The Global Energy Challenge

A Contextual Framework

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1 Introduction

This report gives a brief overview of the global energy challenge and subsequently outlines how and where renewable energy could be developed to solve these issues. The report does not go into a lot of detail on these issues and hence, it is meant as an overview only.

The report begins by outlining the causes of global climate change, concluding that energy-related emissions are the primary contributors to the problem. As a result, global energy production is analysed in more detail, discussing how it has evolved over the last 30 years and also, how it is expected to evolve in the coming 30 years. Afterwards, the security of the world's energy supply is investigated and it becomes clear that there is both an inevitable shortage of fossil fuels and a dangerous separation of supply and demand. The final topic discussed is renewable energy, since it is one sustainable solution to the global energy challenge and to conclude, a brief summary is provided.

2 Climate Change

Fossil fuels such as coal, oil, and natural gas introduced humans to an energy dense and easily transportable fuel, which has accelerated human development over the past 200 years. However, the fossil fuel age has also created two significant issues for the world to deal with: climate change and security of supply.

The earth receives its energy from the sun via solar radiation. As outlined in Figure 1, the earth maintains a balance between the short-wave solar radiation coming into the earth's atmosphere and the long-wave solar radiation leaving the earth's atmosphere. However, as the proportion of greenhouse gases within the earth's atmosphere increases, the 'absorbed by atmosphere' and 'back radiation' increases (Figure 1). This subsequently alters the earth's solar radiation balance: there is now more solar radiation entering the earth's atmosphere than there is leaving it, which is called radiative forcing.

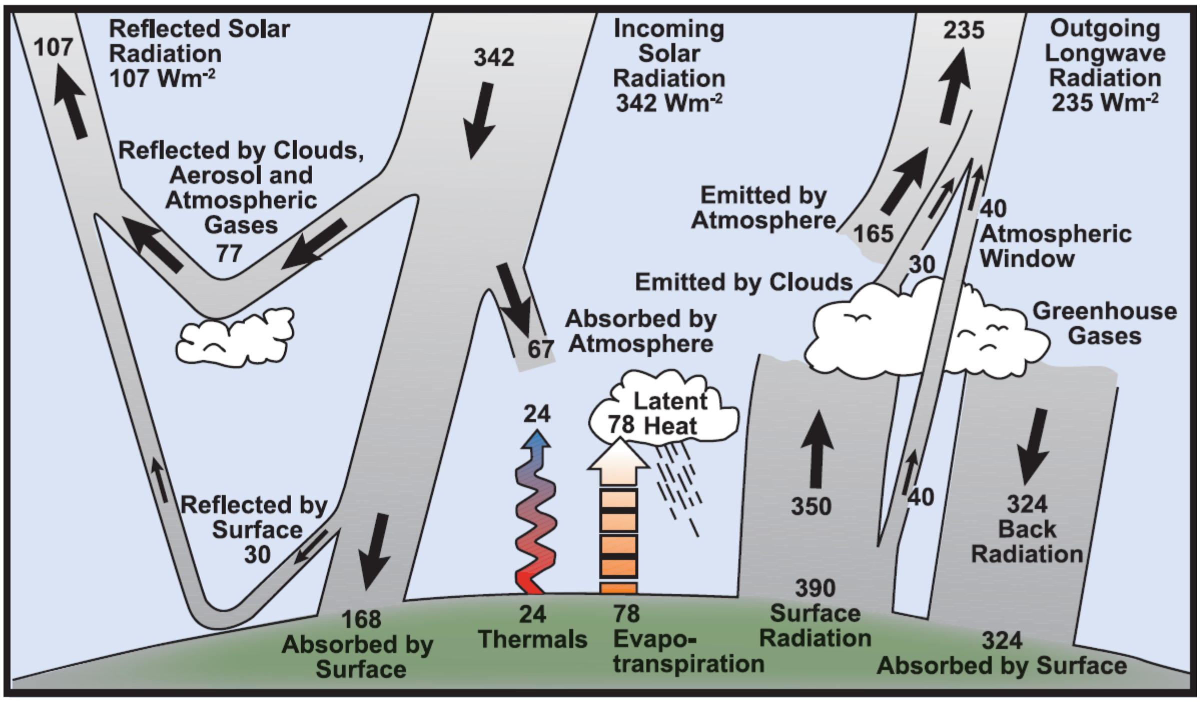


Figure 1: Estimate of the earth's annual and global mean solar radiation balance.

Upon recognition of radiative forcing, two fundamental questions must be answered: what is causing radiative forcing and what are its consequences? As these questions must be investigated on a global scale, the Intergovernmental Panel on Climate Change (IPCC) has been developed under the United Nations (UN) to examine the answers [1]. So far the IPCC has produced four climate-change assessment reports, with the most recent, the fourth assessment report, published in 2007[1] [2]. In this report, the IPCC outlined that human activity and natural processes are both responsible for radiative forcing in the earth's atmosphere, but as outlined in Figure 2, the net effect of human activity is producing a much larger imbalance than any natural process.

[1] The first assessment report (FAR) was published in 1990, the second assessment report (SAR) in 1995, and the third assessment report (TAR) in 2001.

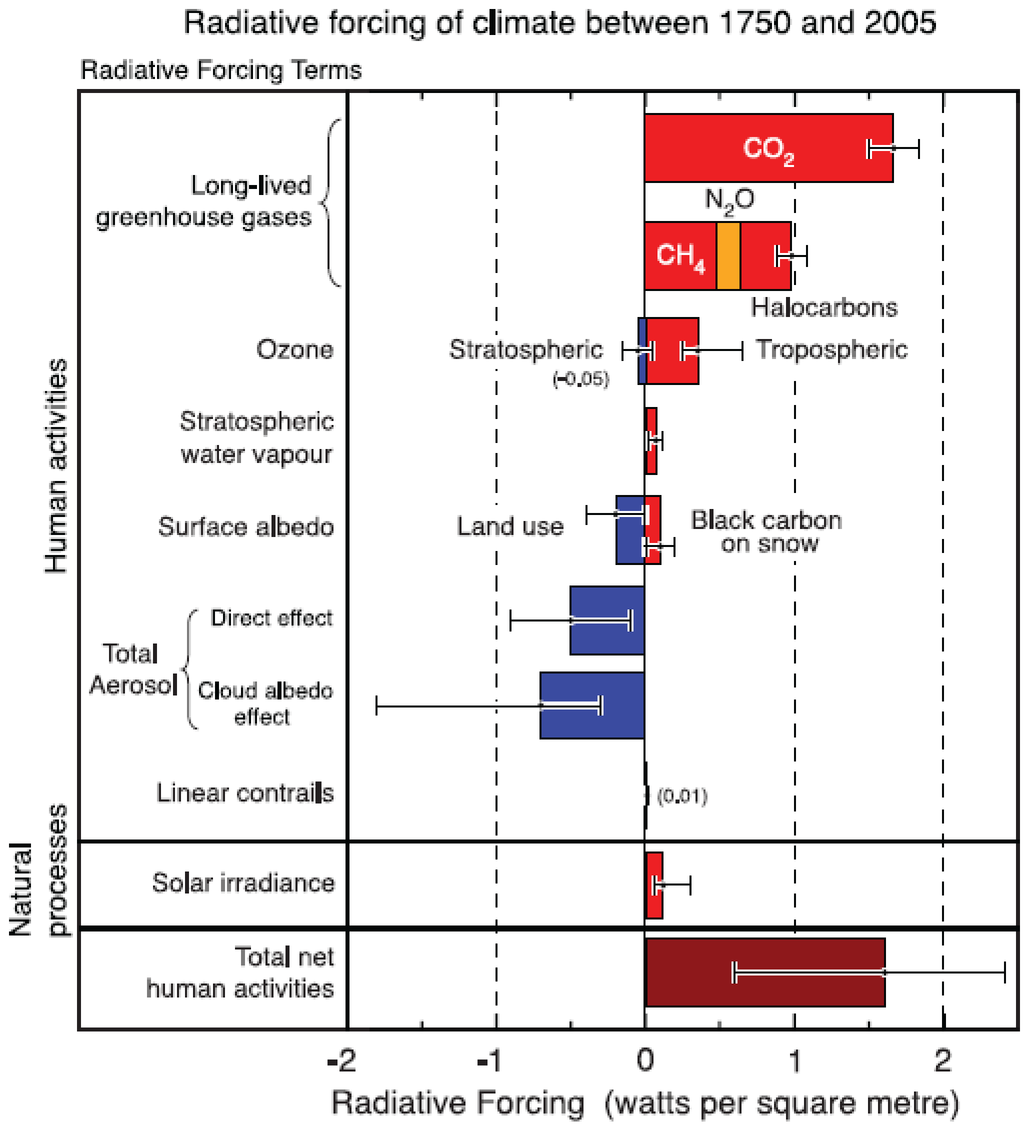


Figure 2: Principal components of the radiative forcing causing climate change between 1750 and 2005 [3].

Historical meteorological data from around globe have vindicated this conclusion. As outlined in Figure 3, the levels of CO_2, CH_4, and N_2O, which are the three largest contributors to radiative forcing due to human activity, have increased dramatically since the 18^{th} century. Figure 4 indicates that the increase in greenhouse gas emissions has coincided with an increase in global average surface temperatures, an increase in global average sea level, and a decrease in northern hemisphere snow cover. As a result, the IPCC has concluded that:

> *"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level." [4]*

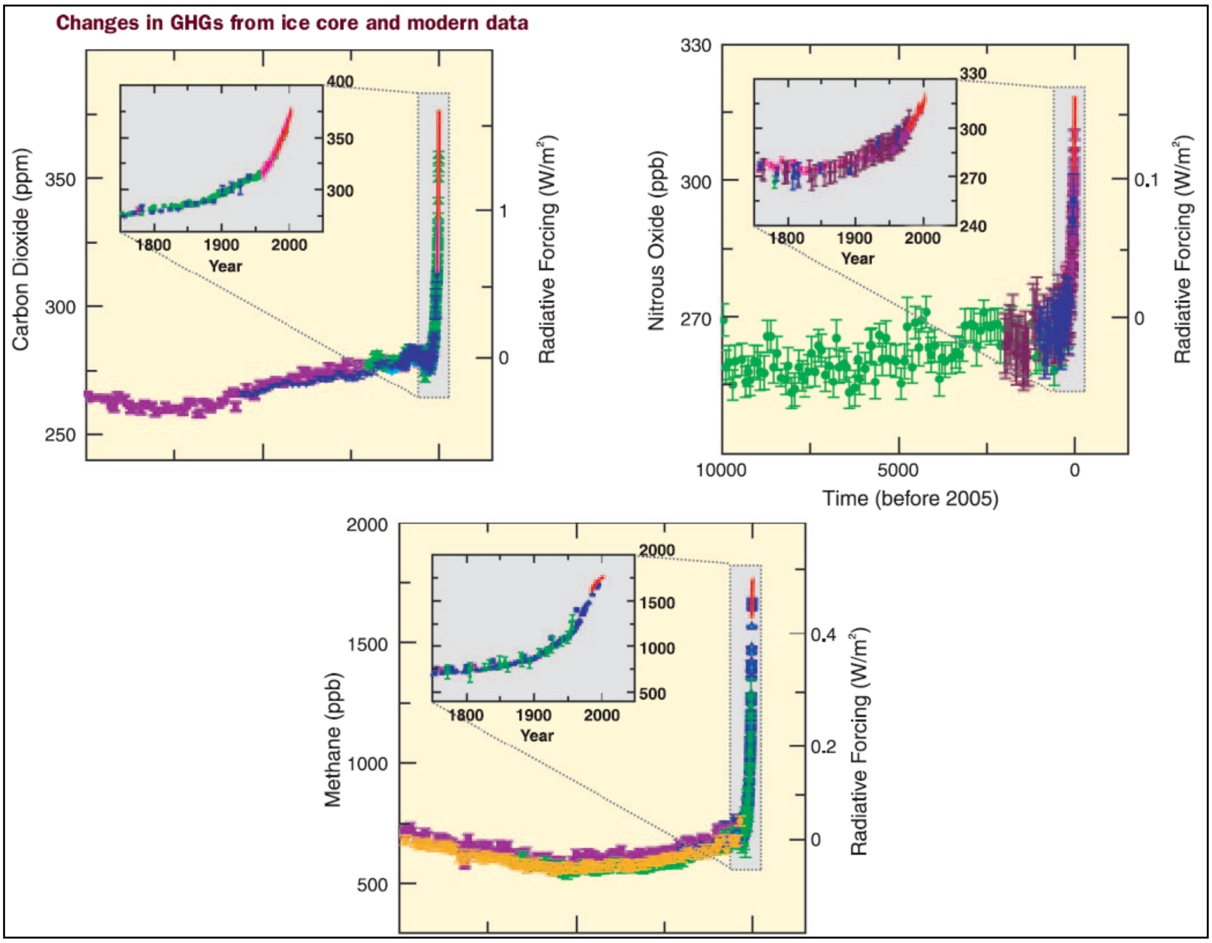


Figure 3: Concentration of CO_2, CH_4, and N_2O in the earth's atmosphere over the last 10,000 years [4].

