole housing stock and a 100% emissions reduction, produces a cost estimate of £4 trillion.

However, the programme was a set of one-off projects, without the benefits of a fully developed supply chain, competing retrofitters, and a large, trained labour force. Learning by doing might therefore be expected to reduce the total cost, perhaps by 50%, but probably not much more, as each house requires a bespoke solution, with precise fitting of all forms of insulation so that no heat leaks.

Most non-domestic buildings are, on average, much larger than houses. Some – office blocks, hospitals, hotels and retail parks – are more complex than homes, but others – warehouses, corner stores – are simpler. A figure of order £1 trillion will probably be needed for these buildings, so a total of £3 trillion for a full retrofit of UK buildings is required.

One has to be aware from here on about the possibility of double counting. A cheap, zero-carbon supply of electricity would mean that buildings would not require all this retrofitting. Alternatively, for a fully retrofitted building, less electricity will be needed. There will be an optimisation exercise to attain the least-cost solution.

Industry

Industrial heat for the manufacture of steel, cement and other materials has not been considered. Electric arc furnaces will accomplish some of the job of decarbonisation, but the highest temperatures still require fossil fuels. Since manufacturing has been on a steep decline over the last 30 years while we have grown a service economy, the remaining industrial heat will be an added cost at the end of this exercise.

Electricity infrastructure

The grid needs to be 2.7 times bigger in 2050 than it is currently if the UK economy as we know it now is to continue to function. Clearly, 30 years is also enough time to drive other changes in the economy that may reduce, or, indeed, add to this 2.7 factor. The engineering consultants Atkins[3] reckon that 12 GW of new capacity will need to be added to the grid over each of the next 30 years. This is eight times the rate at which new capacity has been added over the last 30 years, including all the renewables to date.

But increasing the size of the grid is not just a matter of increasing generating capacity. Another major project that few people recognise is the need to rewire homes, street distribution and local substations. Many older houses have 60-A (amp) fuses, a size set when the most demanding appliance was a kettle drawing 8–9 A, Wiring in the streets and substations was sized to match a maximum 60-A draw from each house (with the average draw much lower). In the all-electric home of the future, much larger draws will be common. Ground-source heat pumps may draw 58 A on start-up, while radiant hobs when starting up draw 27 A, fast chargers for electric vehicles draw 33 A, and even slow ones may draw 12 A, while electric showers draw 33 A. At the very least the mains fuse will need upgrading, and the local substations greatly expanded. In some configurations, the wiring in houses and along streets will need upgrading to carry the extra currents. It has been estimated to cost £700 billion to carry out this work on local distribution for the UK.[4] Without this spending, we will have to live with frequent circuit breaks, and suboptimal performance of domestic appliances.

The next focus is on the transmission of three times as much electricity as today. The grid currently comprises a 400-kV grid of 11,500 km, a 275-kV grid of 9,800 km, and a 132-kV (or lower) grid of 5,250 km. I assume that double this length has to be added, which will cost £130 billion.[5] Including new and upgraded substations, switching and control systems and other equipment, takes the figure to £200 billion. This shows that the National Grid costs to reach 2050 net-zero economy are approximately £0.9 trillion.

The cost of new generating capacity can be estimated as follows. Today we have 75 GW installed capacity, and we need a further 150 GW. We have to be able to cover a peak demand of about 150 GW in 2050 without renewables, as storage at grid scale will not play a significant role in the UK within the next 30 years, even if there were a massive breakthrough in battery technology tomorrow. For power generation, capital costs are often expressed as overnight cost per megawatt of capacity. The relevant estimated costs are:[6] £2m/MW for a mix of onshore and offshore wind, £1.5m/MW for solar, and £4m/MW for nuclear. Assuming a mix of technologies is used – to give better security of supply – we should assume a weighted average of just over £3m/MW, and we can thus arrive at an estimate of £500 billion for new generating capacity.

