THRIVING WITHIN
PLANETARY BOUNDARIES
Net Zero Emissions by 2030

Seniors Climate Action Network (SCAN)

27 December 2021

INTRODUCTION

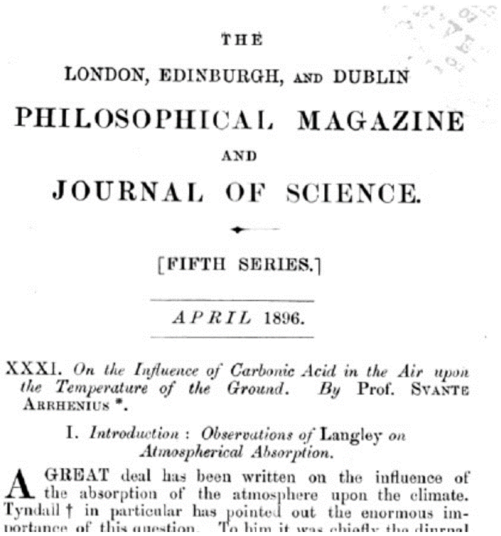
Seniors Climate Action Network, or SCAN for short, is a group of citizens in Dunedin, New Zealand. We are concerned about the current lack of action to mitigate the impact of climate change. SCAN wants to leave behind a better legacy for our grandchildren than the one which is currently developing.

In November 2021, we submitted a 49-page Emissions Reduction Plan to the New Zealand Ministry for the Environment (MFE). Our submission puts forward the case for Net Zero Emissions by 2030 in New Zealand and includes a comprehensive list of actions that the New Zealand government, City Councils, Regional Councils, and communities should adopt to achieve this. Our revised submission can be downloaded here

For many New Zealanders, targeting Net Zero Emissions by 2030 instead of by 2050 is a big ask. Our submission provides a detailed argument backed up by evidence why we need to do this and our reasons for achieving Net Zero Emissions by 2030 are based on reliable sources of information which does not include publications in magazines, newspapers, and websites. Instead, our sources of information are based on the most up-to-date peer reviewed publications published in top ranking international journals and reputable research organisations such as the International Panel on Climate Change and the United Nations. We have based our submission on original primary sources of information and these are fully referenced in our submission. This publication is based on our above submission to MFE and is written for communities in New Zealand and elsewhere.

HISTORY OF CLIMATE CHANGE

The role of carbon dioxide (CO_2) in the atmosphere and the greenhouse gas effect was known over a century ago by scientists. Svante Arrhenius published a paper on climate change in a peer reviewed international journal in 1896 as shown in Figure 1.



THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

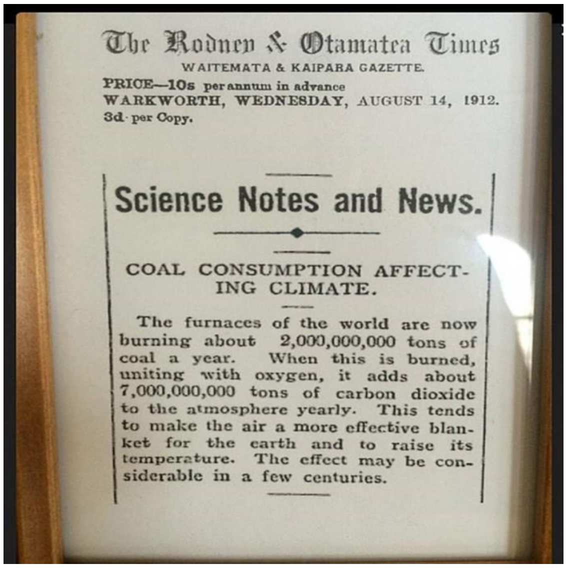
XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* *By* Prof. SVANTE ARRHENIUS *.

I. *Introduction : Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal

Figure 1: Svante Arrhenius April 1896

A few years later, the general public was also aware of the global warming effect of CO_2 in the atmosphere due to the burning of fossil fuels. Figure 2 shows an example of a publication in a New Zealand newspaper, The Rodney & Otamatea Times, published in 1912.



The Rodney & Otamatea Times
WAITEMATA & KAIPARA GAZETTE.
PRICE—10s per annum in advance
WARKWORTH, WEDNESDAY, AUGUST 14, 1912.
3d. per Copy.

Science Notes and News.