Therefore, the IPCC has now provided the answers to the two fundamental questions: human activity is the primary creator of radiative forcing and the consequences of radiative forcing are changes in the global climate. However, these conclusions on the past create two new questions on the future: firstly, how will the global climate change and secondly, can these changes be avoided?

It is difficult to quantify a numeric cost on global climate changes due to the wide range of cultures and the various degrees of economic development in the world, as well as the unequal distribution and the type of consequences that are expected. Therefore, the IPCC have stated that:

> *"It is very likely that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. It is virtually certain that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries and populations. In some locations and amongst some groups of people with high exposure, high sensitivity and/or low adaptive capacity, net costs will be significantly larger than the global average." [5]*

Therefore, Figure 5 gives a general overview of the changes that will be expected with climate changes: a further increase in global annual temperature will lead to very large and in some cases irreversible changes such as increased precipitation, increased droughts, animal extinctions, food shortages, loss of coastlines, and a decline in global health. Crucially from a positive perspective however, Table 1 indicates that the extent of these changes will be defined by the levels of greenhouse gases in the atmosphere in the future. Therefore, the IPCC have concluded that:

> *"Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt." [5]*

BUT

"Many impacts can be reduced, delayed or avoided by mitigation." [5]

Hence, the answers to these two fundamental questions on the future indicate that global climate changes will have devastating effects on the world and these effects cannot be avoided entirely, but they can be minimised by reducing greenhouse gas emission levels. This in turn produces a final key question on climate change: how can GHG emissions be reduced?

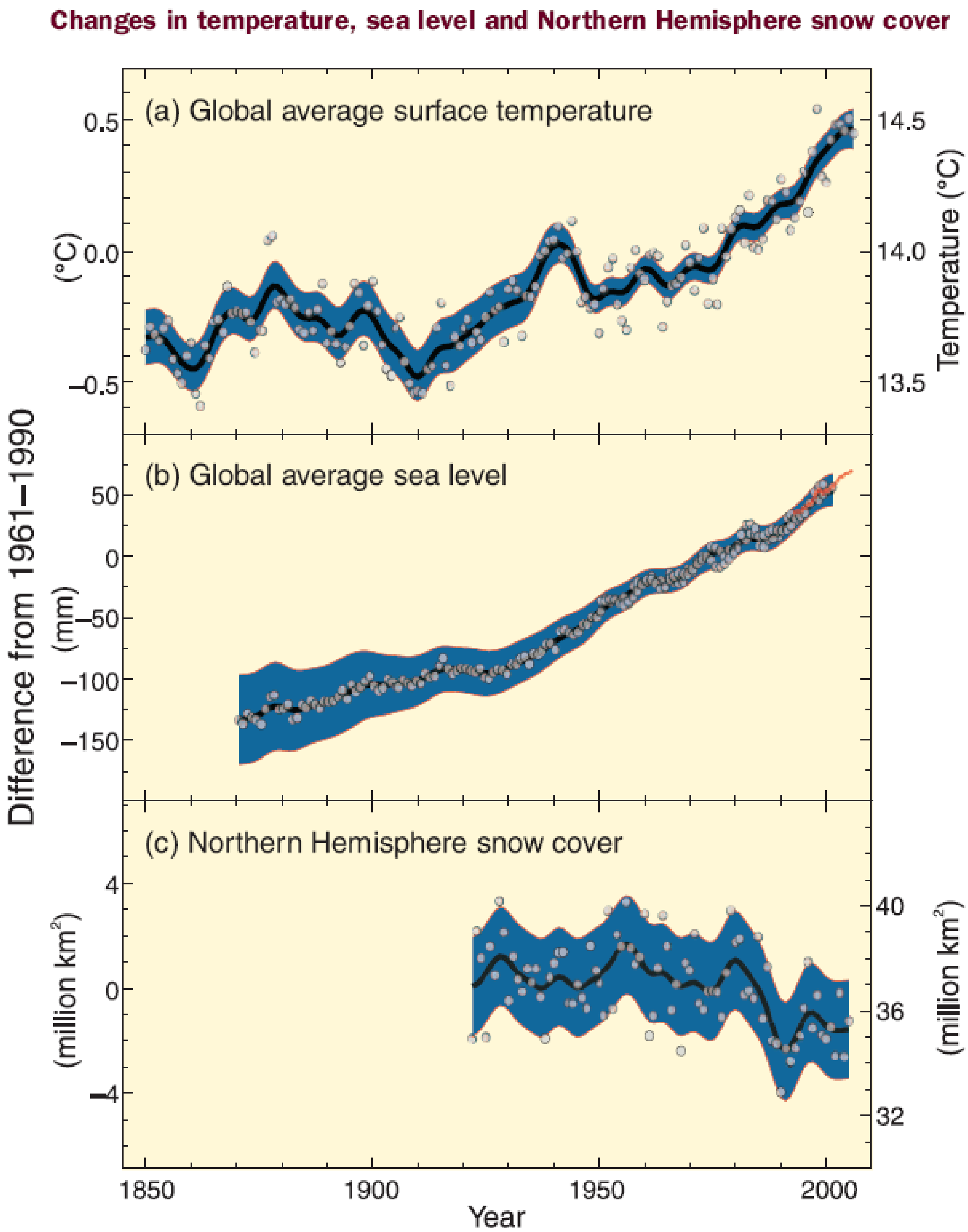


Figure 4: Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990 [5].

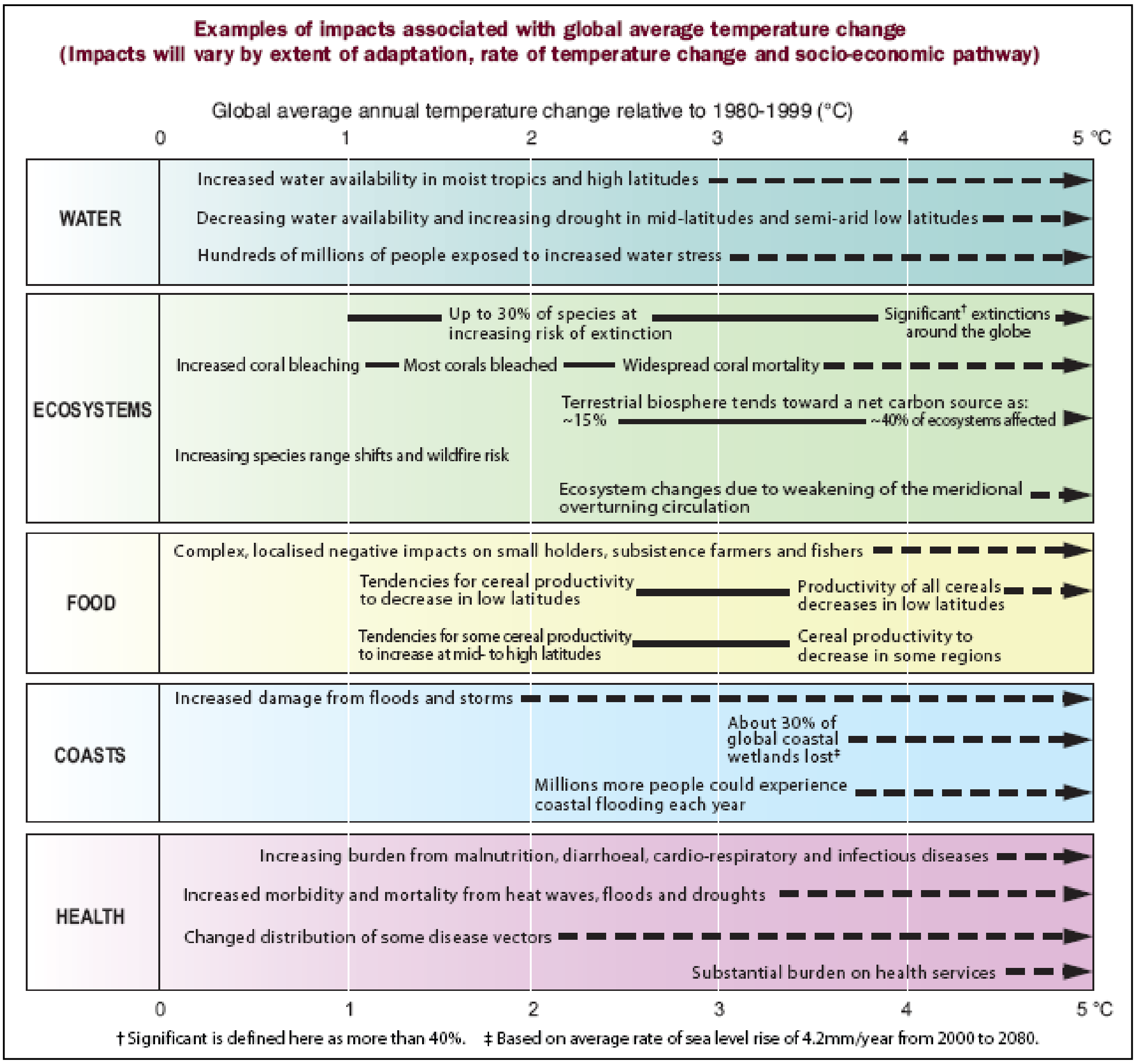


Figure 5: Examples of impacts associated with global average damage [5].

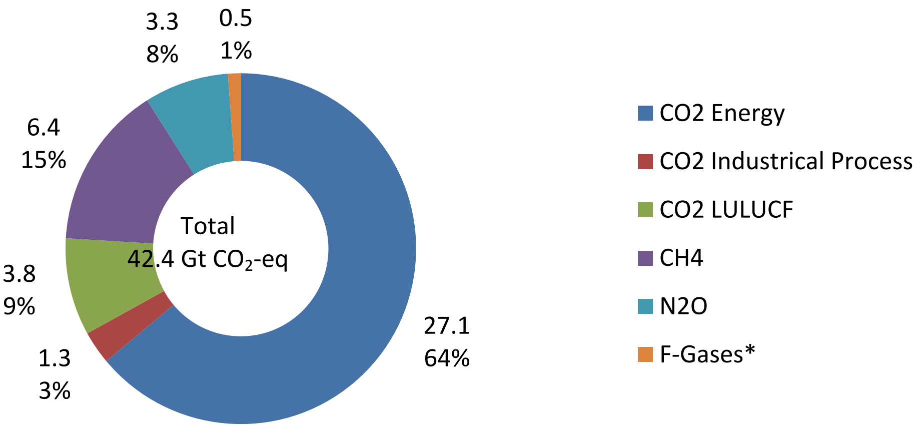
Table 1: Global temperature increase for future greenhouse gas emissions levels [5].

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005=375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d,e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

To identify how GHG emissions can be reduced, the origin of GHG emissions produced from human activity need to be quantified in more detail. As illustrated in Figure 6, energy related CO_2 emission account for 64% of the world's total greenhouse gas emissions. Therefore, based on scenarios developed for the mitigation of GHG emission in the future, the IPCC have concluded that

> *"There are large uncertainties concerning the future contribution of different technologies. However, all assessed stabilisation scenarios concur that 60 to 80% of the reductions over the course of the century would come from energy supply and use and industrial processes." 4th Report WGIV, Synthesis Report, IPCC, P.68*

Consequently, to avoid devastating and irreversible changes to the world's climate over the next century, energy production will need to be decarbonised.



*F-gases include hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride from several sectors, mainly industry. Note: Industry CO_2 includes non-energy uses of fossil fuels, gas flaring, and process emissions. Energy methane includes coal mines, gas leakages, and fugitive emissions. N_2O from industry and waste amounts to 0.12 Gt CO_2-eq.

Figure 6: World anthropogenic greenhouse-gas emissions quantified by CO_2 equivalent and divided by source for the year 2005 [6].

