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Future energy needs and engineering reality

未来能源需求与工程实际

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Abstract - **The need to decarbonize the world economy in short order is the persistent claim of those who think that recent climate change is man-made and the future prospects for mankind are alarming in the absence of action to decarbonize. The statements about what must be done are almost always devoid of any assessment of the engineering reality of what is proposed, and make no reference to lessons on technology change from recent history. In this paper I want to recall some of these lessons and add comments that are further to those made in a previous publication on this topic.**

Keywords – **Energy policy, global warming, decarbonization, renewable energy**

I. INTRODUCTION

The Intergovernmental Panel on Climate Change summarises the current physical scientific understanding of the changing climate every seven years, and complements this with studies of possible impacts and actions in mitigation, the fifth and most recent assessment being published earlier this year [1]. The strength of this case in terms of forward projections is not the subject of this paper but rather the consequences of actions that might be taken in mitigation. There is a difference between policy advice and policy advocacy that seems to have been lost in most of the public debate and in many professional circles where policy is framed. Policy advice puts four scenarios before those (elected politicians) that make the decisions, the up-sides and the downsides of both doing something and doing nothing on any given issue. We have many scientists who claim to give advice when they are advocating. If you look at, for example, the latest joint report from the Royal Society of London and the National Academy of Sciences [2], you will not see any sections that deal explicitly with the upsides of doing nothing or the downsides of any proposals to mitigate emissions of carbon dioxide. In the absence of such balance, it is those elements of alarm that are extreme (two or more standard deviations from the norm in statistical parlance) that get the press coverage.

I have encountered a strong 'leave it to the engineers' meme among the climate scientist community – we do the science, they will have to sort out the consequences. If the community was to learn that engineering will not be able to 80% mitigate CO_2 emissions by 2050 without inflicting massive harm on the global economy and mankind in general, it might improve the quality of the public debate. Furthermore, if was also to learn than it is personal behaviour change that would have the maximum impact over the next 20 years, the members might show leadership in making that change, for example by less frequent flying, and less use of the internet and supercomputers.

More generally, popular writers such as Thomas L Friedman [3], with his 'Hot, Flat and Crowded', describe the problems of the world in a neo-Malthusian sense, and then set about suggesting changes to society, which are reasonable but challenging, but in the background lurks the need for a radical break-through discovery of a source of cheap, plentiful, clean, green electrons. When we consider that nuclear fission is the only new breakthrough source of energy in the last 200 years, and we have sought for fusion based energy for 60 years without success, a sober sense of reality about the immediate prospects of a breakthrough is essential here.

At the time of the IPCC publications, I prepared a paper 'Technology Introduction in the Context of Decarbonization: Lessons from Recent History'. I sent it to a number of professional societies and academies, but it was picked up and published [4] by the Global Warming Policy Foundation. The paper was peer and Peer reviewed both before its publication and since. No-one has seriously challenged any of the scientific or engineering arguments I made therein, or the numbers that I quoted. In this paper I will summarise the same points, but only report material that is supplementary to that provided in the original paper. I summarise ten lessons, and make three concrete suggestions about the way forward. In the final section I deal with other issues that are germane to the general arguments. The lessons below are interrelated as one can see from the frequent cross-referencing.

1. Relevant Lessons from Recent History

1.1. New energy technologies improve the lot of mankind

Many premier journals report breathlessly each week of another breakthrough that will cure cancer, or solve the energy problem. However in the transition from science to a technology, and from a technology to a product for which there is a willing market, there are many hurdles of which the originating scientist remains rather ignorant, too often blithely so. The attrition rate is very high, and simple successes in new technologies in the modern day occur when an as yet unmet societal need is suddenly met. That need may or may not have been predicted. The role of liquid crystals in making electronics portable is a case in point: the long term goal of a flat screen television took another 30 years of intensive development after the first liquid crystal display was sold. The mobile phone was foreseen as a convenient way of communicating by voice, but not by text or picture. The smart phone performs the functions of over 20 disparate and bulky items of only 20 years ago! Any new energy technology is going to have to go with the flow of human development. Where the new technology will replace an existing one, as would be the case of a new energy technology for transport, domestic energy or industrial processes, there will be the added challenge of dislodging an incumbent: the new technology will have to be sharply superior to overcome the problem of stranded assets associated with the existing technology.