◆

COAL CONSUMPTION AFFECTING CLIMATE.

The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

Figure 2: The Rodney & Otamatea Times 1912

A century later, virtually every nation in the world agreed to work together to achieve net zero greenhouse gas emissions by 2050 in the 2015 Paris Agreement. The 2015 Paris Agreement was adopted by a resolution of the United Nations General Assembly. The target of the2015 Paris Agreement was to hold the global average temperature to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increases to 1.5 degrees Celsius. Reductions would be undertaken in accordance with the best science and on the basis of equity. It was recognised that the less-developed nations would require financial assistance from the well-developed nations. The 2015 Paris Agreement recognised that business-as-usual emissions of greenhouse gases must be curbed. Adoption of a carbon budget was agreed upon. The budget is an annual reducing budget, the total size of which is represented by the area under the curve of projected reductions in carbon dioxide emissions as shown in Figure 3.

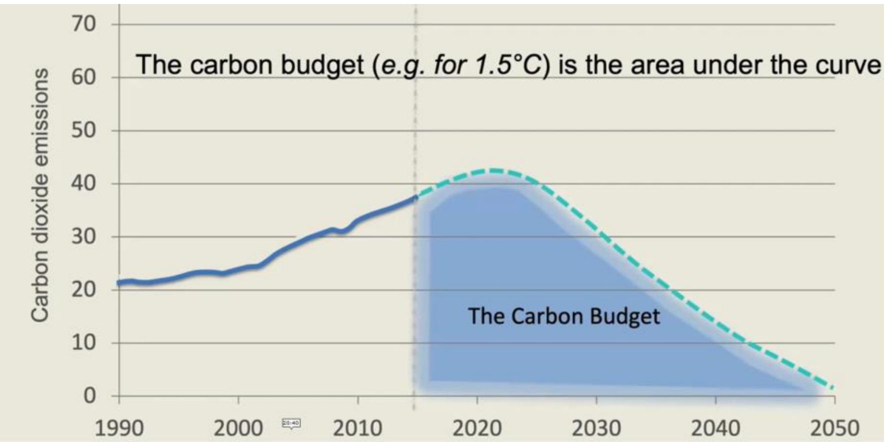


Figure 3: Carbon Budget Required to Mitigate the Impact of Climate Change

Unfortunately, there is a smoke and mirror difference between agreement by world leaders and actual action. Action by our world leaders to mitigate the impact of climate change have been repeatedly delayed until the next meeting. Meeting after meeting has resulted in a lot of hot air. Greta Thunberg has summarised these meetings as being blah, blah, blah. The COP26 meeting held in November 2021 was no different. Over the last 50 years there have been over 34 climate conferences, a half dozen major international climate agreements and various scientist's warnings. Greenhouse gases emissions have continued to accumulate in the atmosphere unabated. Action to match the words have so far been a dismal failure.

In 2019, New Zealand declared a Climate Emergency. As of November 2021, there has been so far no sweeping and rapid social change in New Zealand towards mitigating the impact of climate change. New Zealand's Net Zero Carbon by 2050 policy essentially supports incremental adjustments to business as usual.

Climate Action Tracker has published a November 2021 update.

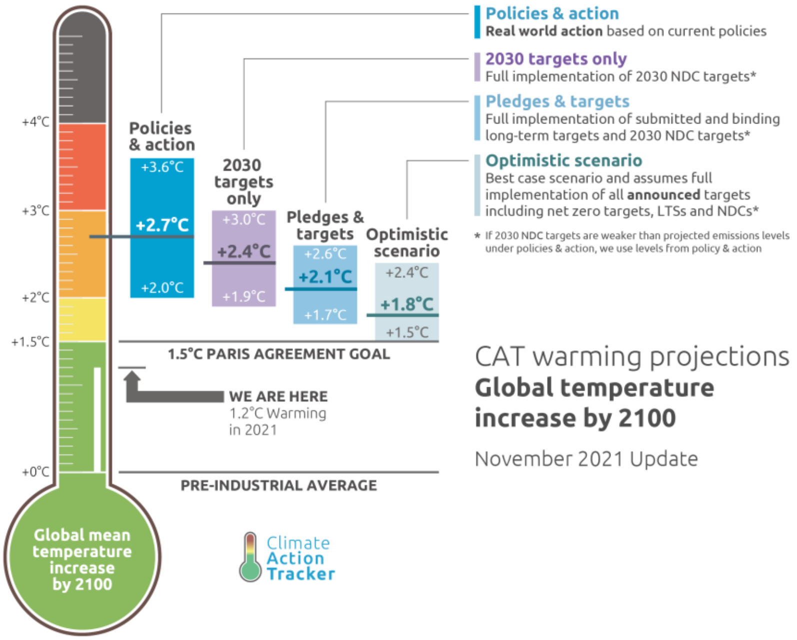


Figure 4: Carbon Action Tracker (2021)