3 Energy Production

As illustrated in Figure 7, the world's energy supply is dominated by fossil fuels. In 2007, 81.4% of the world's energy was produced from fossil fuels, which included 20.9% from gas, 26.5% from coal, and 34% from oil, with almost all of the remainder coming from renewables and waste (9.8%), nuclear (5.9%), and hydro (2.2%).

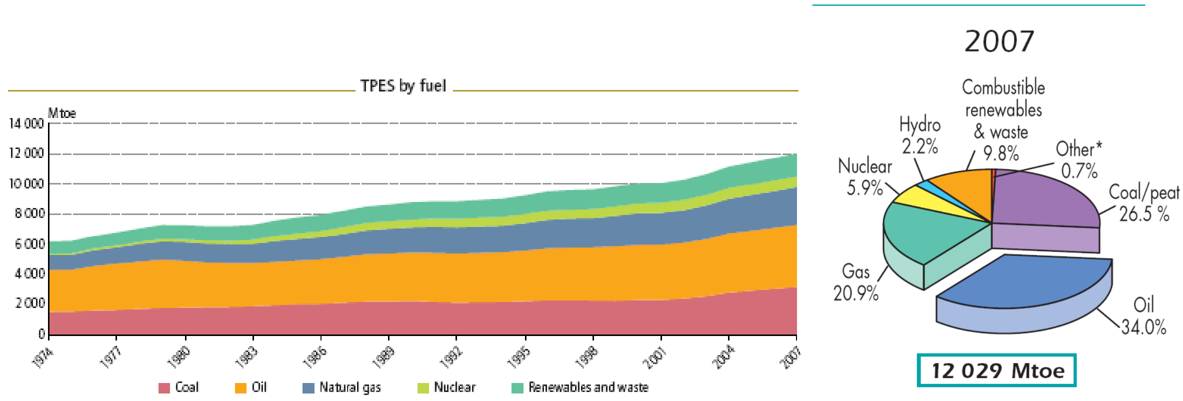


Figure 7: World's energy supply by fuel from 1974 to 2007 [7].

In relative terms, there has always been a large dependence on fossil fuels. In fact, in 1973 fossil fuels accounted for 86.6% of the world's total energy supply. However, it is the continuously increasing demand for energy which is straining the world's fossil fuel resource: as Figure 7 also indicates, between 1974 and 2007 the world's energy supply has increased from 6115 Mtoe to 12019 Mtoe (197%). This has been necessary to provide the increasing demand displayed in Figure 8, which has been primarily driven by the transport (1216 Mtoe), residential (866 Mtoe), and industrial (730 Mtoe) sectors.

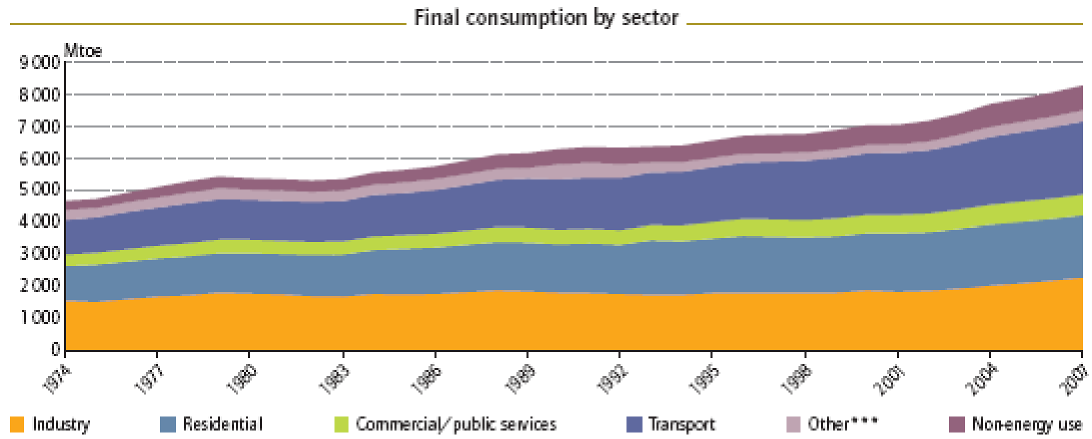


Figure 8: World energy demand by sector from 1974 to 2007 [7].

Even more concerning than the past however, are the current projections for the future [6]. Using current trends, the IEA expects the world's energy demand to grow from 12,029 Mtoe in 2007 to 17,014 Mtoe (142%) in 2030, with fossil fuels accounting for 80.5% of supply in 2030.

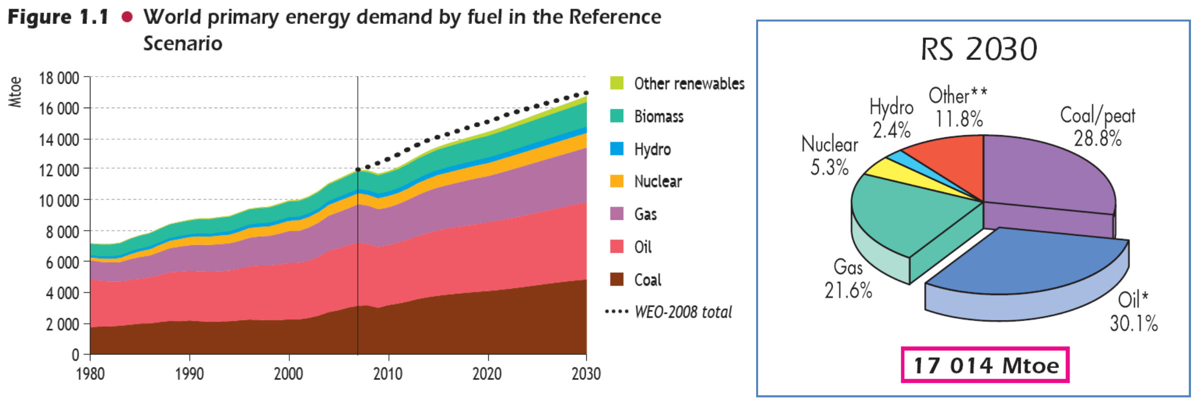


Figure 9: Projected world energy supply for 2030 [6, 7].

As outlined in Figure 10, mirroring this increase in energy production towards 2030 will be an increase in world CO_2 emissions. As discussed previously in section 2, further increases in CO_2 emissions will have detrimental implications for the world and hence, future energy production is currently not environmentally sustainable. Furthermore, this increase in energy production and increase in fossil fuel consumption will lead to another major global issue, which is security of supply.

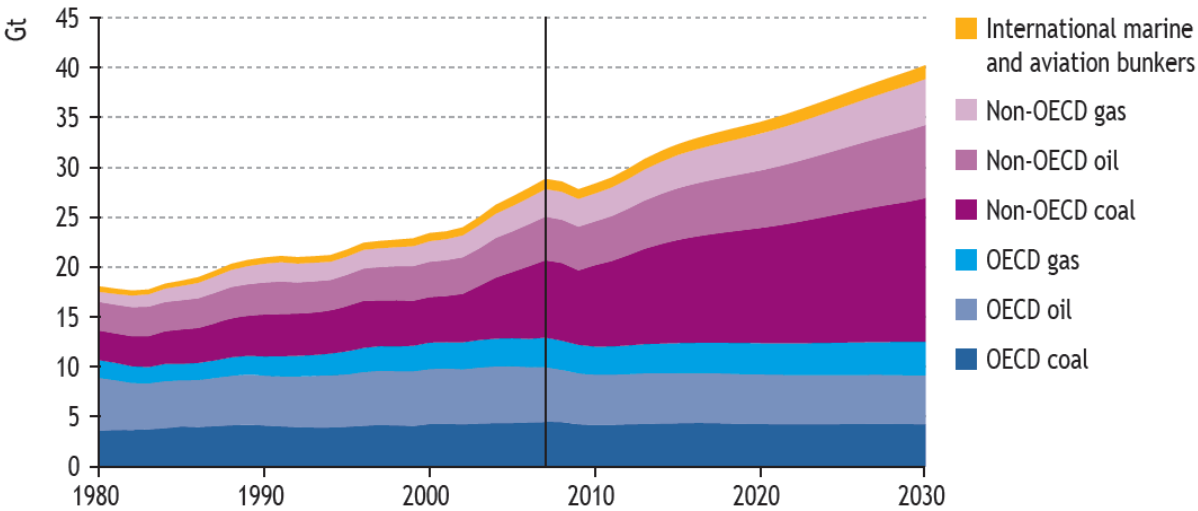


Figure 10: Historical and projected global CO_2 emissions due to energy [6].

4 Security of Supply

Fossil fuel security-of-supply is a key concern for two primary reasons: firstly, it is a finite resource and secondly, it is distributed unevenly around the globe. Therefore, this poses two key questions: how much fossil fuel is left and where is it?

When observing the era of fossil fuel production over thousands of years, it will most likely be viewed as a relatively short period in time. It is clear from historical data when it began, but when it will end has been meticulously debated since the mid 20th century, particularly since the development of the Hubbert curve [8]. Estimates have varied due to the uncertainty surrounding some key assumptions for the future such as the demand, remaining reserves, and the influence of new technologies. This is evident from the broad range of estimates declared by various organisations in Figure 11 for the year of peak oil alone. However, without defining an exact year for the depletion of fossil fuels, there are a number of consistent trends which can be acknowledged.

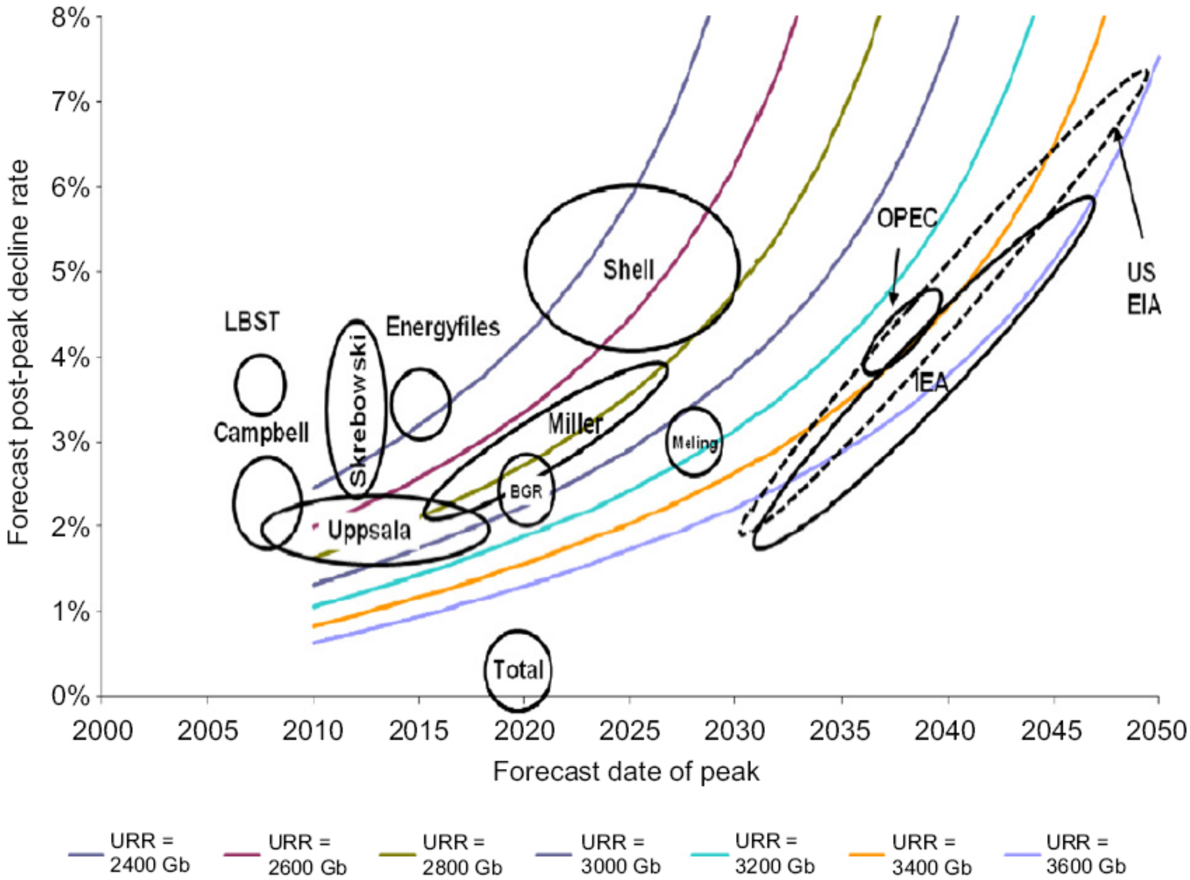


Figure 11: Estimated years by various organisations for the year of peak oil [9]. (URR = Ultimately Recoverable Resource)

Firstly, in section 0 above it was evident that projections for the future demand of fossil fuels anticipate a significant increase: in 2007 it was 9800 Mtoe, but this is expected to grow to 13700 Mtoe (140%) by 2030. In contrast, Figure 12 indicates that the reserves required to meet this demand have been depleting for over 30 year. As a result, the most recent assessment of reserves carried out by BP estimated that there is only 46 years of oil, 63 years of gas, and 119 years of coal remaining, which is economically accessible based on 2009 consumption levels [10]. Although it could be argued that technological developments will increase production in the future, as they have done in the past (Figure 13), any increase will most likely be offset by the aforementioned increase in future demand (Figure 9) and reduction in new reserves (Figure 12). This was quantified by Shafiee and Topal [11] who created a model which includes the projected consumption and depletion of fossil fuels in the future. The results indicated that reserve depletion times for oil, gas, and coal could be as soon as 35, 37, and 107 years respectively [11]. Therefore, although there is ambiguity surrounding the exact date of fossil fuel depletion, it is evident both within [10] and outside [11] of the petroleum industry, that reserves are depleting within decades not centuries. Consequently, due to the scale of the world's dependence on fossil fuels and the timescale required to create alternative sources of energy, changes must occur now to avoid an energy gap in the future.

