Energy and Sustainability: Policy, Politics and Practice

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Abstract. There is no universally accepted definition of what 'Sustainable Energy' means but in general the concept is to achieve a supply of energy that is sustainable over long periods of time with manageable or no negative environmental impacts. Unfortunately, many of these phrases are vague and open to interpretation. For example, when referring to long periods of time, do we mean decades, centuries or even longer? To be sustainable does an energy source have to be renewable and renewable forever? If the latter then no such source exists even the sun has consumed 50% of its hydrogen fuel. So, presumably what constitutes renewable energy depends upon the time frame over which the energy is to be used and the rate of use? What do we mean by manageable environmental impacts? Does this mean we are prepared to accept some negative impacts—whatever 'negative' means?

National concerns about energy have, until recently, been associated with the supply, security and cost of energy. Only as the global human population has dramatically increased, especially since the 1950s, have the environmental impacts of energy use become dominant concerns. The energy sources which have come under the most intense scrutiny are fossil fuels which account for almost 89% of global energy consumption and whose use contributes to, measurable increases in atmospheric carbon dioxide emissions, which are causing the retention of too much solar energy resulting in detrimental 'global warming', increases in the number of disruptive weather occurrences and rises in sea levels. Together these effects could result in over half the earth's population having to move away from coastal regions, whilst longer growing periods in other global regions would result in enhanced agricultural food production. Can all these effects be negated by a relatively immediate cessation of fossil fuel usage? How quickly could 89% of global energy consumption be eliminated or replaced and in a sustainable and affordable manner?

At least for the next few million years, solar and wind energy will provide obvious sources of renewable and sustainable energy. However, in terms of the electrical power generation, these sources are ill-suited for baseload generation, unless large-scale affordable energy storage systems can be developed. In the meantime, hydroelectric, nuclear and especially fossil fuel power generation will still be needed. Realistically, the latter is a finite energy source and for example, since the 1970s, forecasts have been made envisaging that oil reserves will be totally exhausted within a period of 10 to 20 years from the time of the particular predictions. Nevertheless, fossil fuels usage has not gone away—will they ever?

In this presentation, the historic and modern pathways of energy use are discussed along with the accompanying environmental concerns and 'no-harm'

A. Vasel and D. S.-K. Ting (Eds.): EAS 2018, SPE, pp. 1–17, 2019.
https://doi.org/10.1007/978-3-030-00105-6_1

energy sustainability which have become more focused especially in the last half-century. However, in the face of polarized political, economic and societal opinions, will it be possible to achieve an agreed global plan for universal sustainable energy implementation in the near future? Can science and technology alone provide successful solutions to our energy and environmental dilemmas?

1 Introduction

According to sustainable energy values or beliefs, the Earth needs an energy source or sources to support the needs of the human population now and forever in the future, and whose use and acquisition causes no harm to the environment whilst concomitantly not diminishing the source or sources for future generations. How can this scenario be achieved? In the first instance, it would be useful to know what energy sources are used by the global human population now and in the past since if these energy sources do not meet the criteria as outlined then they will need to be replaced. If the replacements are more expensive than current sources, then it seems unlikely that our species will readily adopt them without a governance policy lawfully instituted by a democratically elected government or by edict from an absolute ruler. The former may prove more difficult than the latter especially when there is a strong culture of bipartisanship and the omnipresent requirements of the 'loyal opposition' to opposite, futilely, just about every government decision or proposal. Moreover, if the proposal disaffects too many voters a government may decide, they wish to remain in power, not to pursue the original proposal to its fullest extent and vice versa, i.e. a 'lobbied' proposal may gain traction for the same reason.

A 'lobbied' proposal may be the result of vested interests of varying complexions ranging from profit-based motives, to political and philosophical ideologies, to increasing individual and group government research grants. In recent years, we have been strongly encouraged to believe or at least trust 'the science', exactly what science we should be trusting remains problematic. Nevertheless, accurate measurements of global atmospheric average temperatures have indicated that they have increased in 16 of the last 17 years and if the rate of increase continues to increase without some actions being taken, the consequences could be dire not only for humanity but all living things. Even so predicting the future is usually precarious, for example, just before the events occurred leading scientists and philosophers predicted that flight by machines was 'unpractical … if not utterly impossible' and that scientific lecturers 'demonstrated to satisfied audiences that a ship could not cross the Atlantic by the power of steam' [1, 2]. We also have to contend with the 'Turnbulls' encountered in Trollope's *Phineas Finn,* 'Mr. Turnbull had predicted evil consequences …and was doing the best in his power to bring about the verification of his own prophecies' [3]. If then sustainable energy is to be taken seriously and capture the attention of all, we need to ensure that the actual issues regarding energy—the needs and uses, the associated environmental and societal impacts of non-sustainable and non-renewable energy usage and how continued human population growth affects global energy and the environment—are well and understood and appreciated. As David Suzuki stated four decades ago, 'If we are to have any hope of controlling the elements that will transform our lives, an understanding of science is imperative' [4]. Perhaps, one of the first actions is to agree exactly what we are talking about since we have gone through mantras starting in the 1950s with Hubbert's peak oil theory followed by oil crises in the 1970s with lead to claims of rapid oil reserves depletion [5], followed by global cooling, then global warming and then climate change and weather disruptions. The latter is often confused in the media where climate change is used as the reason for a weather event, especially an extreme weather event. Whereas climate is concerned with very long-term averages, weather is about what is happening now and in both cases geographical location appears to be a crucial factor [6]. Similarly, the Climatologists (Climate Changes) and Meteorologists (Weather Forecasting) need to use 'models' to predict future climate and weather, although the term 'model' is rarely used in the popular and non-technical media, perhaps to avoid the dreaded populist showstopper of 'theory' entering the discussions! Maybe we should have adopted the ancient Greek term, 'Paradigm' and 'Paradigm shift', as promoted in the seminal book 1960s book by physicist Kuhn [7], when discussing energy and the environment in the same way as the terms have become commonplace when discussing business, social movements, education, science and so on?