As of November 2021, climate warming is 1.2 degrees Celsius above pre-industrial levels. In a best case optimistic scenario which assumes full implementation of all announced targets, our climate would be heading towards 1.8 degrees Celsius and as high as 2.4 degrees Celsius above pre-industrial levels by 2100. More commitment is required to keep under 1.5 degrees Celsius. In a real world action scenario based on current policies, our climate would be heading towards 2.7 degrees Celsius and as high as 3.6 degrees Celsius above pre-industrial levels by 2100. This scenario represents a severe existential threat to all life forms on Earth. Urgent action is now more than ever necessary, but the focus of world leaders is currently on COVID-19.

Most people in many countries agree that climate change in the long-term is as serious a crisis as Covid-19. However, focus of attention is on the short-term and immediate impact of Covid-19. Climate change is not going to go away, and the longer we delay in reducing our greenhouse gas emissions, the more greenhouse gases accumulate in the atmosphere, and the more dire the impact of climate change becomes. Immediate action is required on both fronts.

PLANETARY BOUNDARIES

Our planet Earth has a carrying capacity which supports myriads of life forms in various ecosystems, including that of humans. The survival of humans depends on the survival of ecosystems and the life forms supported by those ecosystems. If we overshoot the carrying capacity of our ecosystems, then that carrying capacity degrades. Earth would no longer be able to support the same number of life forms, including that of humans.