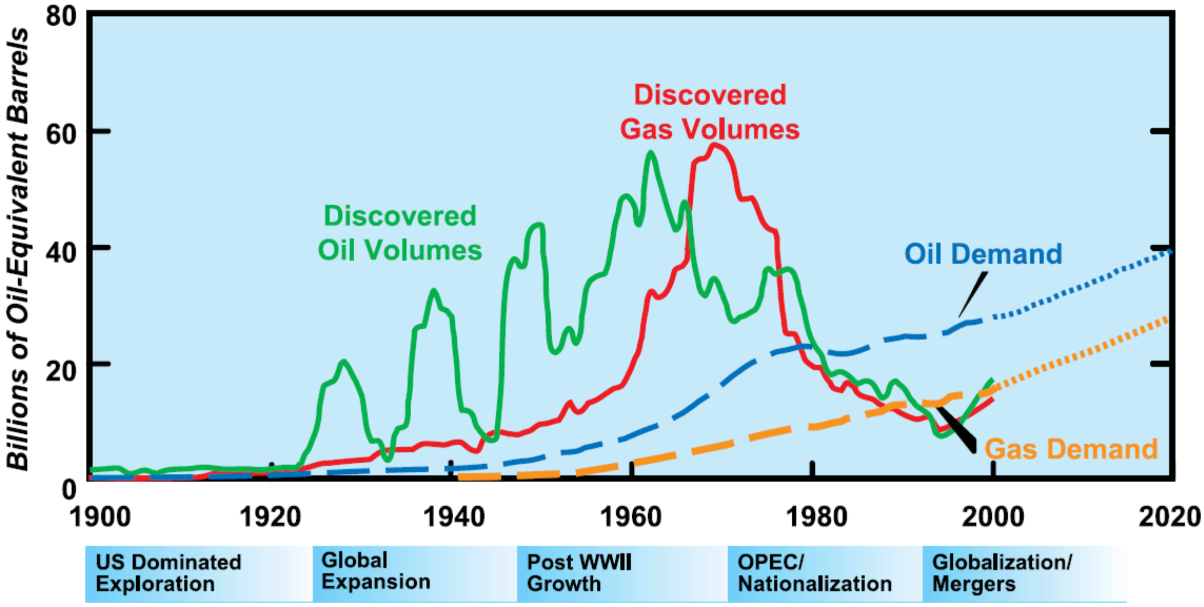


Figure 12: Historical discovery and consumption of fossil fuel [12].

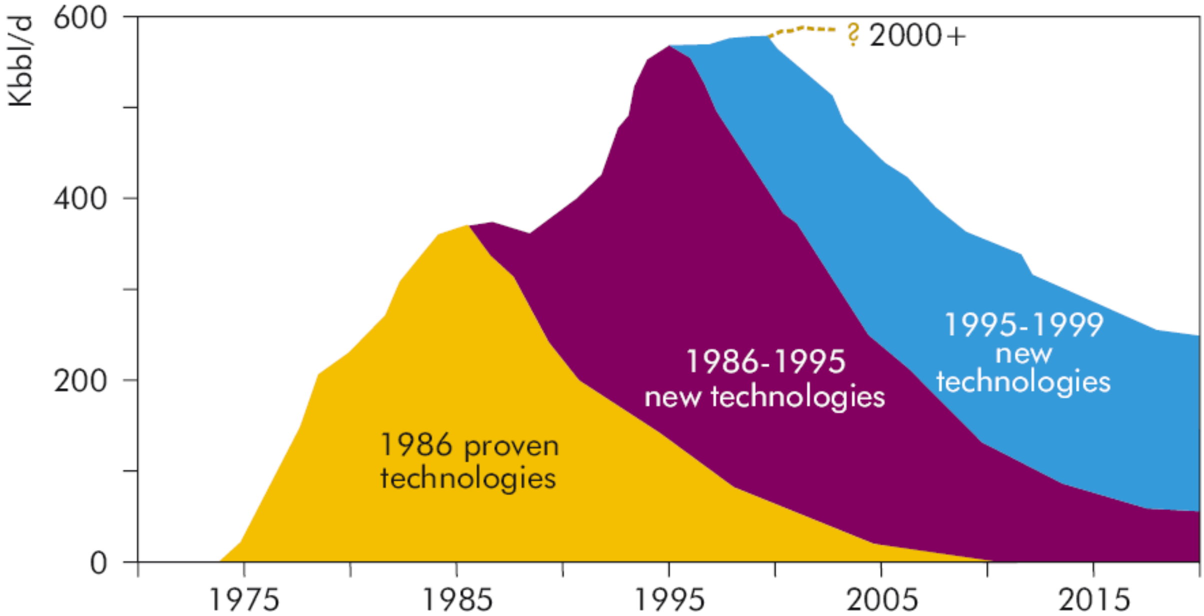


Figure 13: Impact of technology on the production from the North Sea [13][2].

[2] In the initial stage of exploration for a resource such as oil, the success rate for discoveries is small because geologists do not know where it is best to explore. But as more oil is found, it is easier to identify places where it is likely to be found, and the success rate increases. However, because the amount of oil in the ground is finite, there eventually comes a time when most of it has been found, and it becomes more and more difficult to

As well as the inevitable decline of fossil fuel production, there are also significant issues regarding the location of reserves. In particular, oil and gas reserves are centralised in a relatively small number of countries as outlined in Figure 14 and Figure 15 respectively. In fact, 90% of global oil reserves are located within 15 countries and 90% of global gas reserves are located within 20 countries [10]. In contrast however, Figure 16 outlines that global energy demand is not focused within these areas. Consequently, there is a vast global exchange of oil and gas, which is portrayed in Figure 17 and Figure 18 respectively. As discussed previously, oil and gas will most likely deplete within the next century and more than 50 years before coal. Therefore, if the world does not reduce its dependence on oil and gas in the future, then the distribution of these limited resources could become a very politically sensitive issue. Furthermore, from historical energy prices displayed in Figure 19, it is evident that a shortage in supply leads to a dramatic increase in costs. Considering the historical political instability in some countries with significant reserves such as Iran, Iraq, Kuwait, Venezuela, Russia, Nigeria, Libya, Angola, Algeria, and Kazakhstan who between them contain over 50% of global oil and gas reserves, it is possible that a dramatic increase in fossil fuel value could also lead to conflict and disruptions in supply.

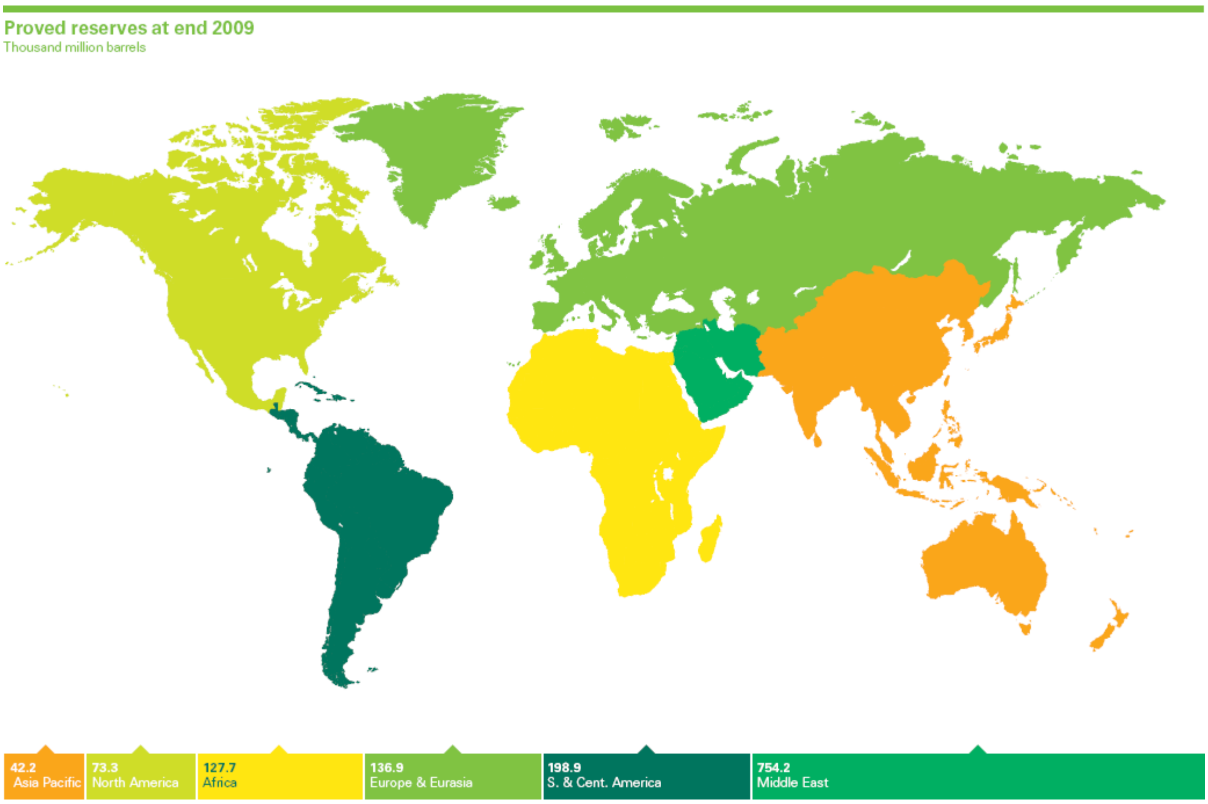


Figure 14: Global distribution of oil reserves [10].

find additional reservoirs: the exploration success rate decreases again. Based on this argument, one expects the amount of oil discovered as a function of time to look like the curve in Figure 13.