There are three dominant fossil fuels, coal, natural gas and oil, and each provides roughly equal amounts of the global energy consumption, Fig. 1. So why the apparent focus on oil and diminishing global oil reserves and the media's minute by minute tracking of spot oil prices and not coal and only rarely natural gas?

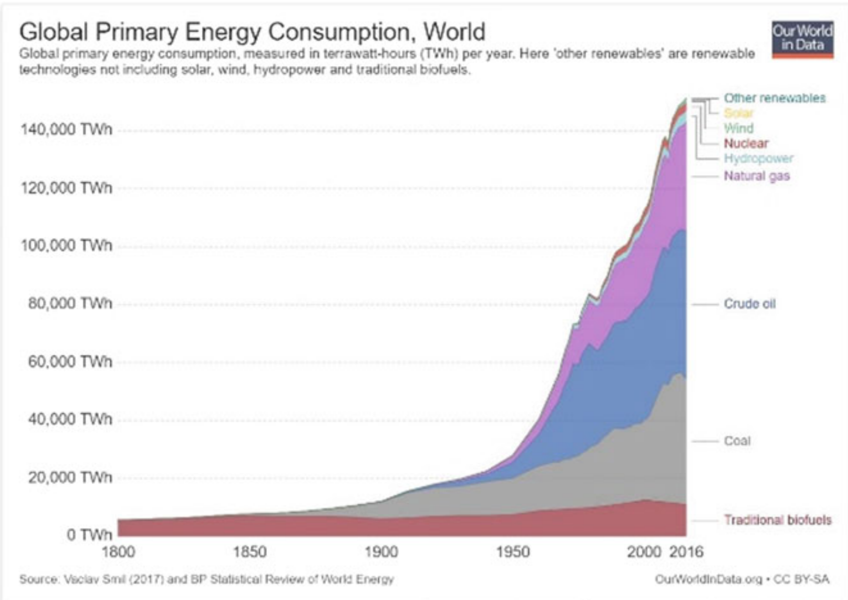

Fig. 1. Global primary energy consumption 1800–2016, OurWorldData.org.

The most probable reason is that oil is the fuel of choice for all forms of powered transportation—land, sea and air. Personal transportation is very important to almost all humans especially in developed countries. In a 2015 survey [8], automobile vehicle ownership was over 80% in South Korea (83%), Japan (81%), America (88%) and topping the list Italy (89%). China has become the world's largest new car market with ownership of cars and motorcycles increasing twentyfold in the first decade of this millennium. It has been estimated that global ownership of personal on-road vehicles is over 1 billion with some 250 million registered in the USA alone [8]. The global focus on oil is then perhaps not surprising. What is surprising is the general misunderstanding of what is meant by oil reserves as typified by Jimmy Carter's Presidential pronouncement in 1977 that, 'If it were possible to keep it {*global oil consumption*} rising …… as it has in the past, we could use all the proven reserves of oil in the entire world by the end of the next decade' [5]. As we shall see later in this paper, 'proven reserves' is an economic definition, which is also influenced by technology, and can be applied to all natural resources not just oil. The amounts of a particular natural resource and the proven reserves of that resource are quite different. The longevity of possible fossil fuel usage could then be significantly greater than usually forecast. Most certainly, fossil fuel is arguably a finite natural resource and therefore not in harmony with the designation of a sustainable energy source. So why the rush to replace fossil fuels especially in personal vehicle powertrains? It is apparent that the main thrust is the concern of the environmental impacts of oil-fuelled vehicles which produce unacceptable levels of greenhouse gases, criteria pollutants and carbon dioxide which in turn significantly contribute to anthropogenic effects on climate change [9] which the majority of climate scientists consider to be adverse and damaging to the 'health' of our planet [10].