The widespread use of renewables means that significant electricity storage will be required. Batteries are very expensive (see below), and there is little scope in the UK for additional pumped hydroelectricity – our biggest facility, Dinorwig in Wales, would only charge 0.7% of all UK cars (all with small 60-kWh batteries) if emptied once.[7] Without back-up storage, extra low-carbon generation will be needed for calm days and at night, especially in winter when demand is at a peak. If this is not delivered using fossil fuels in power stations equipped with carbon capture and sequestration – still very uneconomic – it will have to be nuclear, but this too will result in a further increase in the overall cost estimate.

Note that the costs of electricity will increase because of the need to repay these major capital costs over the lifetime of the assets. Much of the rise of the price of electricity in recent years is attributable to the extra costs of renewables and the need to maintain back-up generation capacity, the latter having to recover its own costs over much reduced operating hours. This trend of rising prices is set to continue until 2050.

We have identified £4.4 trillion so far for the three headline engineering projects, and we have not considered agriculture or the costs of rail, sea and air transport. The total already amounts to £180,000 per household. Although we have already acknowledged an element of double counting from having both zero-carbon houses and zero-carbon electricity, the total will undoubtedly be in excess of £100,000 per household.

The final sum for just the UK is greater than the £3 trillion (in today's terms) that the USA spent on World War II.

Human resources

We now consider the human resource requirements to deliver the target economy. Atkins estimate[8] that a £1 billion project in the electrical sector implies about 1000 years of professional engineering time and somewhere between 3000 and 4000 years of the time of skilled tradespeople. This amounts to 30 or more engineers and 100 or more skilled tradespeople, employed full-time for 30 years. Scaling up these figures up for the £1.4 trillion electricity sector, we will need 42,000 electrical engineers and of order 130,000 skilled people employed full-time for the 30 years to 2050. Since we currently have 38,000 professional electrical engineers in the UK,[9] the workforce will need to double in size. Training this many engineers will take time, and will therefore hamper progress in the coming decade during a build-up phase, meaning even more will be needed later on.

In the retrofit sector, a range of skills – from semi-skilled to highly skilled – is required. Based on the budget, we might expect the putative retrofit sector to need a similar workforce, of order 500,000 people, to deliver everything from the design of individual projects, through the materials supply chain, to the actual retrofitting work.

Clearly these are both major perturbations to the national workforce. There are no prior examples of skilled workers being generated and maintained on such a scale over 30 years.

Bill of materials

The actual costs of the materials required are covered above. Here we consider the quantities required. The transition from fossil fuels to renewables is a move from a fuel-intensive energy sector to a materials-intensive energy sector. There is already considerable popular concern about the role of mining in reducing biodiversity, but this problem is about to get much worse.

As an example, a 600-MW combined-cycle gas turbine (CCGT) comprises 300 tonnes of high-performance steel. We would need 360 5-MW wind turbines, each running at 33% efficiency, and a major storage facility alongside to achieve the same continuous 600-MW supply. In fact, since the life of wind turbines at 25 years is less than half that of CCGT turbines with a single life-extension refit, we would actually need 720 of them.

The mass of the nacelle (the turbine at the top of the tower) for a 5-MW wind turbine is comparable[10] to that of a CCGT. Furthermore, the mass of concrete in the plinth of a single CCGT is comparable to the mass of concrete for the foundations of each onshore wind turbine and rather smaller than the concrete and ballast for each offshore turbine. A corollary of the multiplicity of turbines or solar panels is that connecting them to the grid is more materials intensive.

A 1.8-GW nuclear power plant and turbine produce about 1000 W/kg of steel in the combined unit, compared with around 2000 W/kg for a CCGT and 2–3 W/kg from solar panels or wind turbines. These factors, of order 1000, show that the use of high-value materials (steels, silicon and long-life polymers for wind turbine blades) is much more intensive in renewables. This effect is offset somewhat by their fuel-free operation. However, the extraction of oil and gas only has a small impact on the earth's surface compared with the opencast mining of the minerals used by wind turbines and solar farms.