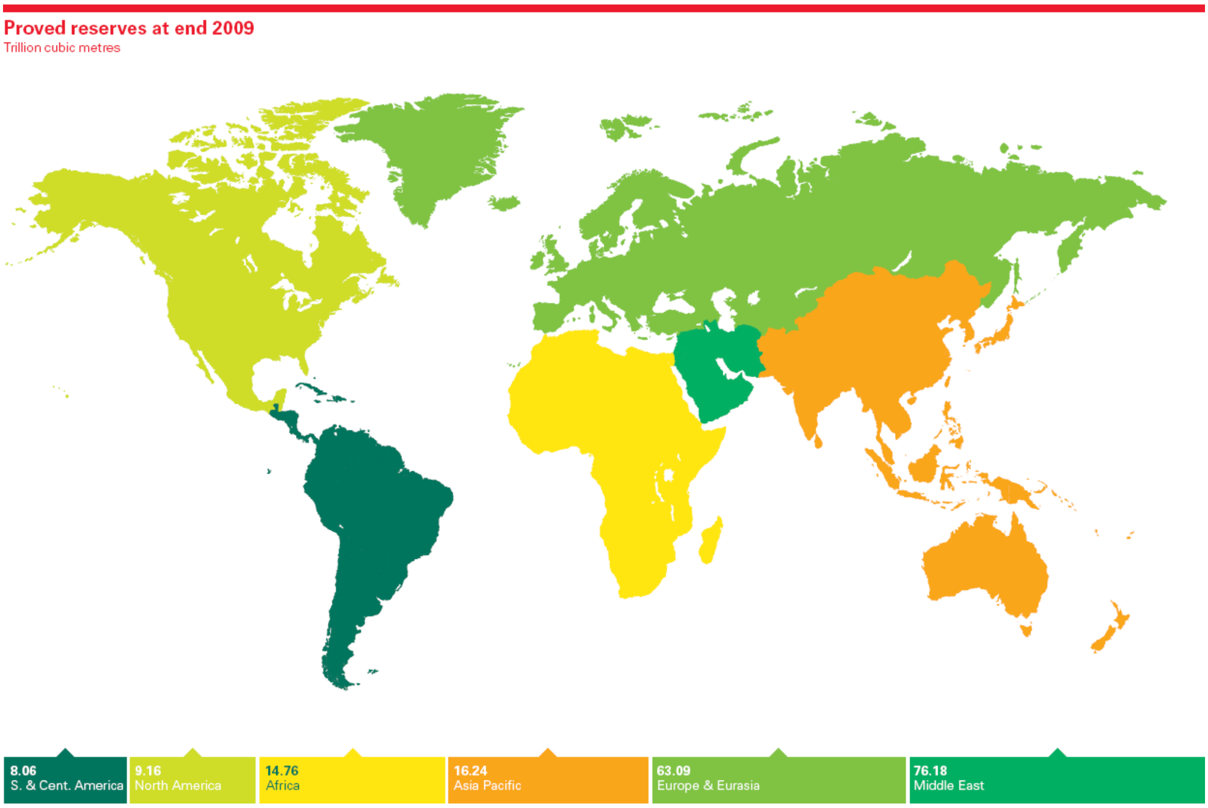


Figure 15: Global distribution of gas reserves [10].

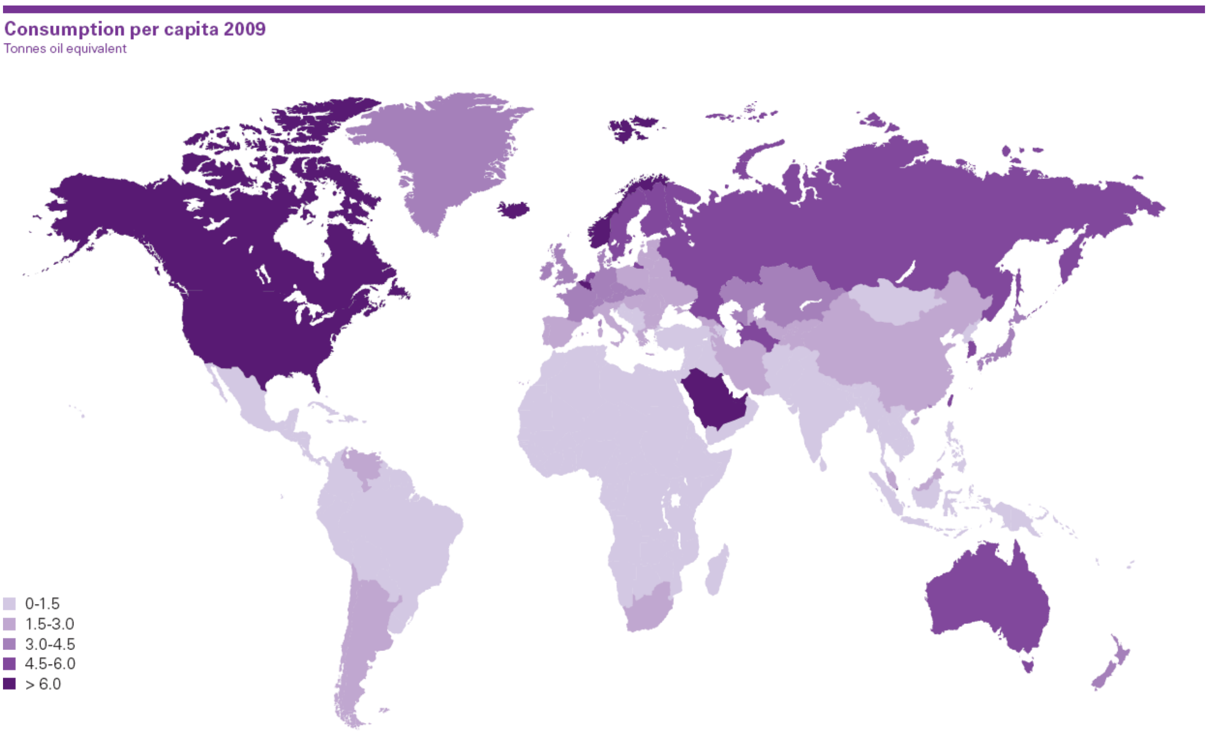


Figure 16: Global consumption per capita [10]

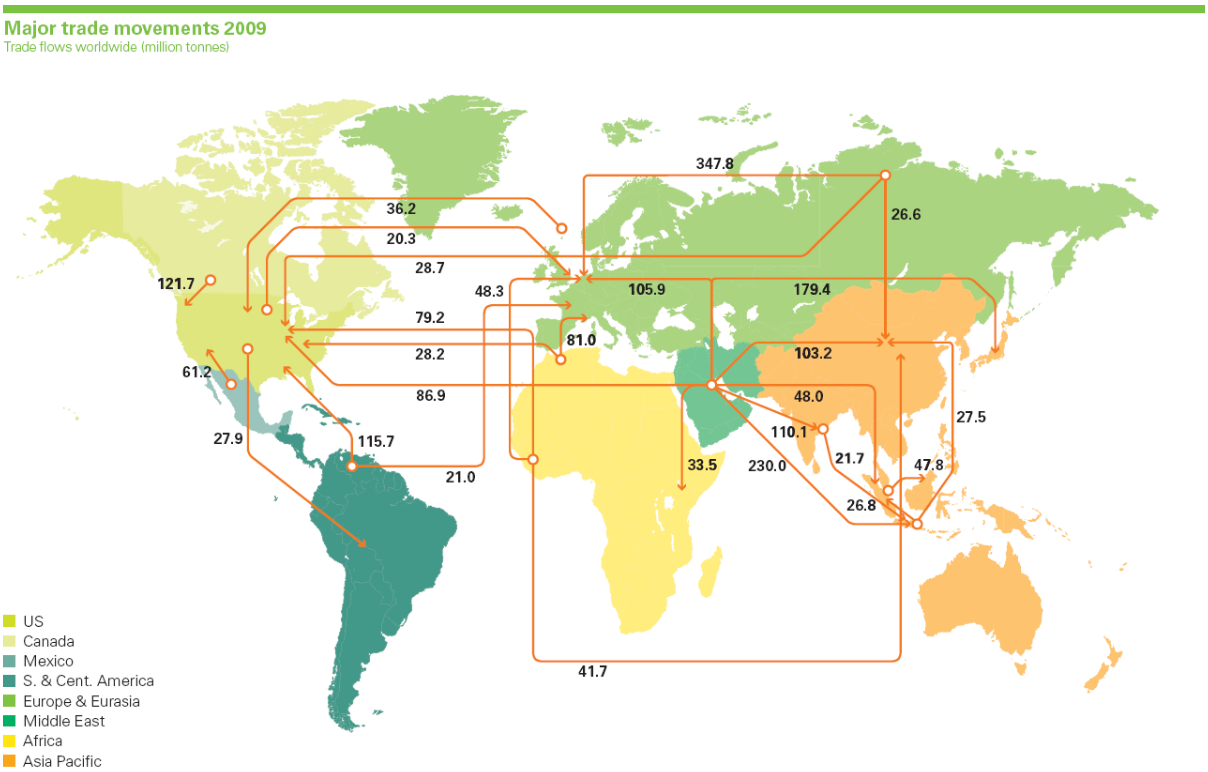


Figure 17: Global trade of oil [10]

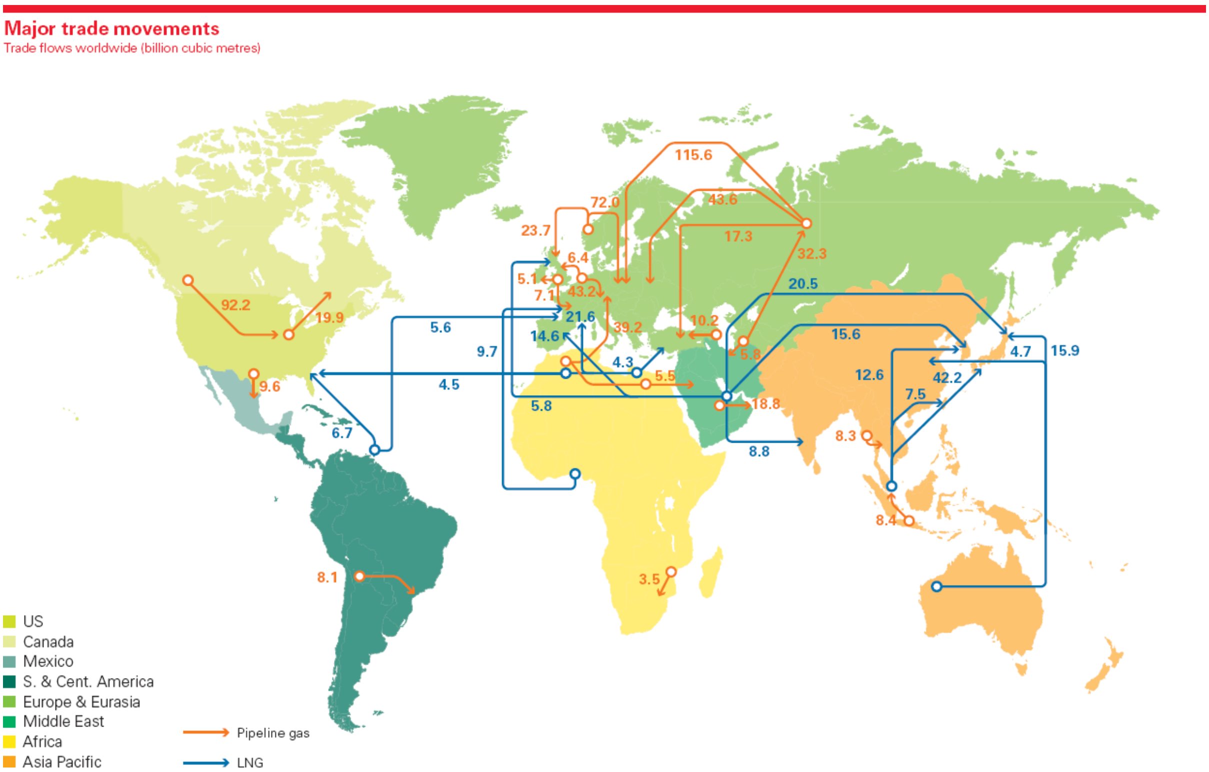


Figure 18: Global trade of gas [10].

To conclude, if the world doesn't detach itself from its fossil fuel dependence, a combination of resource availability and locality could create political and economic unrest throughout the world.

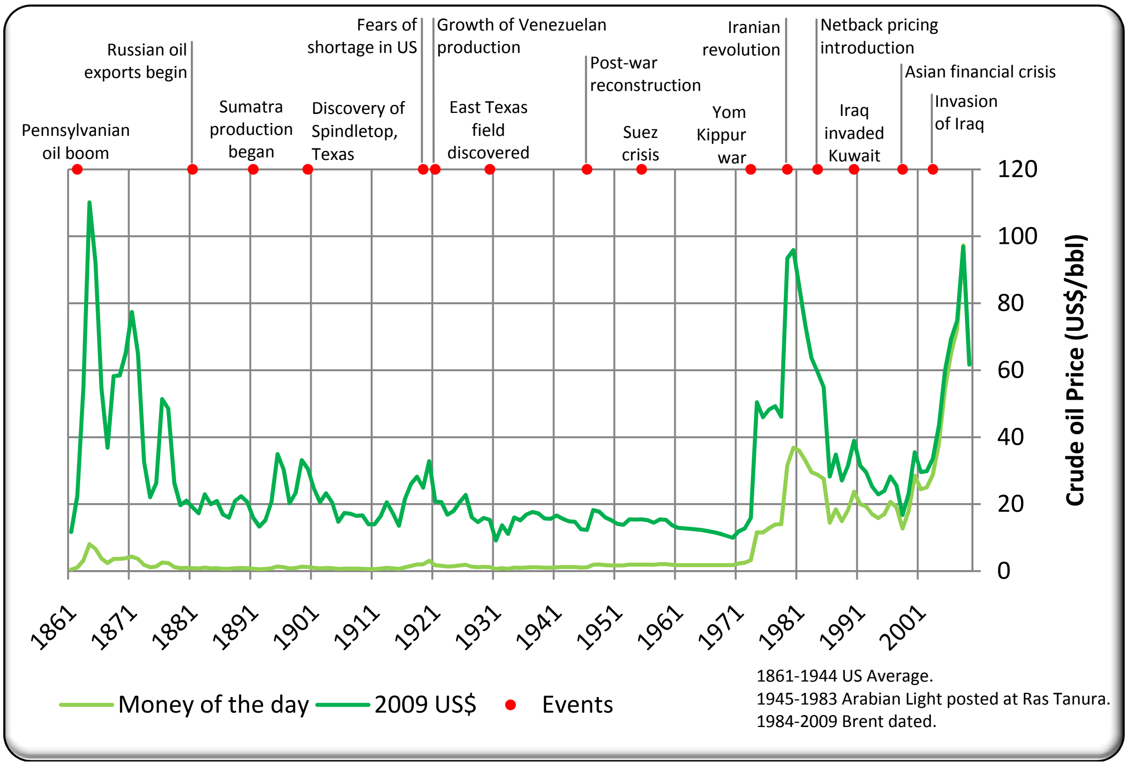


Figure 19: Historical price of crude oil [10].