So it appears that most policymakers, to conciliate the predictions of the climatologists, must promptly if not abruptly institute a 'paradigm shift' away from using almost 90% of the current type of energy source usage and convince at least 1 billion owners to replace their vehicles or at least the powertrains. While it is unlikely that the timeframe will be to the predilection of the scientists and environmental activists, if policymakers are to be successful, then the development of sustainable and affordable energy sources to replace fossil fuel sources is paramount. But is sustainability as crucial to the public as affordable non-carbon alternatives? The most obvious sustainable energy source is solar power as it has been calculated that the sun will not physically destroy the earth for about 7.5 billion years but its heat will render the earth uninhabitable for humans in about a billion years (not forever a renewable and sustainable energy source but close). However, for a fifth of the global population, 1.5 billion, i.e. those living in South Asia, some researchers have predicted that unless 'serious' mitigation of climate change occurs there is a unique risk of the region becoming essentially non-survivable for humans by the end of this century [12]. However, if serious mitigation means stopping using fossil fuels, immediately the literature indicates that 'global warming' will continue for at least several decades and although global average temperatures will eventually stabilize, the level will be higher than in the past [13]. As solar power is still more expensive—mainly because of the initial infrastructure costs—it will be difficult to persuade users to accept revolutionary changes which for most will have no obvious effect in their lifetimes.

Wind energy is also a candidate as a sustainable and renewable energy source as it is largely dependent on the effects of solar radiation. However, like solar power, it is still too expensive in comparison with its fossil fuel competitors and not all are convinced that it is a no-harm environmental technology. Nevertheless, the US Energy Information Administration (EIA) has indicated that wind power is expected to exceed hydropower in terms of electrical generation by 2020 [14], Fig. 2. Solar and wind energy sources are realistic as sustainable replacements for fossil fuel sources but if wholly implemented would require all modes of transportation to be electric. This would be easier to accomplish for land transportation but an increasing challenge for marine transportation—which carries at least 80% of the world's trade [15]—and air travel. Approximately, 30% of seaborne trade is the transportation of oil and gas so with the paradigm shift this would be no longer needed but that would leave over 7 billion tonnes of cargo to be transported [15]. At the moment, marine transportation accounts for 3–4% of global carbon dioxide emissions. Is it realistic to expect all shipping to be electric and/or wind powered immediately or at least in the next decade? Whatever edicts are made by national and international agencies, and they must be unanimous to have the desired impact, will such a very minor reduction of carbon dioxide ameliorate climate change? Of course, eventually, marine transportation will have to seek alternative non-carbon energy sources but until electrochemical batteries can be developed that can power a 100,000 tonne or more ship and its auxiliaries (e.g. refrigerators) for an average sea journey of 10–15 days, it seems unlikely that fossil-fuelled shipping will be replaced any time soon.

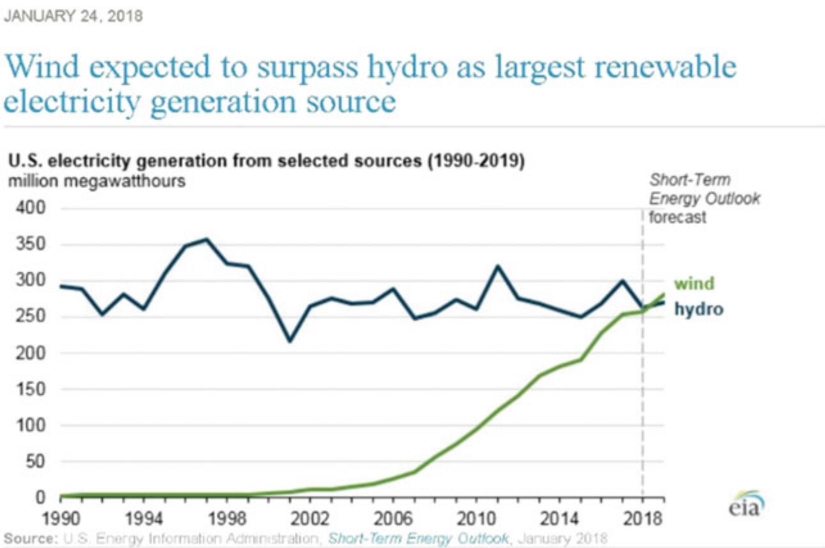

Fig. 2. Wind versus hydropower in US electricity generation, USEIA January 2018.

2 The Rise and Fall (?) of Fossil Fuel Usage

Fossil fuel usage—coal—is usually associated with the British Industrial Revolution of the eighteenth century onwards. The 'success' of this revolution was founded on access to cheap coal and high labour wages. It appears that all the current and future problems regarding global climate change are the result of this and similar industrial revolutions and that they are no positives to attach to these occurrences. The increases in national and individual wealth, improvements in quality of life, education and medicine, human population growth and life expectancy, Fig. 3, are no excuse, it seems, for causing Climate Change especially for future generations.

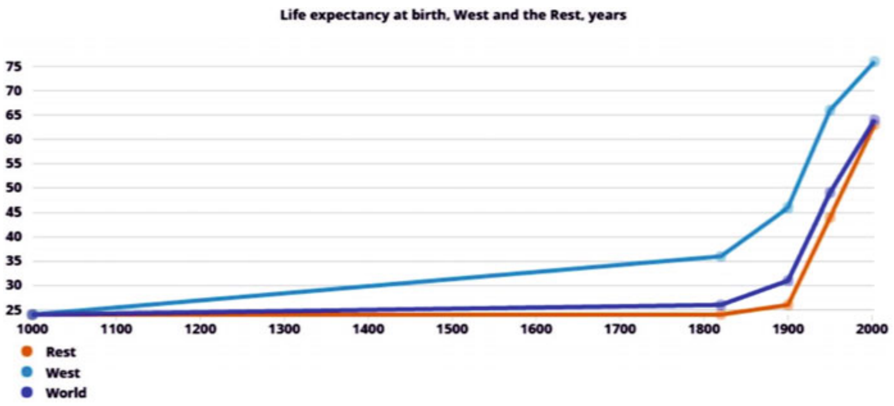

Fig. 3. Life expectancy at birth 1000–2000 CE, [16].