If the UK were to convert overnight to an electric vehicle fleet, the materials requirements for the batteries alone, compared with annual production today are estimated as:[11]

- 207,900 tonnes of cobalt – almost double the annual global production
- 264,600 tonnes of lithium carbonate (LCE) – three quarters of the world's production
- at least 7,200 tonnes of neodymium and dysprosium – nearly the entire world production of neodymium
- 2,362,500 tonnes of copper – more than a sixth of the world's production in 2018.

If the world is to go all-electric in 30 years, we need to convert three UKs per year, and hence we see the need for a very steep rise in the mining of these materials. Unregulated and child labour is implicated in much mining of cobalt, so there are intense research efforts to replace it without losing too much battery efficiency. Biodiversity will be under even great threat from increased mining.

Energy storage

Fossil fuels are much more effective at storing energy than any known non-nuclear alternatives (Table 1).[12]

One example was prompted by a member of Extinction Rebellion, who assured me that the back-up electricity supply for emergency wards in hospitals would be provided by batteries by 2025. The 100-MW, 128-MWh battery installed by Elon Musk

Table 1: Energy density of different fuels

Technology	Energy density (MJ/kg)
Wind turbine	0.00006
Lead-acid battery	0.15
Hydro	0.72
Wood	5.0
Petrol	50
Hydrogen	143
Nuclear fission	88,250,000
Nuclear fusion	645,000,000

Source: MJ Kelly, 'Lessons from technology development for energy and sustainability' *MRS Energy and Sustainability* 2016; 3: 2–13.

near Adelaide in 2018, at a cost of £45 million, would power the emergency wards – 30% of the total – of Addenbrookes Hospital in Cambridge for 24 hours on a single 80–20% discharge. If a storm took out the transmission lines in the East of England for a week, we would need seven such batteries. The back up today is provided by two 1500-kVA diesel generators, which run for as long as there is fuel, and together cost £0.25 million. This means there is a capital cost ratio of 180:1 per day or 1300:1 per week for battery versus diesel. This economic mismatch applies to all other suggested applications of batteries, for example protecting the City of London against blackouts.

There is no short-term likelihood of low-cost large-scale electricity storage. Even hydrogen is very expensive. If one were to generate excess electricity in summer to manufacture hydrogen, which could be used six months later to cover for winter shortages, the container required would be very large. At standard temperature and pressure, the container for Europe would be a cube of side 45 km. The one for Ireland would be a 2-km side cube. Pressurising the hydrogen would of course reduce the volume required, but would waste some of the energy.