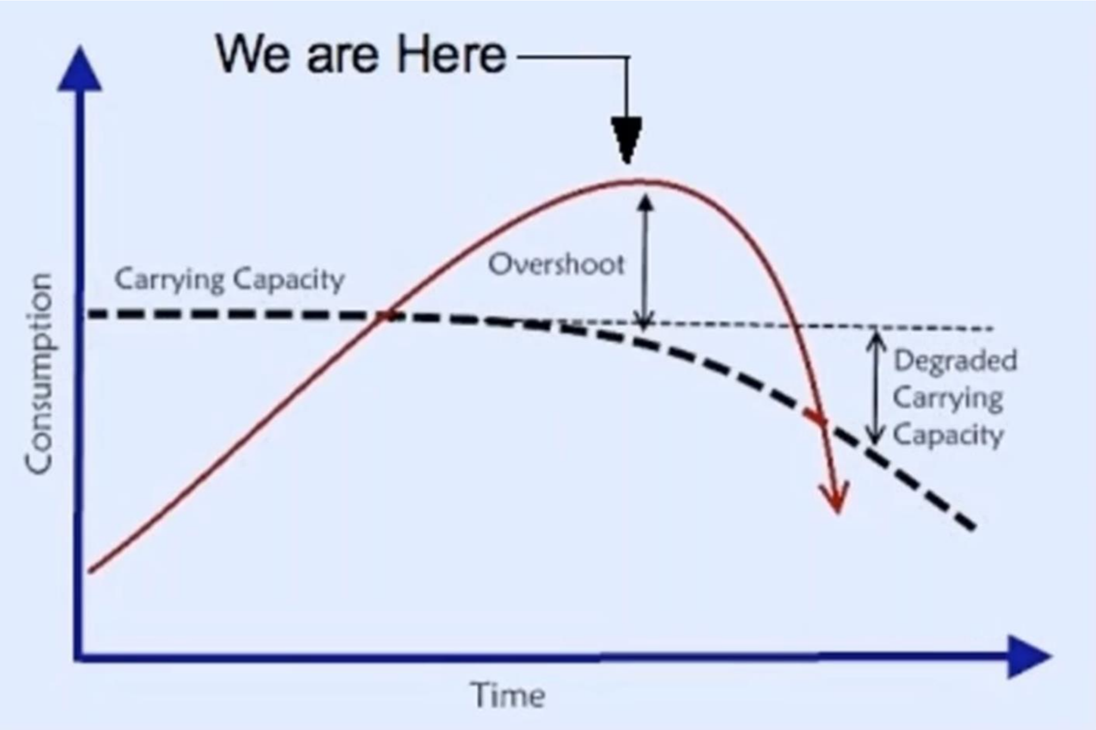


Figure 5: Overshooting Earth's Carrying Capacity

Johan Rockström and colleagues (2009) identified 10 planetary boundaries which must not be exceeded in order to ensure a sustainable future for life on Earth. These boundaries are interlinked, and crossing certain biophysical thresholds can only but have disastrous consequences for humans and other life forms. Human activity has the potential to overshoot the threshold of all these planetary boundaries. Climate change is but only one of many boundaries of overshoot. Other planetary boundaries include ocean acidification, ozone depletion, the nitrogen cycle, the phosphorous cycle, freshwater use, deforestation, biodiversity loss, particle pollution, and chemical pollution.

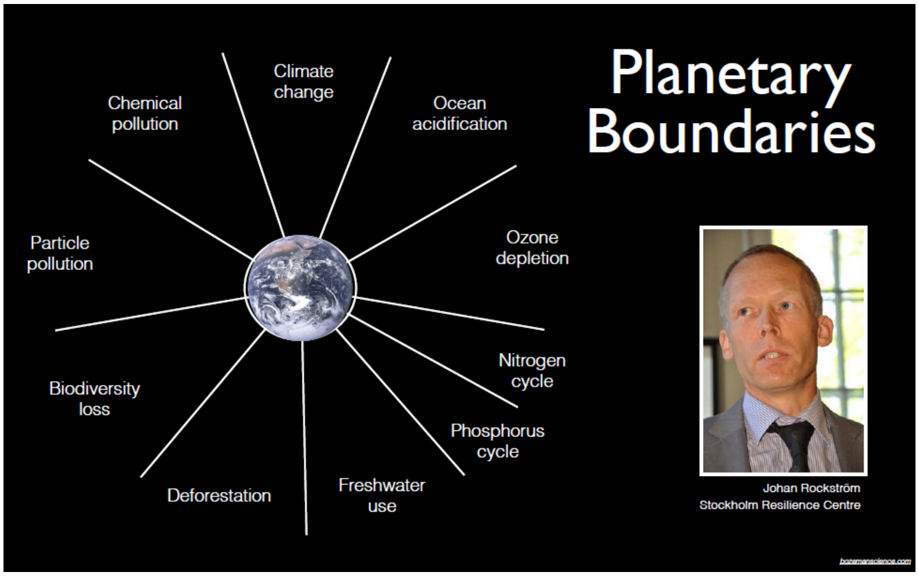


Figure 6: Planetary Boundaries (Rockström et al. 2009)

In 2015, Will Steffen and colleagues identified the extent that planetary boundaries are at risk. In Figure 7, the zones of planetary boundaries which are safe are coloured green, those subject to uncertain but increasing risk are coloured yellow, and those subject to high risk beyond uncertainty are coloured red. The safe thresholds of three of the planetary boundaries – genetic diversity, flows of phosphorous, and flows of nitrogen – have already been well exceeded. A critical boundary is phosphorous which is essential as a nutrient for all life forms. Climate change is in a zone of uncertain increasing risk. Continued climate change will exacerbate the overshoot of several other planetary boundaries.

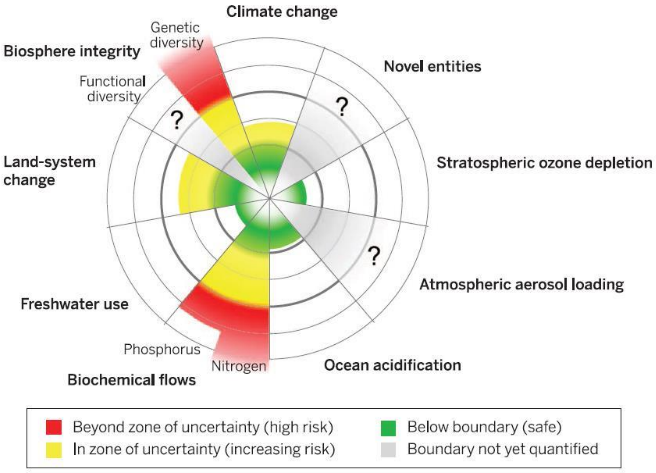


Figure 7: Planetary Boundaries Zones of Risk (Steffen et al. 2015)

Mathis Wackernagel and colleagues (2021) researched the ecological footprint of humans and estimated that in 2020, the demand of humans on biological resources exceeded the amount that Earth's ecosystems produce by at least 56%. Moderate business-as-usual can only but further exceed our demands on biological resources. We need to rapidly reduce our demands. To do otherwise will result in degradation of the carrying capacity of biological resources upon which we rely on for our survival.