1.2. The scale of the decarbonisation problem is unprecedented

Over 90% of all the energy provided world-wide for modern civilization as we know it since 1800 has been provided by burning fossil fuels. Nuclear, hydro and geothermal power, together with the historical burning of wood and straw, provide of order 15%. Even today the first generation renewables provide less than 1% of the world's energy. Furthermore since the mid-1980s, the level of fossil fuel energy and low carbon energy have been growing such that in spite of all the efforts, renewables are not making a dent in the share of total energy coming from fossil fuels which remains stubbornly at about 85% [5]. The implication of this is that the current level of activities will get us nowhere near the 80% decarbonisation targets for 2050 being advocated by the IPCC and others.

1.3. Tackle megacities first

Over half the world will live in cities by 2050, and nearly all the schemes for renewable energies being so strongly advocated in the EU and US are inappropriate for mega-cities. Think about Hong Kong, with a population now 7.2M of confined onto an area of just over $1000 km^2$, and a density of 6500 people per sq km. Much of the land not used for buildings is very steep hills, covered in dense shrub and is prioritised as green space. None of the present generation of renewable energy technologies is going to be able to contribute anything significant towards powering Hong Kong in 2050: there is not enough land area or shallow ocean. Only fossil fuels (with or without carbon capture) and nuclear power will be available at the right scale. These have the energy density of fuels needed for city living. It is one thing to conceive of a low density city like Phoenix AZ becoming a solar city, it is quite another for any of the dense megacities around the world.

1.4. Only deploy new energy technologies when they are mature and economic

It is 40 years since the first oil crises in the 1970s provided the impetus that has led to the present generation of wind and solar energy, as examples of renewable energy. Twenty-five years ago, there was an initial roll out of these technologies in the Mohave Desert, and today there are many square kilometres of industrial dereliction of abandoned solar and wind farms that could not generate a revenue to maintain themselves in operation without subsidy [6]. The windmills were small and the solar panels not as good as today. The clear lesson is that they were neither economic nor mature.

Will they ever mature and become economic? If one compares the energy density of the land used to generate energy, one comes up against a stark contrast. The nuclear reactor at Sizewell B occupies an area that is of order $0.1 km^2$ within which a continuous 1.3GW of electricity is generated using nuclear fuel, and energy density exceeding $10 GW/km^2$. A coal fired power plant can generate comparable energy in the same area, but there is a factor of 1-10 million between the energy density of fossil fuels and of nuclear fuels. In stark contrast, the typical biomass, wind and solar energy density is at the level of 1-20MW per square kilometre, a factor of order 10^3-10^4 less [7]. Over one thousand square kilometres or one quarter of the Fen Country in the East of England, presently growing food, would be needed to produce even 1GW of electricity [4]. These are huge factors that will not be impacted by lengthening the blades of windmills, or increasing the efficiency of solar cells by a few percent. Anywhere that land is at a premium, and that is around most large cities in terms of foodstuffs, these technologies will not change the world in 40 years, let alone 400. If the costs of access, construction and maintenance remain high (see next section), the question of economic competitiveness will be a very tough one ever to resolve.

1.5. Salutary lessons from the first round of renewables technologies

A recent quantitative analysis of the solar energy installations in Spain gives a very sober perspective on the energy rate-of-return of solar energy [8]. Because of legislation associated with subsidies, much clean data is available in the public domain for analysis. It is possible to take the intense period of solar installation up to the year 2009 when no solar installation took place in Spain in view of the global financial crash. It is possible to get reliable estimates of all the costs in getting those solar panels installed and maintained over a 25 year lifetime; this includes the infrastructure of roads and cables needed to install the panels and collect the electricity, washing the panels four times a year and six times if they are near dusty road, the costs of surveillance and security, interest on the loans on capital raised, the cost of manufacturing and transport of the panels, the relevant duties payable, and the cost of renting the large tracks of land involved. These total costs can be converted into an equivalent total energy using the ratio of the GDP in Spain to the total energy consumed by the Spanish economy. This gives the energy invested into the sector. When the actual metered energy generated to date is extended over the 25 year design life, the result is the energy out. The ratio of energy out to energy in, called the energy return on investment (EROI), is 2.5. Thus 40% of all the energy to be generated is already used in fossil fuel equivalents to produce the solar energy system in the first place. A parallel exercise shows that at this level, if all Spain's energy were to come from solar energy in future, there would not be enough energy or revenues left over to support a modern society for which it is estimated that an EROI of order 10 is required from the main source of energy in the economy. Note that even if the solar panels were free (they were only 33% of the costs in the Spanish example), the remaining costs are considerable, and they all scale with the large areas of land needed. Furthermore, if one adds in the extra cost of installing batteries to store the electricity between peak generation and peak demand, the energy input goes up by more than the extra energy, and the energy return on investment decreases still further [9]. The reason that these figures are profoundly disappointing is an EROI of over 10 is needed to support a modern society that includes functions such as higher education and the arts [8]. The comparable fossil fuel EROI is about 30, with hydropower at 49 and nuclear power at 75 [10]!