An argument could be made that many of those making the negative observations about fossil fuels usage would probably never have been born or maybe they would have been dead by the age of 27 to 35, and most likely in their lifetimes they would not have enjoyed access to post-secondary education or indeed any form of education, if such fuels had not been exploited. While there is some substance to these views, nevertheless the potential economic and social costs of climate change could be colossal from the twenty-second century onwards. Regardless of the cause and effects, returning to human muscle power (as often as not as a slave), animal muscle power, water power and wood power may appeal to some, it is unlikely that it would be universally endorsed.

As the modern industrial revolution started in Britain maybe some insight into why they chose—evidently disastrously—to burn 'sea' coal rather than wood [17]. We can trace this choice back to some localized locations in Roman Britain but especially in the thirteenth and early fourteenth centuries coal use became increasingly common [17–19]. At that time, the population in Britain was twice as high as it would be at the start of the industrial revolution. To feed this, growing population required more land for agriculture—also blamed by some for causing climate change—and as forestry management was rudimentary in many northern areas of England, to say the least, wood for heating and cooking became scarce and increasingly expensive. The 'better off' landowners could afford to pay the higher prices—but the majority of the population—could not. Indeed, the rich largely abhorred the burning of 'toxic' coal because of the smoke and smell and has early as 1257 Queen Eleanor was forced to leave Nottingham Castle probably because of 'air pollution' according to Te Brake [17]. Eventually, because of the ready availability of sea coal and its lower cost, the wealthy allowed the medieval lime kiln operators and blacksmiths to use it along with their 'serfs'—the poor Villeins—for domestic heating and cooking. The latter use helped reduce the increasing mortality rate among the serfs. Why *sea* coal? Although the general consensus among historians was that coal was referred to as sea coal because it was transported by sea from the Northern UK coasts to places like London, there is evidence to suggest that the origins of the title came about because coal was found near or just under the sea [17].

However, in 1273, the use of coal was prohibited in London 'as it was prejudicial to health' but by 1306 a Royal proclamation only prohibited certain types of coal. The legislation was to address the complaints about air quality [20]. Nevertheless, in most rural areas and at times in the cities, coal burning increased. So why by the mid-to-late fourteenth century did coal use largely disappear until the seventeenth century? The answer is the bubonic plague—the Black Death—which swept across Europe and Britain in successive waves causing the demise of upwards of a half the population with one of the ramifications being that there were no longer any wood shortages [21]. Only by the start of the eighteenth century did the population reach the levels of the early fourteenth century and by then wood was also needed for shipbuilding as Britain was fast become a global sea power [22]. The technology of steam power was also rapidly advancing and perhaps ironically was put to use to drain quarries and mines to enable deeper coal seams to be worked. Eventually, the start of the modern manufacturing factory and the advent of steam-driven rail transportation consolidated coal as the energy source of choice for all.

Industrialization also led to increased urbanization, a typical example being the British state capital London. At the start of the nineteenth century, the city had a population of 1 million which doubled by mid-century and reached 6.5 million by the end of the century, 20% of the country's total population being squeezed into a relatively small space. It was an unhealthy place to live especially for the poor- and low-income earners because of polluted water and air, the 'better off' moved to the suburbs. The relationship between pollution and disease, essentially 'germ theory', was not believed until the end of the century approached. Clean water became a priority and a network of public parks was established to improve air quality but one of the biggest 'killers' was lung disease [23]. Throughout the nineteenth century, many British cities experienced 'Smog'—pea soupers—and although the number of incidents declined in the twentieth century, the laws were rarely enforced and the general consensus was that the smoke from coal burning was not a big issue. Then, in December 1952, after a period of cold weather, an anticyclone settled over London which caused the wind to drop and the air to become damp, forming a thick fog. This turned into smog as sooty particles became trapped. The anticyclone and smog lasted for 5 days—causing an estimated 4,000 to 6,000 deaths and as many as 100,000 cases of respiratory illness were reported. This lead to the UK's Clean Air Act in 1956 and the Tall Chimney legislation in 1968, requiring the establishment of 'smokeless' zones, the production of cleaner (reduced Sulphur content) coal and clean coal technologies such as smokeless coal fuels and higher chimneys.