EXPONENTIAL GROWTH IN WORLD POPULATION

For 10,000 years the world population grew very slowly until 1800. The world population by then had reached almost one billion people. From then onwards, the rate of exponential growth increased.

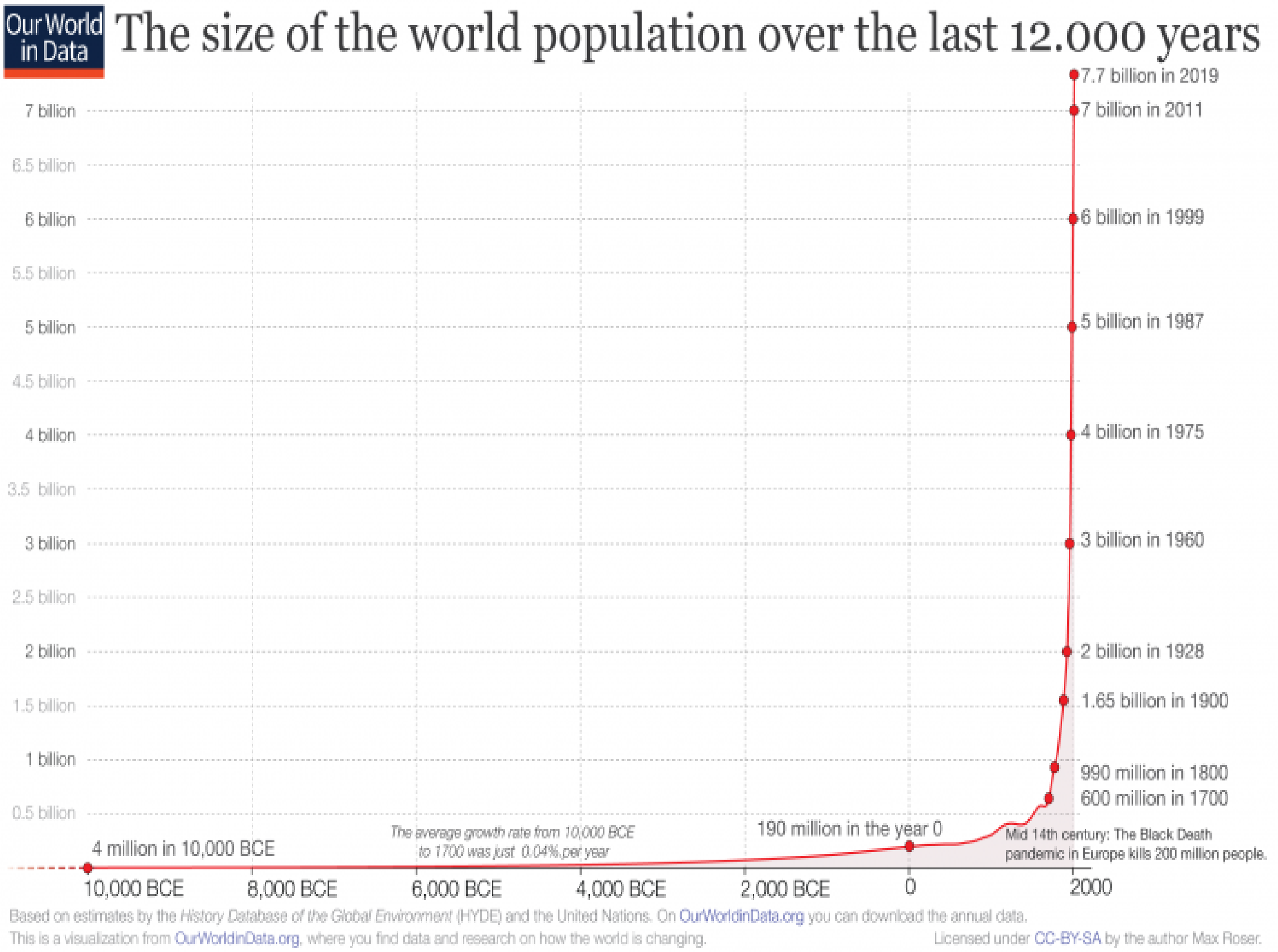
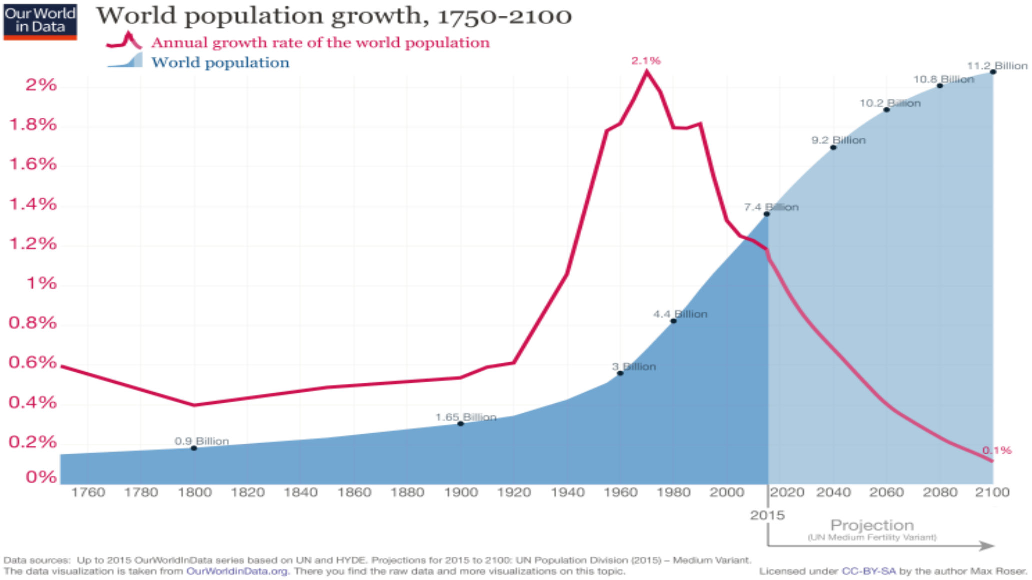