The same analysis can be applied, mutatis mutandis, to wind energy and to cultivated biomass, where the same intrinsic energy diluteness at source is the insurmountable challenge. The conclusion is that a substantial element of fossil fuel energy will be needed in 2050 to maintain a civilized society in Spain or elsewhere.

1.6. Subsidies for premature rollout are a recipe for disaster

One theory of technology introduction is to use subsidies to encourage manufacturers to go down the learning curve and cut the costs of manufacture in the process, so that subsidies can be allowed to wither without undue impact: Friedman [3] describes this in the context of catalytic converters for automobile. In the international energy markets this so far has been a recipe for disaster. The cuts to subsidies caused by the financial crash have caused the bankruptcies of companies across the world working in renewable energies, without any stable conglomerates being formed as had happened in earlier technology introductions, as with the telephone, railroad etc. The scale of the present energy challenge and the total reliance on reliable and affordable energy, let alone sustainable energy, is such that subsidies have been too small and ephemeral. Unlike high-technology interventions where 5-10 years of intervention will see the required take up, infrastructure technology like energy has timescales of order 40 years, and few countries have stable multi-party multi-government support that lasts that long.

1.7. Technology developments are not usually pre-programmable

Writers such as Friedman [3] and others hope for a technology breakthrough that will provide a new clean cheap and sustainable source of electrons for an electrically powered world. If that should emerge over the next decades, it will be a bonus. When 'necessity is the mother of invention' is cited in the present context, it is a mistake. The solutions to earlier necessities were largely brought about by the timely deployment of newly known science. Radical new technologies over the last 200 years have followed on from scientific discovery, typically in a timescale of 40 years for automobile, telephone etc. This time, apart from nuclear fusion, there is simply no new science in any primitive form that is offering access to untold sources of energy. Nuclear fusion has been under investigation for 60 years, and it is not clear that faster progress would have been made if the budget for that research had been doubled. There are lengthy timescales for building the equipment, and global collaboration has gone about as fast as possible. Even if there was a radical breakthrough tomorrow, the level of further engineering and technical development required to provide a stable, reliable and affordable source of electricity is still decades away in terms of contributing (say) 10% of the world's energy needs. It would be irresponsible with nuclear technology to promise anything faster, even if the effort were increased. The current battery technology has struggled to provide energy for portable electronics - battery life is still measured as a few hours between recharge - and there is no question of batteries supporting (say) Hong Kong in any form of load balancing mode.

1.8. Nothing will happen if the population is not trusting

There were a number of millennium development goals devised and adopted by the UN for completion in the period 2000-2015. Some have been achieved, others have not. This is the only basis on which the global population has experience of solving pressing problems facing humanity as a whole. While environmental degradation is one problem, all the progress that has been made has come from advanced economically sound countries cleaning up past mistakes and preventing future ones. The lack of clarity with which long-term climate change will really make major impacts does not seem to generate the public appetite for much larger scale public intervention. When some of the more alarmist views have not come to pass over the 20-30 years since they were first made in terms of vanishing Pacific Islands or millions of climate refugees, the impetus to achieve a global agreement to circumscribe personal behaviour in the cause of reducing CO_2 emissions is simply not there. A recent call for a global regulator 'with teeth' to curb air-travel did not get fulsome or widespread support [11].

1.9. Finance is limited, so actions at scale must be prioritised

I have estimated that one could retrofit all the UK building stock over 40 years at the cost of £1.7T, £40Bpa [4]. This would require an army of workers of order 1M, i.e. comparable with the health service, and a very large increase in the supply chains. Using state of the art technologies of today, but leaving the interventions to be future-proof, the result would be to halve the energy consumption in buildings (both domestic and non-domestic), and reduce the nation's carbon foot print by 23%. The payback time in terms of savings in energy bills is too long to justify raising the money on the capital markets so that some state intervention would be needed. This intervention would compete with the Government's ability to raise funds for supporting a renewal of the current energy infrastructure for which £200B over the next decade is the widely quoted figure. How to factor such enormous sums into national budgets while trying to maintain contemporary commerce, manufacture, agriculture, defence and logistics is a square that has not been circled. What is the appropriate fraction of the national budget to be spent on energy over the coming decades, given it has been about 8% over recent years?