The global context of UK actions

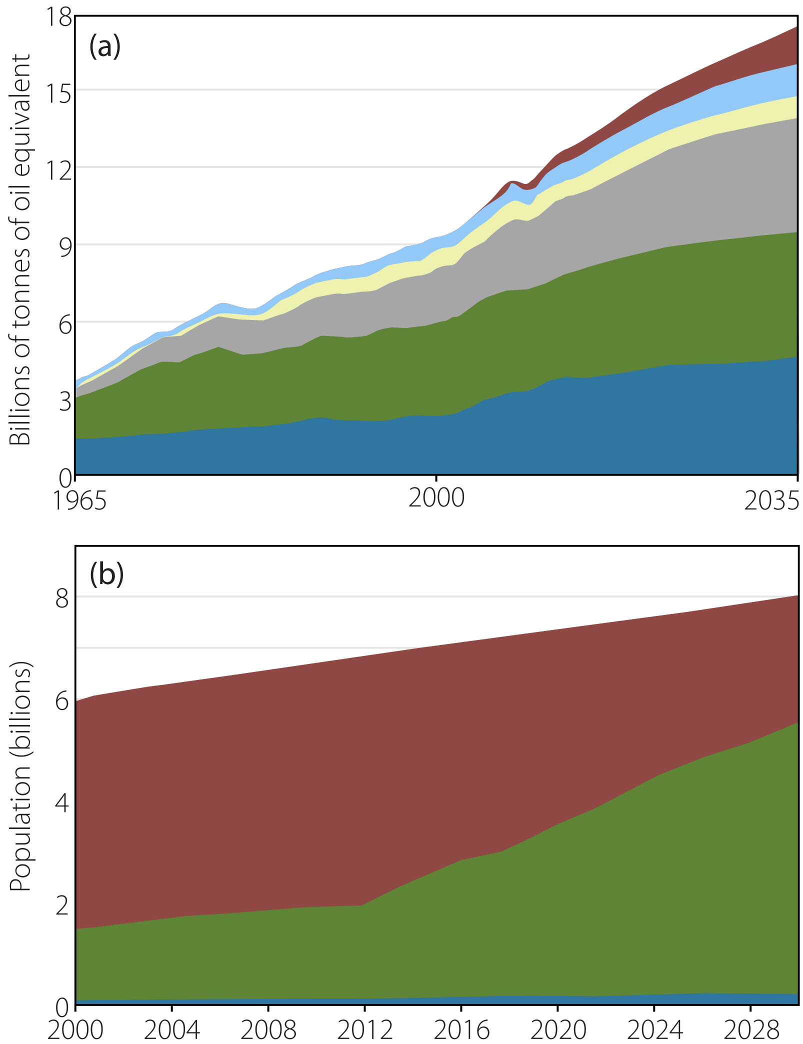
If the 2050 target of a net-zero economy seems a very unlikely proposition, there are several other pieces of data that reinforce this view. Figure 2 shows the principal driver of the growth in energy use and carbon dioxide emissions over the last 40 years and the next 30 years, namely the growth of the middle class in developing countries – most of the increases in emissions in coming decades will be in India, Asia and Africa. Consider a person who leaves an urban slum or rural hovel to dwell in a high-rise apartment in a city with electricity for heating, lighting and communication: if the middle class person uses between three and four times the amount of energy per day as the poor person, the data on energy consumption between 1980 and 2035 (even extrapolated to 2050) can be explained quantitatively.

Figure 2: Energy and wealth

(a) Global energy consumption by fuels 1965–2035 (BP data) and (b) global population by wealth 2000–2030 (World Bank data). Actuals to 2020, and estimates beyond.

- Coal
- Oil
- Gas
- Nuclear
- Hydro
- Renewables

- Poor
- Middle classes
- Rich



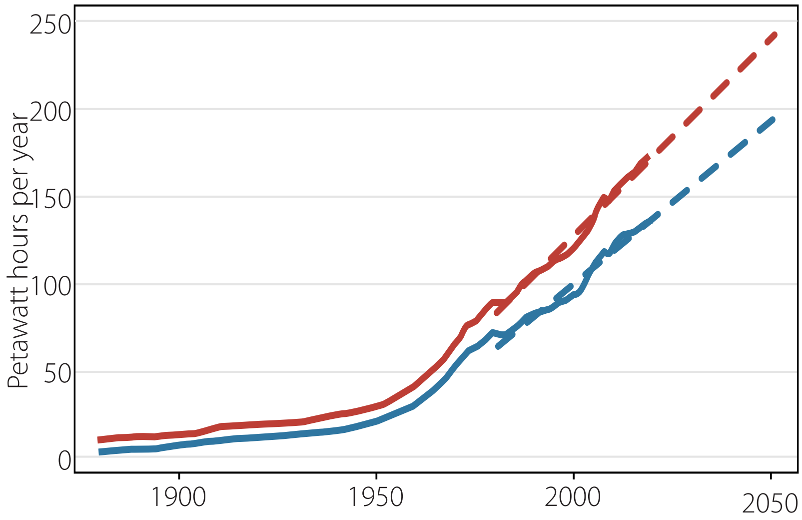
Note, furthermore, that the first and second UN Sustainable Development Goals are the elimination of world hunger and poverty; action on the climate is the thirteenth. On basic humanitarian grounds, there can be no case for moving climate action to first place.