Almost seven centuries after, coal usage legislation was first introduced Government started to take the air pollution issues seriously and enforce and implement the laws. This was not as difficult as might be imagined since both the coal and electrical generation industries were nationalized, i.e. 'Government' owned. Today, other than a few opencast sites, there is no coal mining industry in the UK and electrical generation has been privatized. However, starting in the mid-nineteenth century, a new 'alternative' fuel which at the time was somewhat expensive came to market—petroleum (oil). With the advent of the use of the Internal Combustion engine for vehicular propulsion in the early twentieth century and cheaper oil products, gasoline, petrol and diesel alternatives to coal were now readily available albeit they were also fossil fuels. In the same way, as cheap coal had driven Britain's economy to the premier league of global economies, oil would do the same for the USA. Gradually, oil became the energy source of choice for many applications, for example, the decision made by the Royal Navy to convert from coal to oil—lead by the future Prime Minister Winston S Churchill—lead to other navies doing the same although most had no known national oil resources. In due course, oil exports would be used by the USA for geopolitical purposes as part of economic sanctions against the Japanese after their armed invasion of the Chinese mainland in 1937. The Asia-Pacific war broke out 4 years later culminating in the use of thermonuclear weapons.

Like coal, the use of oil and natural gas has a far longer history than many imagine. The Mesopotamians used oil sources, and the famous Greeks, Aristotle and Herodotus wrote about such deposits almost three millennia ago and in more recent times a seventeenth-century French missionary wrote about Seneca First Nation using oil burning in their religious ceremonies [24]. In almost every case up to the eighteenth and nineteenth centuries, oil and natural gas were used solely for lighting purposes and very occasionally as lubricants for axels of horse-drawn vehicles. However, chemists were able to separate paraffin (kerosene) and by the mid-century chemical refining—especially in the USA—was enabling petroleum fuel products to be produced which could be used in dynamic heat converters.

The USA and, to a lesser but not insignificant extent, Venezuela became the main oil exporting countries with 75% of the world's coming from the US well into the twentieth century but by the 1980s Saudi Arabia was producing more oil than the US and by 2015 Russia was producing more oil than Saudi Arabia, Fig. 4 [25]. Today, around 100 different countries have oil production of some sort. The use of a type of third fossil fuel—natural gas—rapidly escalated following the invention of the 'Bunsen Burner' which enabled its use for many applications other than lighting, although the Chinese had used natural gas 2,500 years ago in their desalination plants. Initially, in the first flush of the industrial revolution, natural gas was manufactured from coal on a commercial basis in 1785 by Britain to be used for residential and street lighting. Four decades later, industrial extraction of natural gas—usually found in the vicinity of other fossil fuels such as oil and coal—began in the USA. Today, like oil extraction, natural gas production involves many countries with North America, Europe and Eurasia still the major sources, Fig. 5 [26].

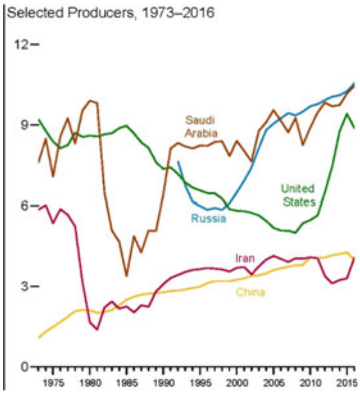

Fig. 4. Major oil producers [25]

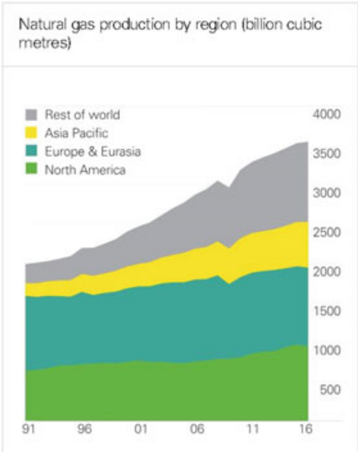

Fig. 5. Natural gas production (1991–2016) [26].

So it would appear that the production of fossil fuels, in particular, liquid oil and natural gas, is increasing not decreasing. Does this mean, for example, that the global ‘proven’ reserves of these fuels will soon be depleted? The epithet, ‘proven’, is often dropped in discussions about fossil fuels especially in the popular media. Maybe this is intentional or maybe the concept of ‘proven’ in relation to fossil fuels is misunderstood. The use of the term ‘reserves’ can give the impression that their stated amounts provide a complete picture, a total, of all there is left. This is not the case. Proven reserved are defined as, ‘fossil fuels that are technically and economically recoverable at current prices’ [27]. If for example oil prices increase, then it could be reported that proven reserves have increased, whereas lower prices could result in decreases in estimated reserves. The oil is still in the ground but may or may not be included in the amounts of proven reserves because of economically rather than geological reasons. Thus, until relatively recently, Canadian oil sands and oil and gas from shale deposits were not included in the proven reserve calculations. The situation is further complicated by the fact that 'shale oil' and 'oil shale' are different entities and while shale oil—which refers to trapped hydrocarbons and accessed by 'fracking'—is starting to be included in proven reserves calculations, and oil shale is obtained from rocks containing kerogen—a precursor to oil. The technologies for producing oil from mined rock are still too expensive although oil shale rocks are plausibly an enormous source of oil and gas [28]. Over 90% of shale oil and gas resources exist outside the USA, and shale gas represents a third of the total global gas resources.