5 Renewable Energy

One solution which can produce energy without catastrophic climate issues and in a sustainable manner is renewable energy. This can create energy with no GHG emissions, while using a naturally recurring and abundant resource. However, renewable energy exists in many forms, with each type offering some unique advantages and drawbacks. To fully portray these issues, it is important to understand how the modern energy system was established.

In the 19th century, renewable energy was the most widely used energy resource (Figure 20). However, in the 18th century the steam engine introduced people to cheap source of abundant power. Coal introduced an energy dense and abundant fuel which enabled the development of steam engines, while steam engines were a cheap and powerful method of transportation, which brought coal to many people. Together, coal and the steam engine created the world's first source of cheap, abundant and easily transportable fuel, which kick-started the world's first industrial revolution. This new power enabled the development of new technologies such as electricity and automobiles, which as displayed in Figure 21 caused the world's population to boom.

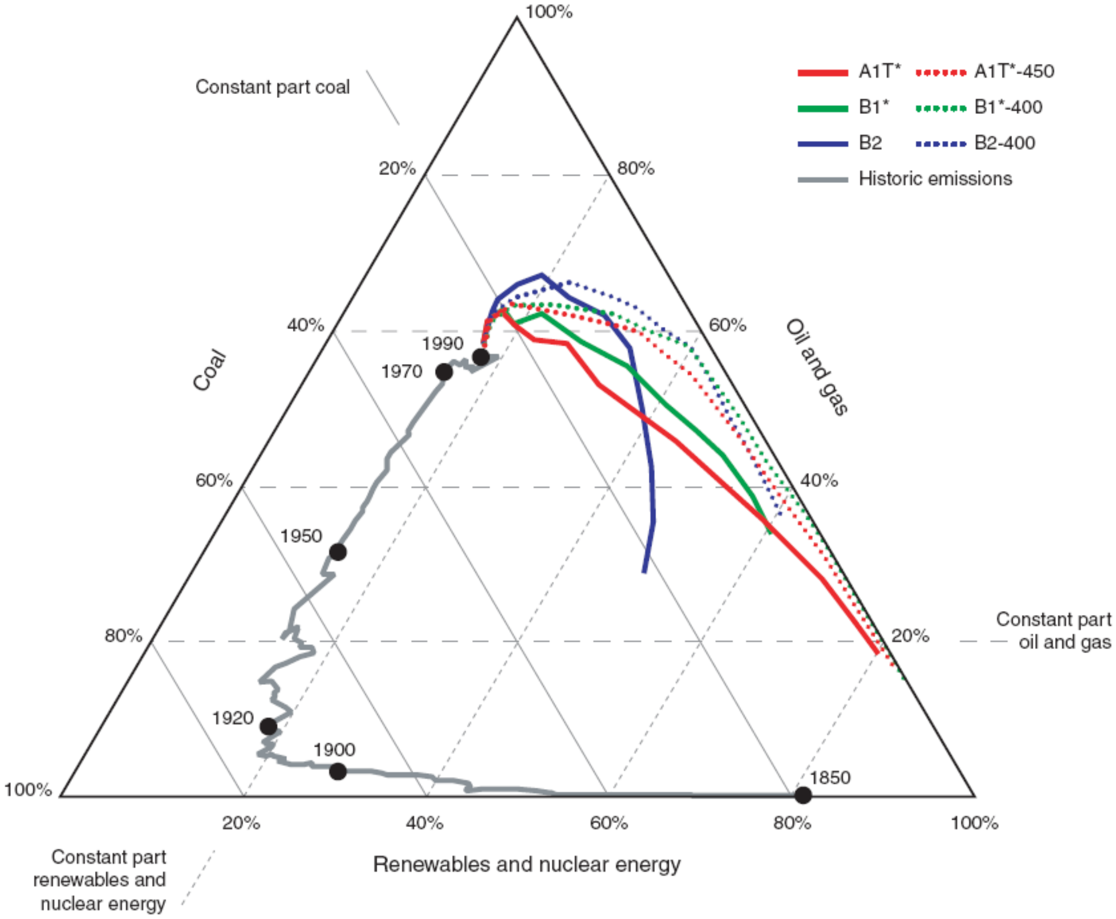


Figure 20: Evolution of energy consumption from 1850 to 1990, with various projections up to 2100 [14, 15].

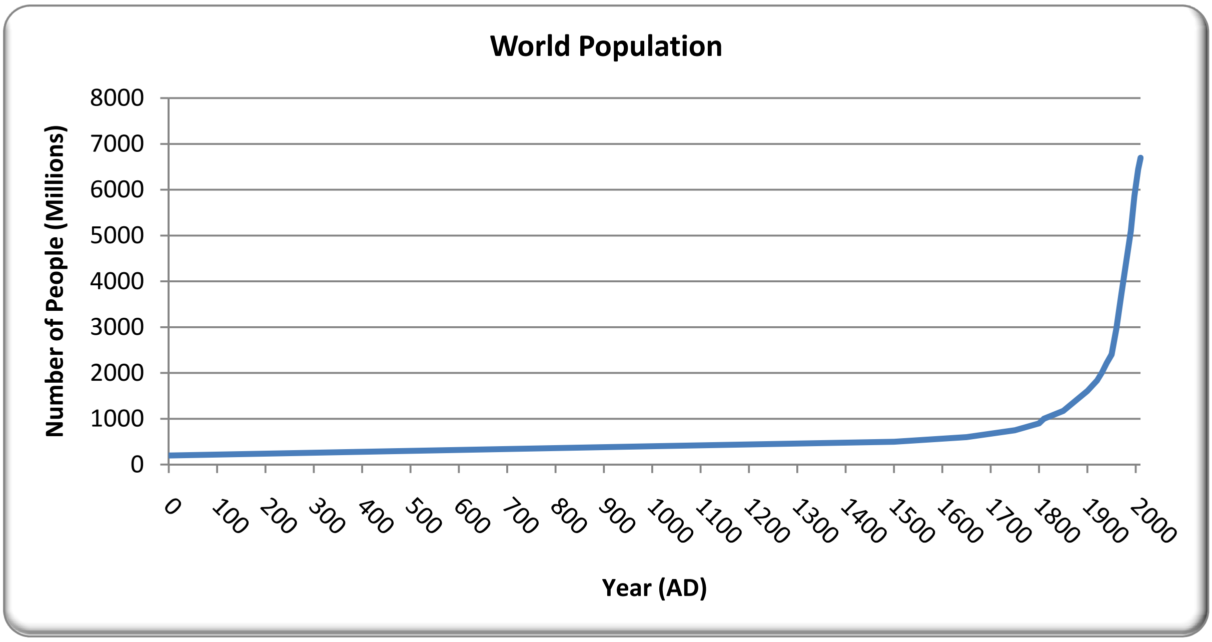
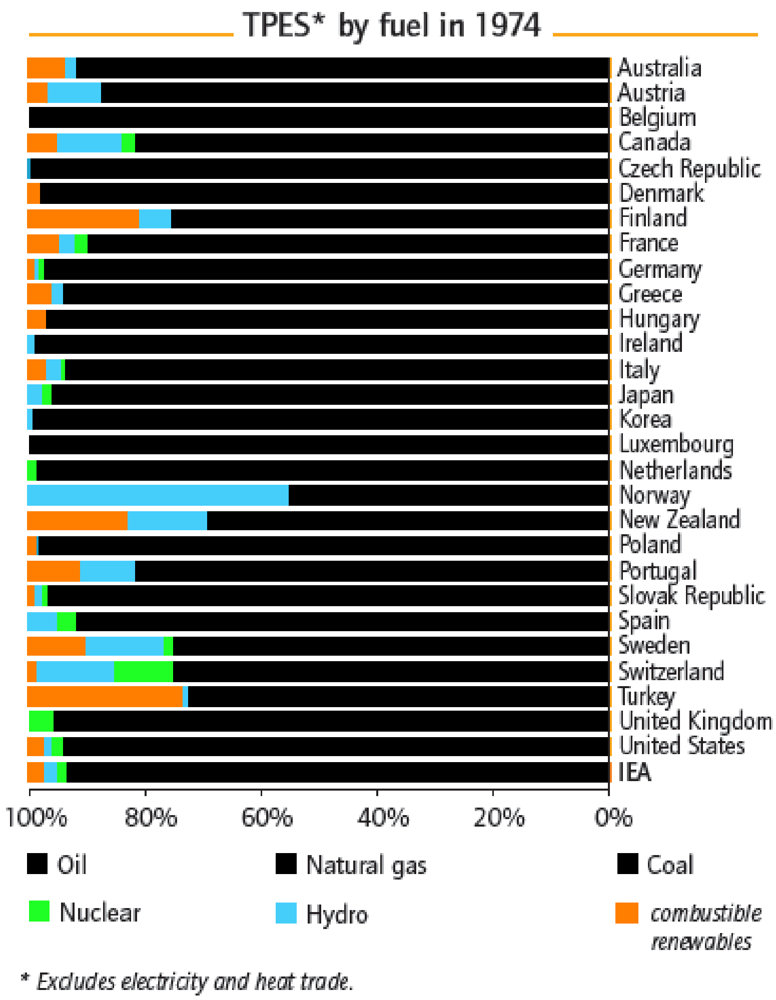


Figure 21: Historical world population from 0 to 2010 AD [16].

As more technologies evolved, energy production became more and more dependent on fossil fuels. Power plants were centralised and located near fossil fuel supply chains, automobiles were designed to burn oil, while heating systems were developed and optimised for fossil fuel consumption. Under this model, the only renewable energy technologies that could compete were those which offered similar control characteristics to fossil fuels. In other words, they needed to be dispatchable, abundant, and provide cheap energy. With these criteria, the only two renewable technologies that could compete with fossil fuel production during the early 20th century were hydro and biomass. Therefore, as Figure 22 indicates, by 1974 the world was very dependent on fossil fuels, as nations immersed themselves in cheap and abundant power. However, during the 1970's the first backlash of this dependence was realised.



1973 TPES (Mtoe)		
World	6115	
Coal/Peat	*1498*	*24.5%*
Oil	*2819*	*46.1%*
Gas	*978*	*16.0%*
Total FF	**5295**	**86.6%**
Nuclear	**55**	**0.9%**
Renewables	**764**	**12.5%**

Figure 22: TPES by fuel in 1974 for selected developed countries [17, 18].

In 1973, the United States aided the Israeli military, who were fighting in the Yom Kippur war with Syria and Egypt, who were supported by a coalition of oil-producing Arab states. In response, the Arab coalition reduced their oil production and hence created a global shortage. Again in 1979, the Iranian revolution occurred which reduced Iranian oil production, which created another global oil shortage. Iranian oil production effectively stopped altogether in 1980 after it was invaded by Iraq. As displayed in Figure 19, in both 1973 and 1979, there was a dramatic increase in global fossil fuel prices when a global oil shortage occurred. This illustrated how dependent the world was on fossil fuels and how unprepared people were to adapt to life without it. Consequently, the quest for new forms of energy began that reinvigorated interest in renewable energy generation, which is evident from the sharp increase in renewable energy RD&D budgets at the time, as displayed in Figure 23.