One can see in Figure 3 the dominant role that fossil fuels have had in energising the world economy since the 19th century. All the efforts on renewables have so far contributed only a slight divergence and fall in the fossil fuel fraction since 1980 – this has been of order 85% for a century, but has fallen to nearer 82% now. An extrapolation out to 2050 indicates a 79% contribution in 2050: there is no sign of a rapid divergence and a zeroing of the fossil fuel fraction in the next 30 years. These and many other developments, such as the quadrupling of the SUV global market in the last decade, all show the world moving away from the net-zero target.

I have made no allowances for radical technological breakthroughs in the energy sector, which might relieve the situation on the timescale of decades. Equally, however, incremental developments, such as those seen in battery technology, might be slower than anticipated, as the intrinsic limits of materials properties are approached. Any such delays would worsen the situation.

Figure 3: Energy and fossil fuels

World consumption of energy (in red) and the fossil fuel contribution (in blue) from 1880 to the present date and extrapolated to 2050.



Public acceptance

The fourth project listed at the outset may be the hardest. It is clear from the public debate that the citizenry has no idea of the scale of the task of a transition to a net-zero emissions economy in 30 years. This is not only a matter of the costs, human resources and materials, but also the disturbance to everyday lifestyles as the target is approached. Opinion polls indicate that few are willing, let alone able, to pay more than very modest sums, and certainly nothing like that implied by the figure of well over £100,000 per household set out above. Worse, there will be no measurable difference in the future climate as a result of all the spending and hardship in the UK. To make a difference we would need the rest of the world, and in particular the developing world, to come on board. Poorer nations, such as India and the countries of South Asia, the Middle East and Africa, would need financial help to do so. If we assume that Europe and North America are to underwrite the rest of the world's net-zero activities, then the costs to the UK could rise by a factor of 4.5.[13] The resulting cost of getting to the global target then rises to £450,000 per household, and £13 trillion for the whole UK, which is a fantasy in practical terms.

By all commonly understood value-for-money measures, climate mitigation exercises simply do not add up. For homes, the £100,000 per household would be recouped over 50 years (at today's cost of energy), far longer than any sensible investor would tolerate. Indeed, we would require a command economy during the period to 2050 to secure the finance, skilled workforce, and the materials needed to reach the target. Further, from where we are today, it is not clear how this public acceptance can be achieved on the timescale required.

Funding for adaptation to an actual changing climate is an easier ask. Using the Thames Barrier as an example, extensive flooding in the 1953 storms in the East of England triggered the commissioning of various actuarial calculations.

When should a Thames Barrier be constructed such that over its lifetime the value of flood insurance claims avoided was equal to the cost of the barrier itself? The answer was 'in the 1980s'.

In developed countries with seismic activity, it is easy to set aside and invest multiple billions of pounds to cover future earthquakes, but that is because most people know they could be claimants during their lifetimes. For the slow-burning issue of climate change, however, that is not possible. Instead, the use of appropriate actuarial calculations could allow investment in adaptation to be attracted as and when necessary.

Spend profile and secured finance

Most of the preceding analysis assumes a constant 30-year project. In practice, however, the spend will start from near zero and ramp up. If a 40-year retrofit roll out had started in 2010, we would by now have spent of order 15–20% of the £3 trillion total improving housing and other buildings. In practice we have spent of order 1%. Each year of delay adds more to what must be achieved in the coming decades, requiring even greater flows of finance, human resources and materials. The training of a skilled workforce and building up the supply chain must precede mass roll-out in all sectors. The expansion of the grid must precede the mass uptake of electric heating and transport: having the cars and heat-pumps without the green electricity is the height of folly.