Economics aside, geologists also calculate 'resources', i.e. known fossil fuel deposits that exist but whose extraction is not economical at current prices. These resources also include methane hydrate—a mixture of natural gas and water usually found beneath sea floors. The difference between the amounts of 'resources' and 'proven reserves' is a factor of 2.8 to 4 for oil, 4 to 58 for natural gas and 14 to 23.5 for coal [29]. If the resources become proven reserves, then at the current rate of usage, coal could last for over 2,000 years, gas for over a 1,000 years and oil into at least the twenty-first century. While these are unlikely scenarios, it has to be remembered that new deposits and sources of fossil fuels are being found on a regular basis which partly explains why, for example, the calculated timeframe for the complete depletion of oil has not changed since the 1970s despite increased consumption. The ratio of consumption to proven reserves has remained sensibly constant as depicted in Fig. 6.

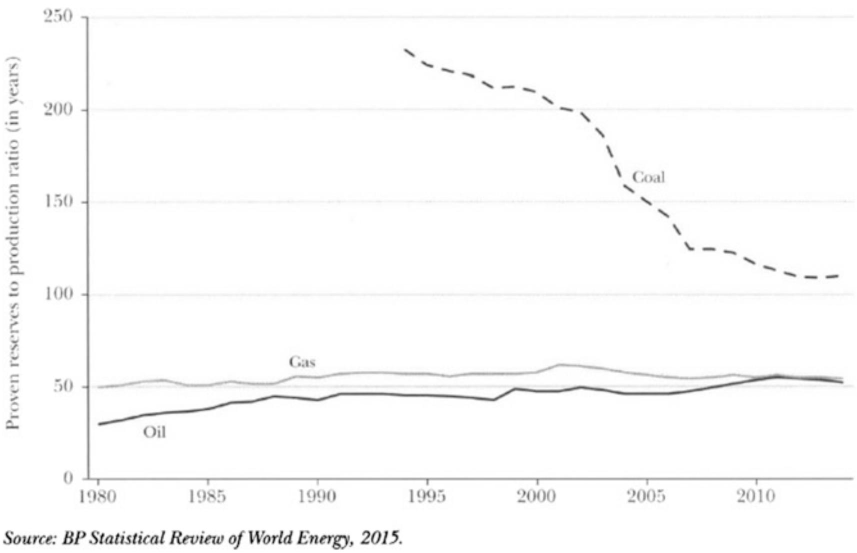

Fig. 6. Ratio of proven reserves to consumption [5].

Even if all the fossil fuel resources became 'proven' reserves, their longevity of up to a millennium or two would not qualify as defined 'sustainable energy'. Nevertheless, the diminishing reserves and resources arguments, once the facts are objectively delineated, may not be as convincing—at least to the public and future government administrations in a number of countries—including the top three oil producers. Consequently, if there is to be a paradigm shift away from fossil fuel usage, then the potential costs of the non-mitigation of anthropogenic climate change will be enormous and outweigh any of the benefits accrued in the past, the present and the future of using fossil fuels. The lack of longevity contentions is unlikely to be as persuasive as clearly validated cost and health issues. The health hazards associated with polluted water and air eventually gained general attention but even then it required enforced government action to address the problems, which in many parts of the world still exist. Prior to the greenhouse gas/climate change issues becoming recognized significant issues, Governments in North America, for example, had defined 'Criteria Pollutants' (USA) and 'Air Contaminants' (Canada). The two national lists are not identical and the same is true for the 'lists' of another nations; however, they were and are a number of commonalities on all lists, especially with regard to fossil fuel emissions from electrical generation and transportation, as shown in the next section, Table 1.

Table 1. Greenhouse gases, US pollutants and Canadian contaminants as specified by national regulations.

Greenhouse gases	US-EPA criteria pollutants	Canadian air contaminants
Water Vapour (H_2O)		
Carbon Dioxide	Carbon Monoxide	Carbon Monoxide
	Particulate Pollution	Particulate Matter (PM)
Nitrous Oxide (N_2O)	Nitrogen Dioxide	Nitrogen Oxides
Ozone (O_3)	Ozone	Ground Level Ozone
	Sulphur Dioxide	Sulphur Oxides
	Lead (Pb)	Ammonia
		Volatile Organic Compounds (VOC)
Methane		
Chlorofluorocarbons and Hydrofluorocarbons		

3 Pollutants, Contaminants and Responses

The actual agreed harmful and greenhouse gases emissions are given in Table 1. Sustainable energy sources must, by definition, produce no such emissions or at the very least only produce them in manageable quantities, presumably to negate any future adverse effects on anthropogenic climate change and eventually reverse the impacts of fossil fuel usage.

It has to be noted that carbon dioxide is not on the pollutants and contaminants lists. Indeed, when the various clean air acts came into force in the last quarter of the twentieth century, the main concerns were PM emissions from coal-fired power stations and diesel engines and nitrogen oxides—often collectively referred to as NOx—from a range of devices using fossil fuels and in particular gasoline-powered vehicles. Despite the British efforts, ‘smog’ was still a problem especially in large cities and urban areas in general. Thus, in North America, regulations were imposed whereby there would be only an allowable amount of tailpipe emissions of NOx. The Automotive engine manufacturers responded quickly by introducing exhaust gas recirculation (EGR) with the aim of lower in-cylinder temperatures to levels which chemically precluded the formation of NOx. This was partially successful but came at the cost of reducing fuel efficiency (e.g. miles per gallon, litres per 100 km and so on). The US Congress responded by enacting the requirement for the Corporate Average Fuel Economy (CAFE) to be enforced by 1978 onwards for cars and light trucks. The purpose of CAFE was to reduce energy consumption in view of the almost imminent demise of oil reserves and to ensure energy security for the USA which was starting to consume more oil than it was producing. The overall strategy was to aggressively increase the CAFE requirements by legislation.