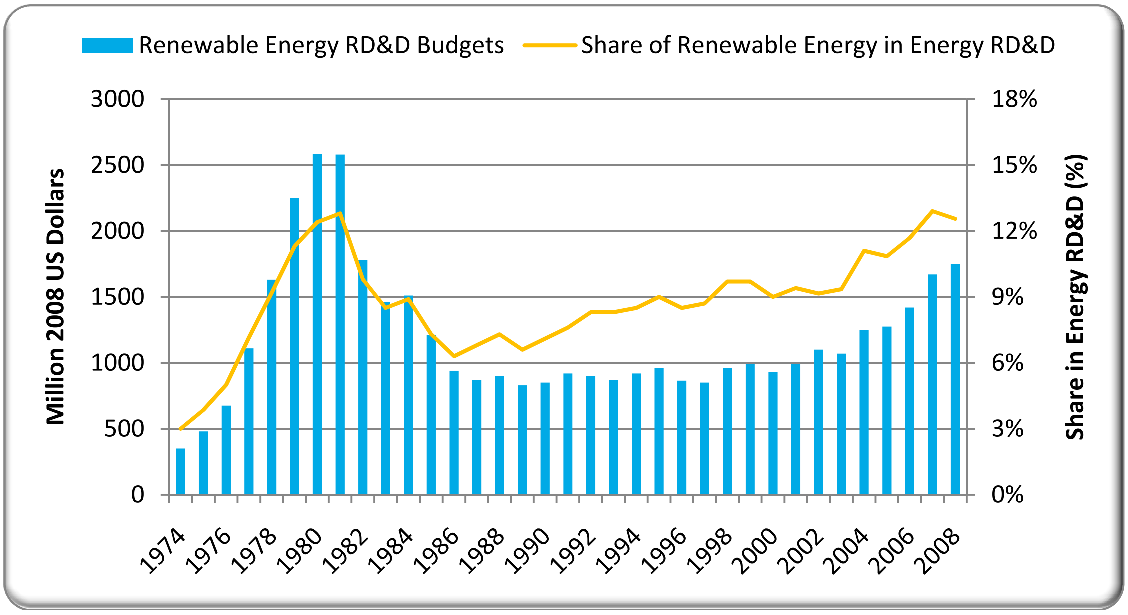


Figure 23: Renewable energy RD&D budgets within the IEA from 1974 to 2008 [17].

In total, there are five sources of renewable energy: biomass, wind, water, solar, and geothermal. As mentioned earlier, only biomass and water, in the form of hydro, were competitive with fossil fuels during the early 20th century. However, after 30 years of significant RD&D funding into renewable energy (Figure 23), a number of renewable technologies have now become economically competitive with conventional fossil fuels (Figure 24). As a result, renewable energy has started to play an increasing role in energy production (Figure 25). Furthermore, with continued RD&D, projections indicate that the cost of renewable energy is expected to fall even further (Figure 24). Consequently, from the economics of generation, renewable energy has and will continue to be a realistic alternative for large-scale deployment. However, there is one key difference between conventional fossil fuels and a number of evolving renewable energy technologies: control.

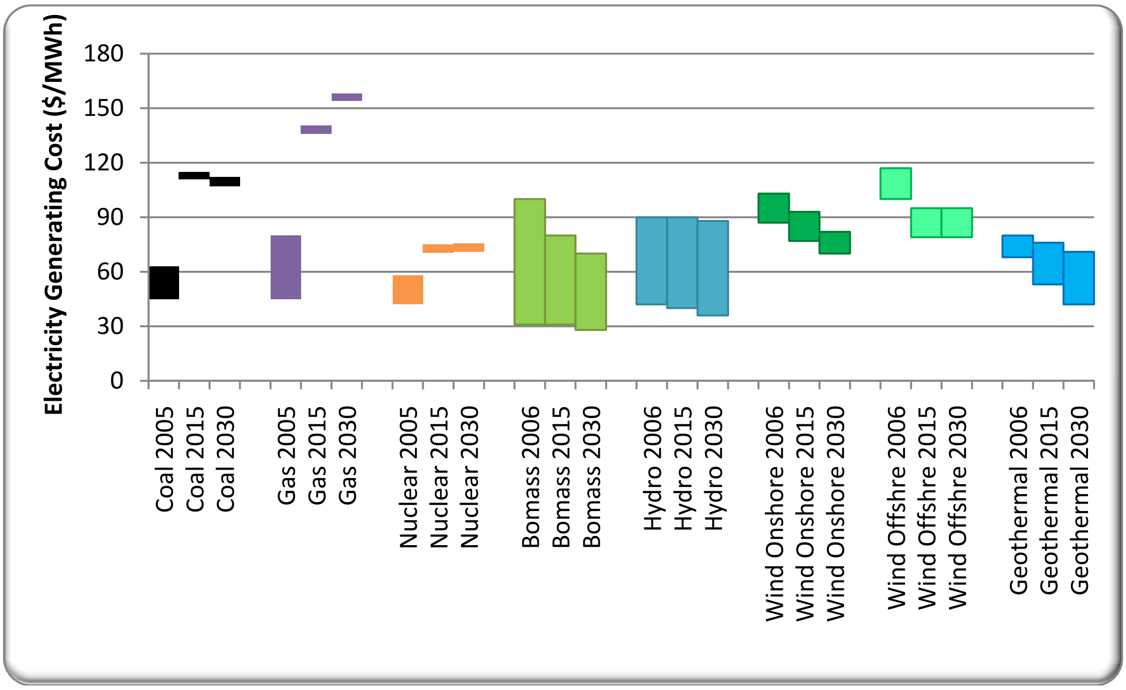
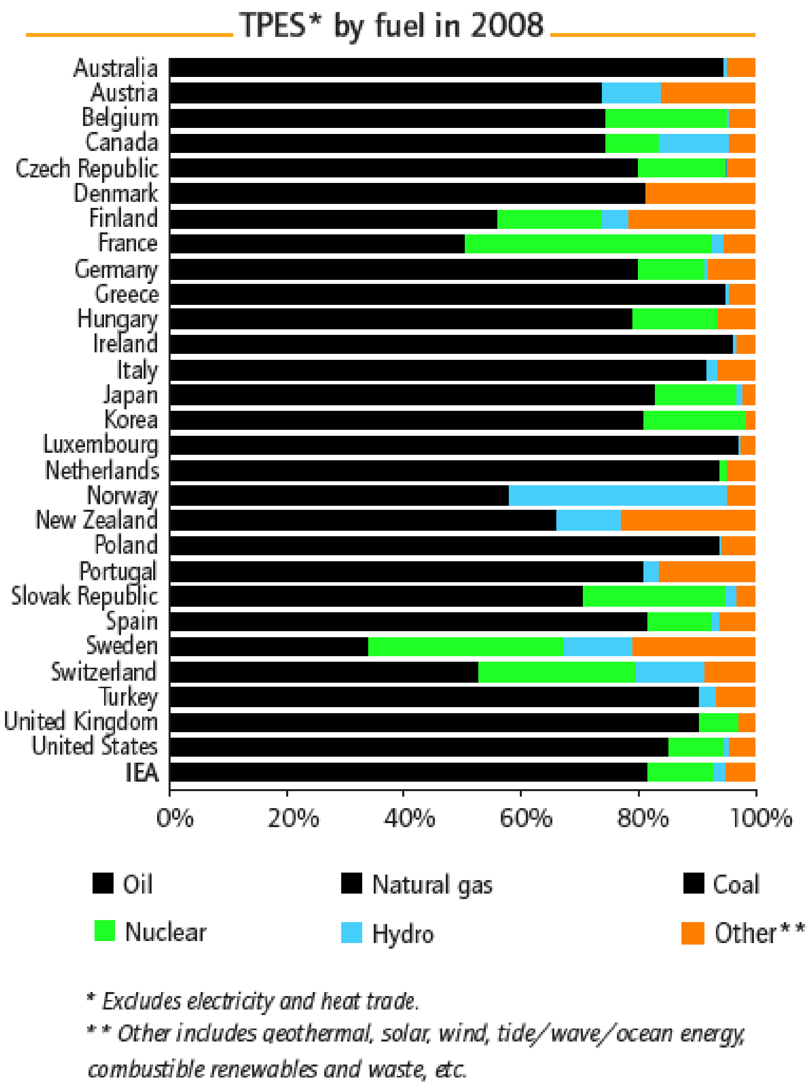


Figure 24: Current cost of renewable and fossil fuel based electricity production along with projected costs for 2015 and 2030 [19-21].



2008 TPES (Mtoe)		
World	12,267	
Coal/Peat	*3312*	*27.0%*
Oil	*4073*	*33.2%*
Gas	*2588*	*21.1%*
Total FF	**9973**	**81.3%**
Nuclear	**712**	**5.8%**
Renewables	**1313**	**10.7%**

Figure 25: TPES by fuel in 2008 for countries within the IEA [17, 18].

As displayed in Figure 26, fossil fuels began to form around 300 million years ago from the remains of dead plants and animals. Over time, the earth condensed and heated these remains to create coal, oil, and gas. Therefore, fossil fuels are effectively millions of years of solar energy stored into a solid, liquid, and gas. This enabled fossil fuels to be utilised in a very controlled and predictable fashion, which as mentioned previously, limited the competitiveness of renewable energy in the early 20th century to two technologies: hydro and biomass. Unfortunately though, these technologies cannot replace the global demand for fossil fuels: biomass competes with food production so its resource is limited and there are relatively few hydro sites remaining (Figure 27). Therefore new renewable energy technologies have been developed, but they will not be capable of the same control due to the resources that they harness.

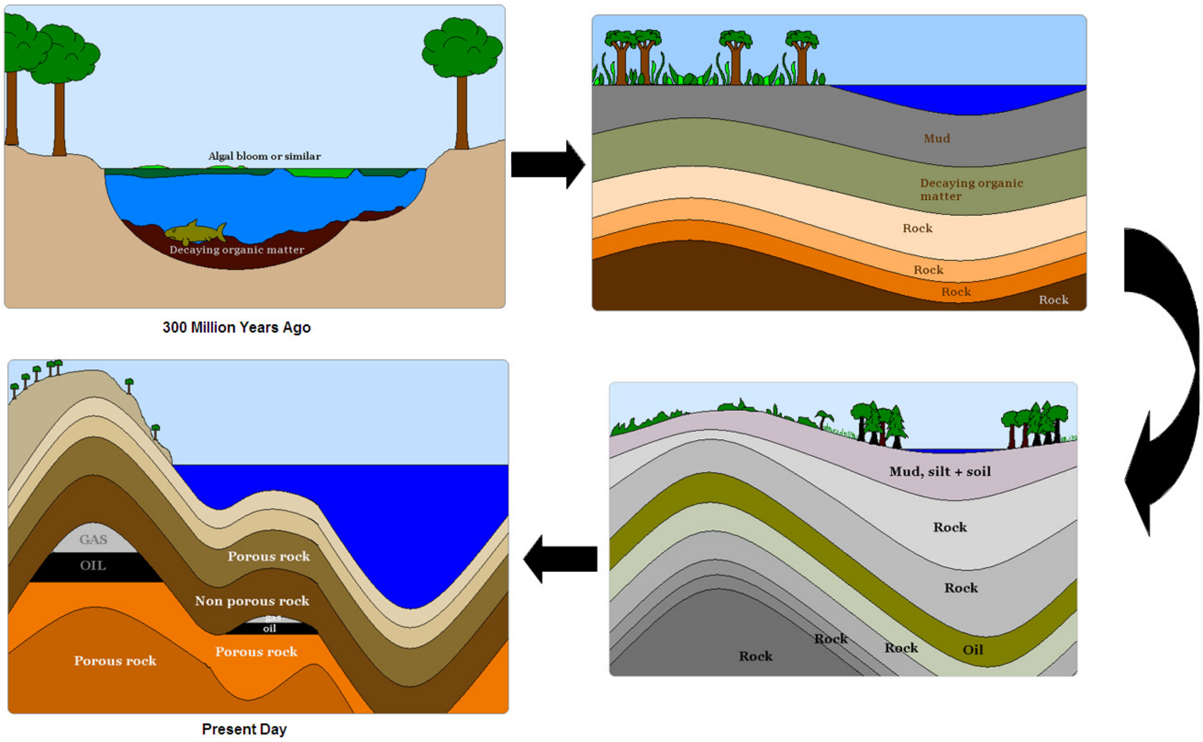


Figure 26: Formation of fossil fuels [22].