A project on this scale will need bespoke financing at the national level, as it is beyond the scope even of the richest companies in the world today. Even international money markets would struggle if all the world pursued net zero. Completely new economic thinking would be needed, and the Stern Report of 2006 is way out of its depth on this practical point.

A partial list of factors not yet considered

I have given no attention to agriculture, and especially methane emissions, nor forestry, which permits negative emissions while trees are growing. I have not considered aviation or shipping and specific costs there. Aviation fuel will be with us through and beyond 2050, and evolution of electric shipping is very slow beyond commuter ferries in large city harbours. The global economy depends very much on both these forms of transport, and any severe curtailment will be accompanied by falling standards of living of the middle class.

I have not included the extra costs of simultaneously running the two new infrastructure systems required to support fuelling internal combustion engines and recharging electric motor batteries. I have not considered the practical choices associated with where and how the extra electricity generation should occur, nor have I factored in the costs of any forms of electricity storage (which are very high, as seen earlier). These issues will need an early resolution, because many of the desired outcomes depend on the new infrastructure being in place. I have not examined the ever-growing costs of balancing the grid, costs which grow dramatically as more intermittent sources of electricity are used.

A major change in peoples' lifestyles, with reductions in travel, consumption, and food variety could make a dent in the numbers above, but not reduce much the scale of the engineering projects.

A roadmap for Net Zero

The success of the IT revolution over the last 40 years is in no small part due to the existence of the International Technology Road Map for Semiconductors (ITRS). Representative engineers from every part of the sector, and all parts of the world, have gathered every two years to thrash out in great detail what needs to come out of the laboratory into development, and out of development into production, to keep Moore's law of transistor miniaturisation on track, and with it the increase in computing power. Every player in the field knows that the other players are investing and working day-by-day to the same agreed objective.

Note the contrast between ITRS and international climate meetings. Meeting the 2050 net-zero emissions target is much more complex than semiconductor development, and can therefore go wrong in many more ways. Despite this, it is being attempted without any kind of roadmap. The project is therefore more likely than not to veer in the direction of the historical Tower of Babel. No engineer would invest time or money in such a project. Investors should expect better given the scale of the enterprise.

Summary

With extra costs comfortably in excess of £3 trillion, a dedicated and skilled workforce, 70% of that of the NHS, and key strategic materials demanded at many times the supply rates that prevail today, and all for no measurable attributable change in the global climate, the mitigation of climate change via a net-zero emissions UK economy in 2050 is an extremely difficult ask. Without a command economy, the target will certainly not be met.

The practical alternative

Many in the world are convinced that we face a climate catastrophe in the coming decades if this target economy is not delivered. I suggest we are certain to have an economic and societal catastrophe if we persist on the projects to deliver the net-zero economy by 2050. There is a get-out-of-gaol card, and that is the demographic transition, which started 70 years ago. The average family size in the world has halved, from 5 children in 1960 to 2.5 children now, and is continuing to fall. In developed countries, with universal primary education and more people living in cities than the countryside, the figure is below 2, and indigenous populations are in absolute decline, as it takes 2.1 children per family to maintain a population. Stable developing countries, such as Bangladesh and Lesotho, are already down to 2.5. The Chinese population will peak in the 2030s and the world population in the 2060s. A century from now, when we need copper, we will not mine it, but strip it from abandoned cities.

My analysis requires the climate change community to go back, in all humility, and ask themselves really how bad will (as opposed to might) the world's climate become? The proposed solution seems far worse for society than the problem. Half of their analyses of the future climate are based on a CO_2 emissions scenario (RCP8.5) now debunked as excessively high. Their candour at this point would assist those making the case for funding climate adaptation, which will only be carried out when it becomes necessary. In the parlance of the Second World War, 'Is this journey really necessary?'