The vagaries of chemical reactions and chemical thermodynamics (especially dissociation) meant that fuel economy could not be increased at the same time as NOx was to be reduced and that carbon monoxide and unburned fuel would always be produced regardless of engine design. This lead to the understanding that tailpipe emissions would need to be different from actual engine emissions so began the age of ‘after-treatment’. Until this time, the tailpipe (or exhaust) pipe which carried away the engine out gaseous emissions would only involve a muffler or silencer to reduce the noise. The solution was to pass the engine out emissions through a catalytic converter containing chemicals which would react with the unburned hydrocarbons and carbon monoxide (two-way converter) and transform these unwanted emissions to carbon dioxide (then considered harmless) and water vapour. Eventually, three-way catalytic converters were developed to also deal additionally with NOx and in more recent years four-way converters have become available which also remove particulates from gasoline-powered vehicles [30]. This has become necessary as gasoline engines now use fuel injection rather than carburetted pre-mixed fuel–air mixtures. Such fuel delivery systems long used in diesel-powered engines inevitably produce particulate matter [31]. The success of the technologies to reduce harmful emissions is illustrated in Fig. 7 [32].

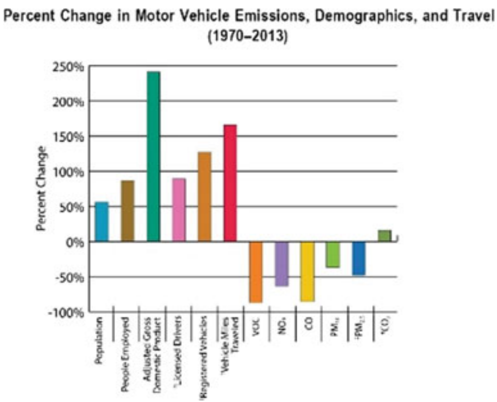

Fig. 7. % change if emissions, demographics and travel in the USA 1970–2013 [32].

Overall, the contributions of fossil-fuelled transportation to the global level of pollutants and contaminants is minimal especially for VOC, PM and NOx, whereas agricultural activities and fossil-fuelled electrical power generation and industrial processes are major polluters.

The systems developed to reduce the pollutants and contaminants from fossil-fuelled engines have achieved this by converting harmful emissions to water vapour, nitrogen and carbon dioxide. However, with the latter being identified as the major culprit in global warming and climate change the very success of the tremendous engineering feats achieved in the development of after-treatment systems—including the more recent use of Selective Catalytic Reduction (SCR) to further reduce NOx—is becoming their Achilles' heel. Solutions to this problem could include carbon dioxide sequestration but the practicalities of achieving this in personal transportation vehicles are probably insurmountable although sequestration in other fossil fuel applications has proved possible. But what to do with the sequestered carbon dioxide? One of the more intriguing ideas is to use solar power to convert the carbon oxide and emitted water vapour into gaseous fuels such as methane or synthetic liquid fuels [33]. This could be described as a type of mitigation approach and such approaches and are at least worthy of further investigation if the global average temperature is to be kept within the targeted maximum 2 °C rise [34] throughout the whole of the twenty-first century during the potential transition away from fossil fuels.

Although the efforts made by the majority of vehicular IC engine designers and manufacturers have been nothing short of miraculous—in engineering terms—in addressing pollutant, contaminant and fuel economy targets, which is why they have been used as an exemplar in this paper of what can be achieved, fossil fuel usage in this sector is but a part of overall picture [35]. If the consensus is that the climate change problem is wholly about carbon dioxide emissions from human activity, then the

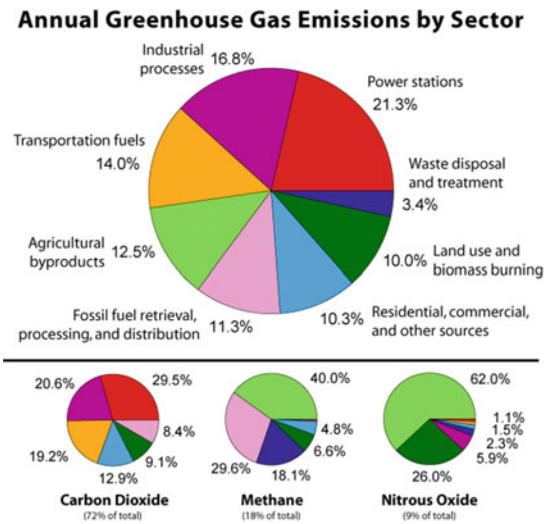

Fig. 8. Greenhouse emissions 2016 [35]

following figure, Fig. 8, depicts why the paradigm shift away from the current use of fossil fuels is of paramount importance.