Figure 8: Exponential Growth in World Population (Our World in Data 2021)

The doubling time of any entity which is growing exponentially is the time it takes to double in size. The doubling time is approximately 72 divided by the annual percentage rate of growth. For example, if a population is growing at an exponential rate of 2% per year, then the doubling time is 36 years.

In 1803, the world population was one billion people. By the end of 1927, the world population had grown to 2 billion people, a doubling time of 124 years. By 1975, the world population had grown to 4 billion people, a doubling time of 48 years. The most rapid growth rate in the world population occurred in the 1950s and 1960s peaking at 2.1% per year in 1971. From 1971 onwards, the world population growth rate started to decline. In recent years, we have been adding about 80 million people to the world population every year. The current world population in 2021 is 7.9 billion people (Our World in Data 2021). The United Nations Population Division expects the world population to level out at 10.9 billion by the end of this century.



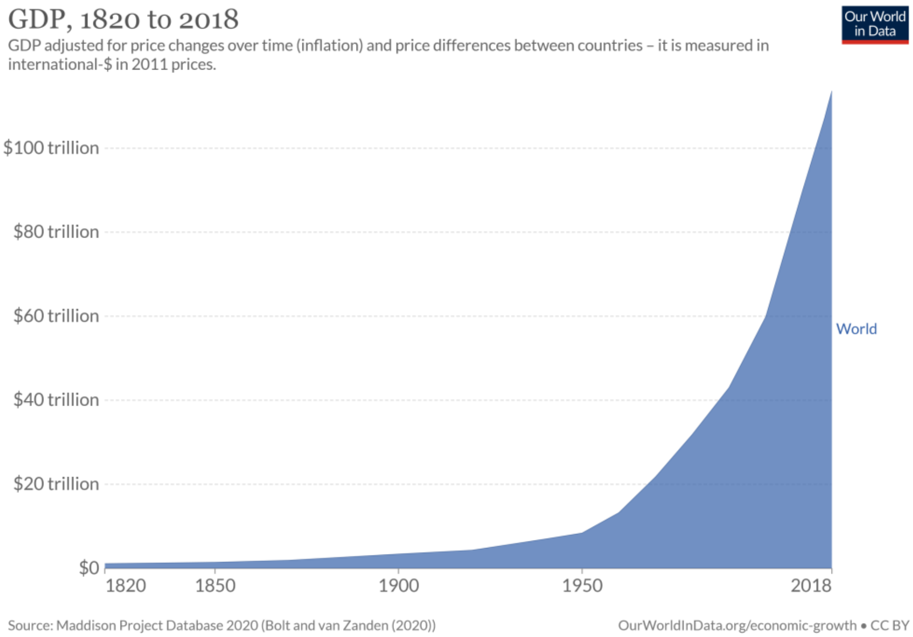
Data sources: Up to 2015 OurWorldInData series based on UN and HYDE. Projections for 2015 to 2100: UN Population Division (2015) – Medium Variant.
The data visualization is taken from OurWorldinData.org. There you find the raw data and more visualizations on this topic.