Personal view

I hope this report gives the bare facts about what is implied by committing to a net-zero emissions economy for 2050. Short of a command economy, it is simply an unattainable pipe dream, and we will struggle to get 10–20% of the way to the target, even with a democratic mandate to proceed. I think that the hard facts should put a stop to urgent mitigation and lead to a focus on adaptation. Mankind has adapted to the climate over recent millennia, and is better equipped than ever to adapt in the coming decades. With respect to sea-level-rise, the Dutch have been showing us the way for centuries. Climate adaptation in the here and now is a much easier sell to the UK citizenry than mitigation.

There is a very strong case to repeal the net-zero emissions legislation, and replace it with a rather longer time horizon. The continued pressure towards a net-zero economy will become a crime of sedition if the public rise up violently to reject it. The silence of the Royal Society, the Royal Academy of Engineering and the professional science and engineering bodies about these engineering realities is a matter of complicity.

Notes

1. https://www.thegwpf.org/content/uploads/2019/11/KellyWeb.pdf.

2. Rajat Gupta, Matt Gregg, Stephen Passmore and Geoffrey Stevens. 'Intent and outcomes from the Retrofit for the Future programme: key lessons', *Building Research & Information*, 43(4); 435–451, 2015. See https://www.tandfonline.com/doi/pdf/10.1080/09613218.2015.1024042.

3. The Race to Net Zero, https://www.snclavalin.com/~/media/Files/S/SNC-Lavalin/download-centre/en/report/the-race-to-net-zero.pdf.

4. https://www.thegwpf.org/content/uploads/2020/07/Travers-Net-Zero-Distribution-Grid-Replacement.pdf.

5. MISO USA: £1.6 million/km for 132kV, £2.0 million/km for 275kV and £3.3 million/km for 400kV line https://nocapx2020.info/wp-content/uploads/2019/07/Transmission-Cost-Estimation-Guide-for-MTEP-2019337433.pdf.

6. Cost of electricity by source (per Wikipedia):

   - gas/oil combined cycle power plant: $1000/kW (2019)
   - combustion turbine: $710/kW (2020)
   - onshore wind: $1600/kW (2019)
   - offshore wind: $6500/kW (2019)
   - solar PV (fixed): $1060/kW (utility), $1800/kW (2019)
   - solar PV (tracking): $1130/kW (utility), $2000/kW (2019)
   - battery storage power: $1380/kW (2020)
   - conventional hydropower: $2752/kW (2020)
   - geothermal: $2800/kW (2019)
   - coal (with SO_2 and NO_x controls): $3500–3800/kW
   - advanced nuclear: $6000/kW (2019)
   - fuel cells: $7200/kW (2019)

7. https://www.thegwpf.org/content/uploads/2020/05/KellyDecarb-1.pdf.

8. Private communication.

9. Wikipedia.

10. Development of 5-MW Offshore Wind Turbine and 2-MW Floating Offshore Wind Turbine Technology (hitachi.com).

11. https://www.nhm.ac.uk/discover/news/2019/june/we-need-more-metals-and-elements-reach-uks-greenhouse-goals.html.

12. https://www.thegwpf.org/content/uploads/2019/11/Kelly-1.pdf.

13. Assuming similar per-capita spending as here.

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.

In addition, for most publications, we invite external reviews from a parties who we would expect be critical. If these critics have substantive comments, we offer to publish these alongside the main paper. In this way, we hope to encourage open debate on the important areas in which we work.

The review process for GWPF papers is therefore somewhat more in depth than a typical review for an academic journal.

- More potential reviewers are involved
- The number of substantive comments typically exceeds journal peer review
- The identity of the author is known to the potential reviewers.

As an organisation that is subject to sometimes very hostile criticism, our review process has to be very careful. All parties involved therefore treat the reviews with the utmost seriousness.

Final responsibility for publication rests with the Chairman of the Trustees, Terence Mordaunt, and the GWPF Director, Dr Benny Peiser. But In every case, the views expressed are those of the author. GWPF has never had any corporate position.

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.

GWPF NOTES

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.