4 Final Observations and Concluding Remarks

In a short paper such as this, it has only been possible to scratch the surface of the vast topic of sustainable energy sources. Yet, hopefully, it has been shown that no source meets the utopian definition of sustainable energy but that solar power (and by association wind power) and its development provide the most obvious way ahead. There is still much work to be done especially with regard to thermal and other forms of energy storage. The complete replacement of the energy sources of our present generation stations, industrial processes and transportation system is a gargantuan challenge and in the author's opinion, it is unrealistic to suggest that this could be achieved in the next 10 years as some academic researchers have advocated. Apart from the energy storage issues and the actual cost of solar power and its main conversion system—the solar panel—needs to be further reduced or the cost of oil has to double or triple in price to make the economic arguments persuasive to all concerned. Although great strides in the cost reduction of solar panels have been made this century, they are still too expensive, Fig. 9 [36], unless government incentives are evoked. However, in the USA, the price of solar panels to the consumers has been increased by the imposition, by the present administration, of a 25% tariff on imported panels. A policy decision which may help the mainland USA industry presently only meets about half the demand. Eventually, they may be able to address the potential shortfall but it is likely the panels will be more expensive and the policy will delay the transition to solar power. Ironically, the major US suppliers manufacture most of its components in Mexico.

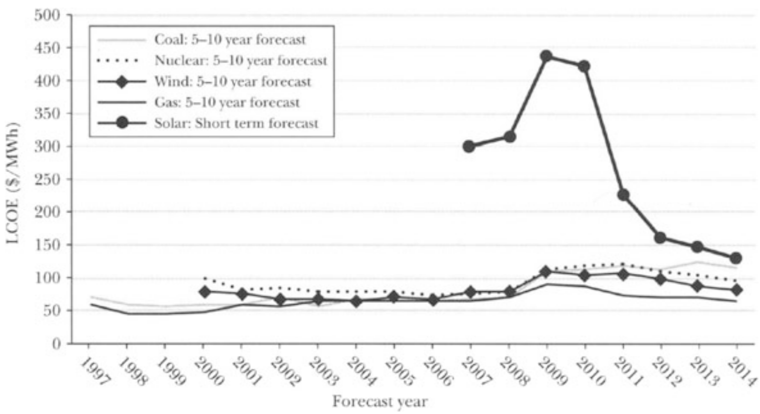

Fig. 9. Levelized Cost of Energy (LCOE) forecasts using USEIA data [36]

Solar panels and wind turbines do not last forever although ‘warranties’ for panels (if not all system components) can be obtained for at least 20 years and up to 40 years. They will then need to be replaced. However are end-of-life panels to be sent to landfill sites? As their use rapidly increases a lot more contaminated landfills sites will be needed unless the panels are recycled. Solar PV panels, however, contain heavy metals such as cadmium and lead as well as, in some cases, rare elements such as gallium and indium [37]. The panels are also constructed using a variety of different and disparate materials which will be a challenge to separate and recycle. Are recycling processes and facilities already in place?

The global automakers especially in Japan and North America have—usually because of legislation—developed sophisticated recycling processes and facilities which may be of some use to the solar power industry. These same automakers have reinvigorated the development of the electric car after earlier failures—caused as much by over-stringent regulations as technology—and while it seems that—at least in North America—the present electrical generation capacity coupled with smart grids could cope with a transition to electric vehicles only if such power generation is produced by non-carbon energy sources which will reduce carbon dioxide emissions. To replace all fossil-fuelled, and perhaps nuclear, generated electrical power is going to be a challenge and it maybe that natural gas-fired power stations would allow the cradle-to-grave carbon dioxide emissions of electrical vehicles to be lowered until solar, wind and hydro wholly replace fossil fuel power generation. Increases in nuclear power could also be instrumental in enabling the transition to electric vehicles but fears, largely unwarranted, of explosion catastrophizes and concerns about what to do with fission wastes will likely preclude nuclear playing a major role.

All current energy sources will become depleted in the future and it is unlikely that renewables will be able to be developed in time to meet all the global energy demands or all of the sustainability criteria. However, as far as we know solar energy, and by association wind energy, will be available for the next billion years or so and we should work towards its global use in a measured manner not by precipitous abandonment of current sources. Governmental policies will need to be pragmatic and unburdened with political ideologies. In practice, if there is no social buy-in on a global scale, then business as usual will prevail and anthropogenic damage to the climate will continue and increase. Of course, it has to be acknowledged that air pollution is not the sole preserve of fossil fuel use. Like the London smog of 1952, a 3-day weather inversion caused in 1948, the ‘Donora’ disaster in the town of Donora 39 km southeast of Pittsburgh in which 20 residents died and over 6,000 became sick. The disaster was caused by the emissions from the US Steel Zinc works being trapped by the inversion [38, 39]. According to the township, this incident was the ‘birthplace of clean air’ and instrumental in the passage of the Federal ‘Clean Air Act’. In 2017, researchers looking for chemical markers of the disaster in local river sediments found none [38]. Unfortunately, the damage to the global heat shield caused by carbon dioxide emissions is going to last for far more than 70 years.

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