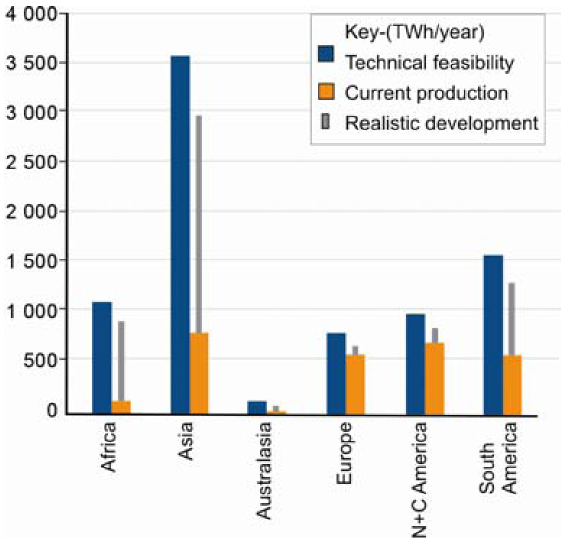


Figure 27: Global hydro resource that has been utilised and that is feasible in the future [23].

These new renewable energy devices harness resources such as wind, wave, tidal, and solar power. Naturally, these resources cannot be controlled to suit the demands of humans and hence the electricity generated from these renewable devices can vary significantly, which is portrayed in Figure 28. In addition, not only do these variations vary between technologies, they also depend on the location of the technology. As displayed in Figure 29 to Figure 32, the energy available from wind, waves, tidal, and solar is very dependent on the location of the technology around the world. As a result, renewable energy is providing a new form of varied and intermittent power onto a system which was designed to operate using dispatchable and predictable fossil fuel technologies. Therefore, it is imperative that solutions are developed which overcome this challenge as there is a significant renewable resource waiting to be utilised.

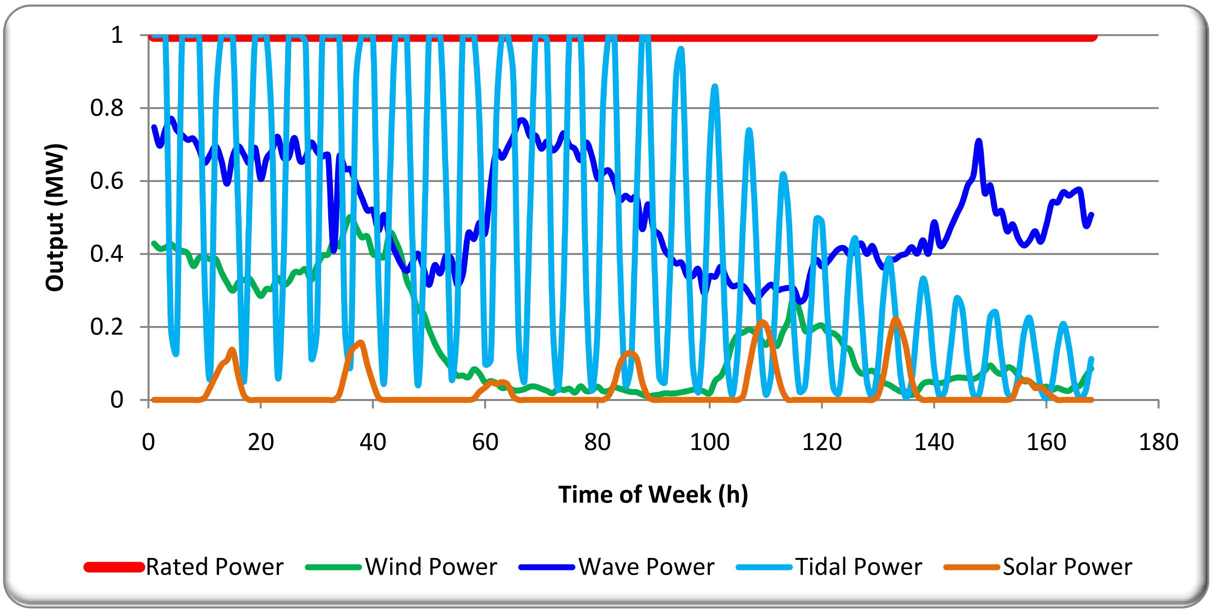


Figure 28: Predicted hourly output from a wind, wave, tidal, and solar electricity generator in Ireland during week 1 of January 2007.

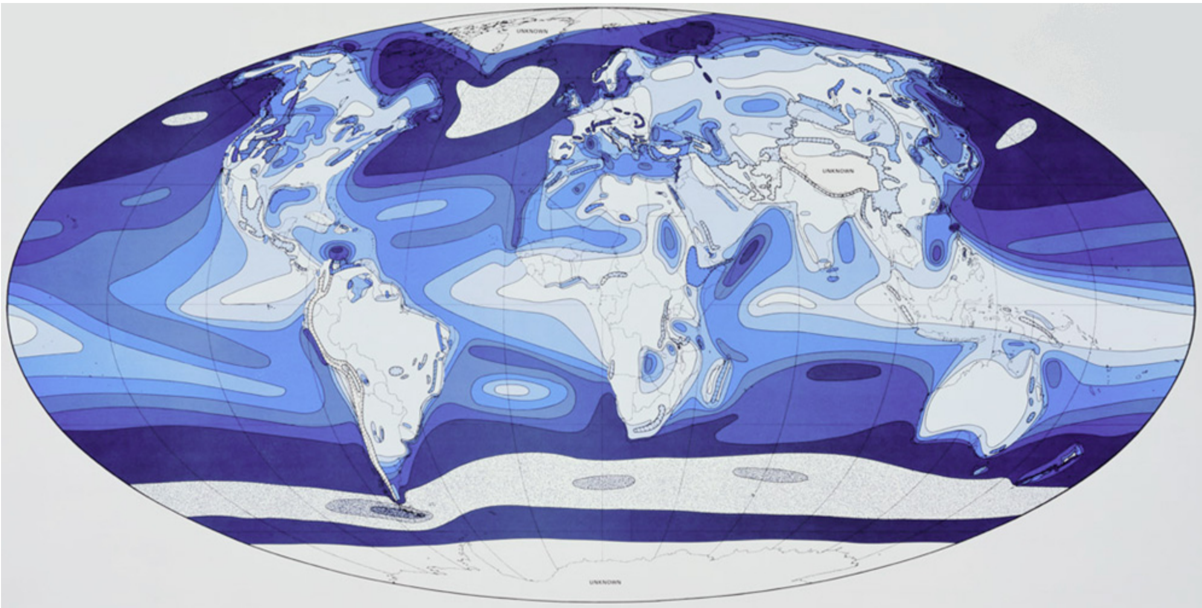


Figure 29: Global wind energy resource (darker blue areas have higher wind speeds) [24].

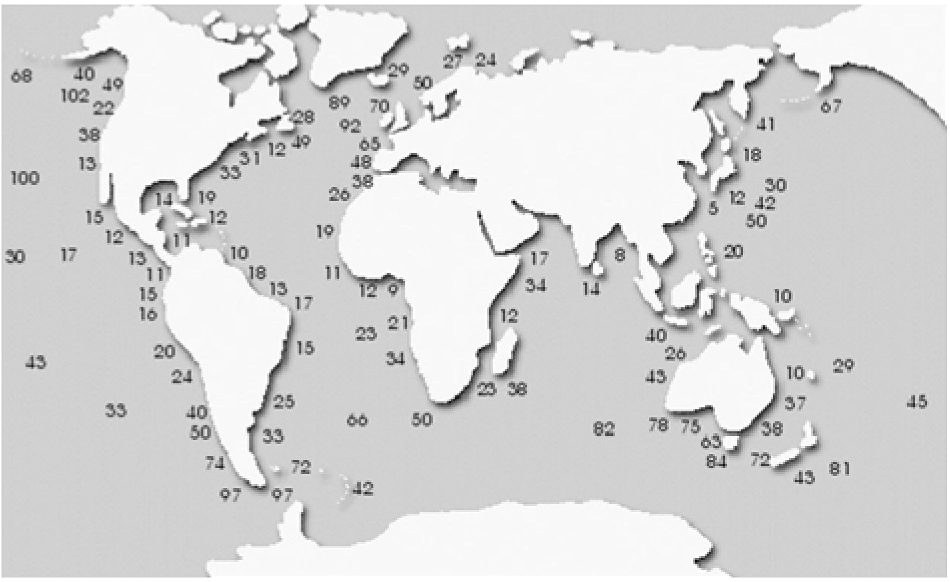


Figure 30: Estimated global wave energy power in kW [23].

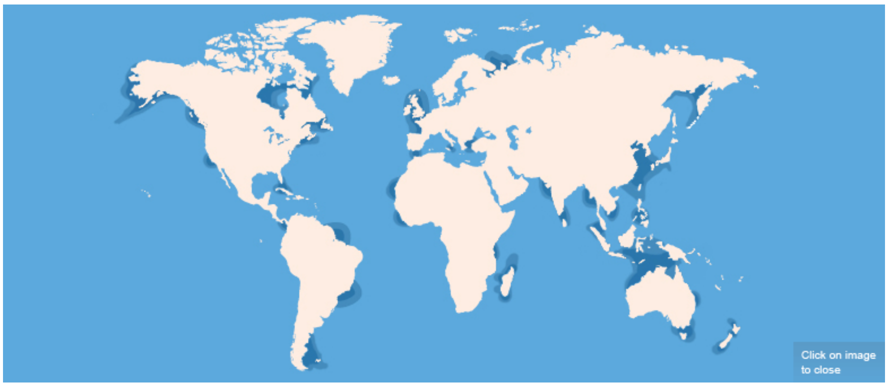


Figure 31: Global tidal energy resource [25].

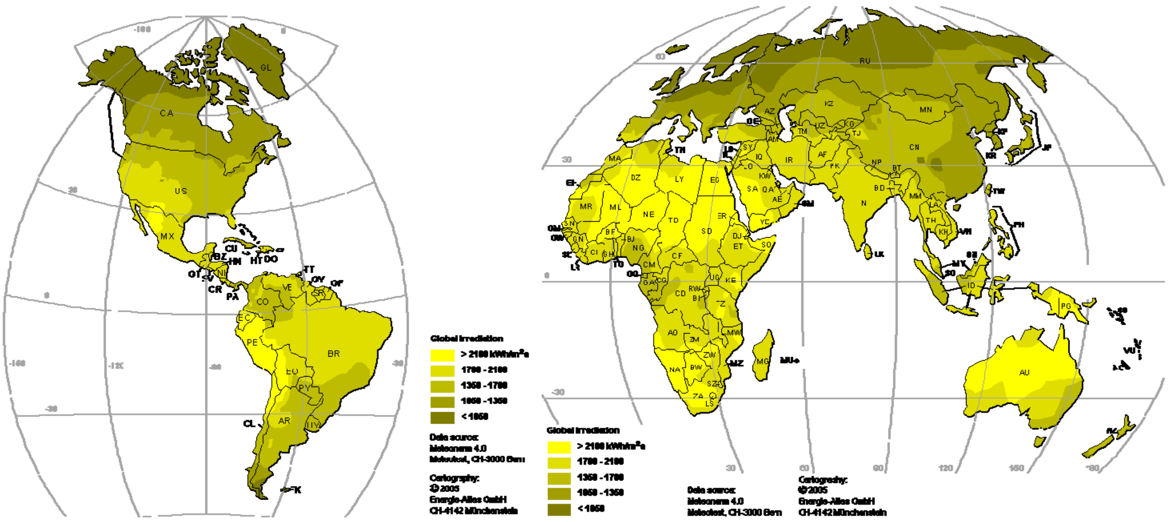


Figure 32: Global solar energy resource [26].

6 Summary

Climate change is already being witnessed around the globe through increasing temperatures, rising sea levels, and decreasing snow cover. However, these changes are expected to intensify as more GHG emissions are emitted to the atmosphere. After analysing the source of GHG emissions in the atmosphere, it is evident that 83% of total GHG emissions are related to energy, primarily the burning of fossil fuels. Therefore, to minimise the impact of any future climate changes, the energy sector needs to be decarbonised. After analysing the current and projected trends in global energy production, it is clear that the world's dependence on fossil fuels will increase and hence, GHG emissions will also increase. In addition, due to the scale of the world's fossil fuel dependence it is currently predicted that oil and gas resources will have depleted within the next century. Therefore, from both an environmental and a sustainability perspective, it is essential that the world eradicates its addiction to fossil fuels.

Renewable energy is one potential solution to this global problem. This investigation illustrates that renewable technologies are now competitive with fossil fuel alternatives and there is a significant renewable resource spread across the entire globe.

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