1.10. If the climate imperative weakens, so does the decarbonisation

In the early days of climate change 25 years ago, the scientific community pointed to rising globally averaged surface temperatures as the clearest evidence of a problem. Since the start of the present hiatus in the globally averaged surface temperature, now 17 years old, the rhetoric has used other signals of climate change such as rising sea levels, ocean acidification, extreme weather events, melting polar icecaps etc., as the evidence. Since sea level rise has not been accelerating, and severe weather events not become more common (although the damage is because there are more of us in the way with more possessions at risk), the rhetoric is under challenge by the accumulating real-world data. Last year over 70 peer-reviewed papers came to the conclusion that the sun was playing a greater role in the climate change of the last 50 years, and this year this trend is continuing, with the possibility of a return to a little ice-age by mid-century being predicted [12]. There would be a supreme irony if that were to happen, as every ton of human generated CO_2 in the atmosphere would be called upon to help feed 9B people in 2050 rather than the 1B people during the last little ice age.

The IPCC's most recent (5th) assessment report [1] has pulled back on the severity of some of their more catastrophic projections in the face of clear evidence that their climate models are running systematically hotter than the earth itself. If the temperature hiatus lasts another decade, we will be approaching 30 years without a temperature rise while the level of human-induced CO_2 will have increased by over 50%, then anyone respecting the canons of science as the explanation of nature will demand a going back to the drawing board as far as the current understanding of the atmospheric temperature systems is concerned.

These ten lessons together indicate profound shortcomings in the understanding of the engineering realties associated with decarbonisation, and in many cases the poor return on investment represents an opportunity cost that has inhibited possible human development in other quarters, as outlined in 2.3 below.

II. THREE PRACTICAL PROPOSITIONS:

2.1. Work within business as usual with a focus on the efficient use of energy

Since energy costs money, it has always been an imperative to reduce energy use, and that is likely to continue and especially if fuel continues to become more expensive. In the case of several energy-intensive industries such as metals, ceramics and cement, there are limits to the potential energy savings set by basic thermodynamics.

2.2. Derisk infrastructure projects

Since energy is expensive, and energy infrastructure is supposed to last for decades, we cannot afford to get it wrong. Small scale deployment for trialling new technologies is appropriate, but a hasty roll-out leaves stranded assets there to attract the mockery of passers-by for decades to come [6]. By definition such unused assets have an opportunity cost, and we need much care to avoid mistakes. The imperatives of climate change are not sufficient to overrule this principle. How much of the investment over the last 30 years in greening the economy will be written off? We simply must be much more sophisticated in our approach to decarbonisation than we have been to date.

2.3. Public attitudes and personal behaviour are much the most effective place to work now

Colleagues in Cambridge have estimated that people in the UK could live a civilized life on about half the energy usage per person per day [13], provided the citizens were more overtly energy conscious and came to regard energy profligacy as deeply antisocial. Cars could be much smaller and lighter if we asked for them to be: so far we like the acceleration and safety associated with large and heavy vehicles and the demand for fuel seems remarkably price inelastic. Public attitudes and behaviour have changed in issues like smoking in public confined spaces, drink-driving and wearing seat-belts. In the short term, the energy, cost and other savings from behaviour change dwarf anything made possible by new technology. Even IT is now an energy intensive operation, with each google search using enough energy to boil water for a medium size cup of coffee, at over a trillion searches a year and growing at 10-15% in recent years [14]. Exemplary changes in personal lifestyles should be undertaken by the advocates of decarbonisation as a sign of their commitment.

III. Other Generic Issues

3.1 Demographics

No-one yet factors in the demographic consideration of peak population predicted for the period 2050-70 so that much new infrastructure may be needed for only 100 years at most. Some predictions indicate a population back at 7B by 2100, and we will have unused assets for 2B people on our hands [15]. How is it best to prepare infrastructure with a finite lifetime in mind? There are parts of Eastern Europe where the population has been in absolute decline for 20 years now, and towns are being abandoned and villages razed. Current fertility trends if continued would have the Italian population down to 8M by 2100 and that of Germany down to the present population of Berlin! [16].

3.2 Decarbonization as a Focussed Global Project

Suppose the world were to agree to provide £1T per year for a decade to be spent on mitigating climate change by reducing carbon emission. This is about enough to capture all the CO_2 from existing coal-fired power stations. It is questionable whether it could be done in ten years. What would we notice in terms of future climates? The answer is simply that no one knows. The same £10T would enable the poorest 1B in the world to receive £10K each, and one could expect to see some very tangible change after ten years in terms of the elimination of world poverty on the (admitted large) assumption of global good governance. Mitigation of future climate change is not a sufficient justification for any large scale engineering project in the absence of foreseeable and measureable outcomes. The insurance premium argument does not work – the risk remains uninsured.

3.3 A Day of Reckoning

In the absence of a temperature rise in the next few years, there should be a day of reckoning about the way that the current stress on climate mitigation came to the fore in the public debate - even more so if the sun heralds a little ice age, where the global temperature cools and the world struggles to feed 9B in 30-40 years. We will ask how it was possible that we prepared for the wrong 'catastrophe'. Work to reduce resource use and waste is an intrinsically good thing, but the large-scale mis-investment in averting something that only ever might have happened, should not go unreviewed and without sanctions. At the very least, the key scientists will have to be ever more circumspect in their pronouncements, and that would be a welcome return to the canons of normal as opposed to post-normal science that prevailed until recently, and still prevails in engineering disciplines, where individual engineers can be held legally liable for the consequences of their actions and professional judgements. The same discipline should apply to those who advocate spending public money on major projects. The lack of continued incisive debate, closed off by expressions such as 'the science is settled' has done untold damage to the reputation of sciences which, as a class, will be vilified as rent seekers. The first debate on this whole subject at the Royal Society in London was held only two months ago [17] under the title 'What is the right level of response to anthropogenic induced climate change?'

3.4 Adaptation

Professor John Holdren the US Presidential Scientific Advisor is quoted [18] as saying: "What this means," he said, "is that we have to figure out how to meet transport needs with less oil and economic aspirations with less carbon dioxide. There are only three options: Mitigate, adapt, suffer." The Dutch down the centuries have been exemplary as they have coped with rising sea levels: they have adapted as and when necessary. Again, the Thames barrier has saved London from flooding and the height of the barrier will be increased in 20 years in good time to cover the medium term future. Here the problem is not global warming but that the East of England as a whole is sinking. These are the entirely positive and practical solutions that apply to most of the problems that have been adduced as the result of our use of fossil fuels to energize modern civilization. Moreover, adaptation is a trait of humanity down the ages, with the few exceptions proving the rule.

IV. Conclusion

The major actions currently taken in the name of decarbonizing the world economy are ineffective and unlikely ever to succeed. We need a debate that is altogether more sophisticated, open and humble, and policies that might succeed rather than being guaranteed to fail. I end with a classic example: two of the three aluminium smelters in the UK have closed because of higher energy prices, and the UK imports aluminium from coal-fired smelters in China, with a net addition to the global CO_2 emissions – total madness!

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[2] https://royalsociety.org/~/media/Royal_Society_Content/policy/projects/climate-evidence-causes/climate-change-evidence-causes.pdf

This paper purports to be purely a scientific description in the form of answers to 18 questions. Taking one in

particular, we note the last sentence as a totally inadequate counterbalance!

17: Are climate changes of a few degrees a cause for concern?

Yes. Even though an increase of a few degrees in global average temperature does not sound like much, global average temperature during the last ice age was only about 4 to 5 °C (7 to 9 °F) colder than now. Global warming of just a few degrees will be associated with widespread changes in regional and local temperature and precipitation as well as with increases in some types of extreme weather events. These and other changes (such as sea level rise and storm surge) will have serious impacts on human societies and the natural world.

Both theory and direct observations have confirmed that global warming is associated with greater warming over land than oceans, moistening of the atmosphere, shifts in regional precipitation patterns and increases in extreme weather events, ocean acidification, melting glaciers, and rising sea levels (which increases the risk of coastal inundation and storm surge). Already, record high temperatures are on average significantly outpacing record low temperatures, wet areas are becoming wetter as dry areas are becoming drier, heavy rainstorms have become heavier, and snow packs (an important source of freshwater for many regions) are decreasing.

These impacts are expected to increase with greater warming and will threaten food production, freshwater supplies, coastal infrastructure, and especially the welfare of the huge population currently living in low-lying areas. Even though certain regions may realise some local benefit from the warming, the long-term consequences overall will be disruptive.

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