Licensed under CC-BY-SA by the author Max Roser.

Figure 9: World Population Growth 1750-2100 (Our World in Data 2021)

EXPONENTIAL GROWTH IN GDP

GDP is a measure of economic activity in an economy both good or bad, and it has grown exponentially since the start of the industrial revolution and the use of coal in steam engines. Growth in GDP accelerated with the discovery and drilling of oil fields in the late 1800s (Hall & Klitgaard 2018).



Source: Maddison Project Database 2020 (Bolt and van Zanden (2020))

OurWorldInData.org/economic-growth • CC BY

Figure 10: Exponential Growth in GDP (Our World in Data 2021)

GDP per capita has also grown exponentially since the start of the industrial revolution. The most rapid rate of growth in GDP per capita shown in green has been in the United States, Canada, Australia, and New Zealand. The rate of growth in the average world GDP per capita shown in black has been much slower.

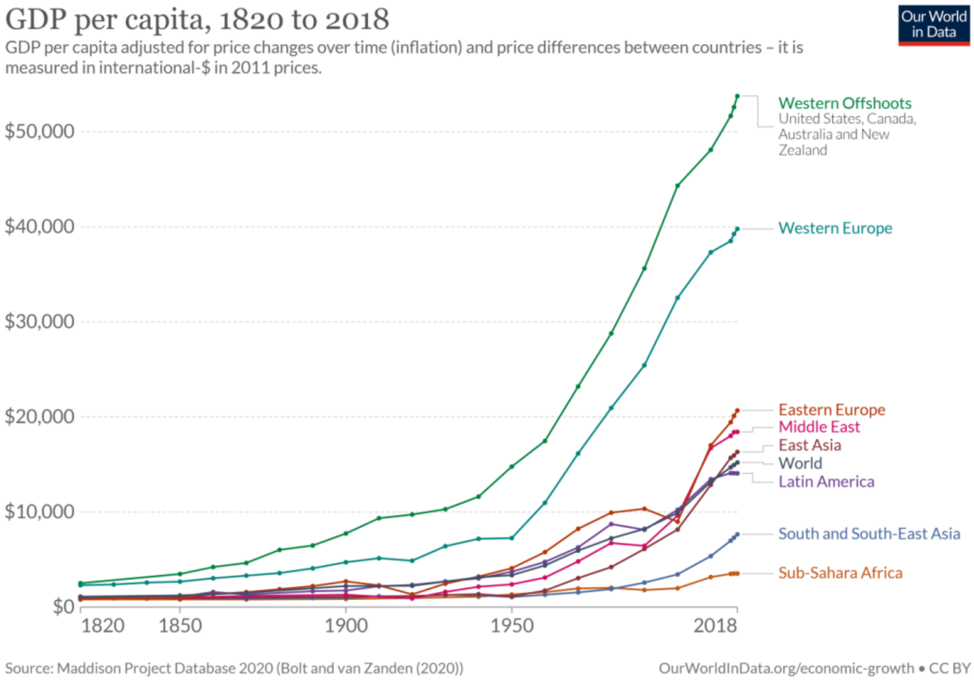


Figure 11: Exponential Growth in GDP per Capita (Our World in Data 2021)

GLOBAL CONSUMPTION OF FOSSIL FUELS

Economic growth has been possible due to the exploration, mining, and drilling of fossil fuels (Hall & Klitgaard 2018). As much fossil fuel energy used from 1800 until 1990, a period of 190 years, was used over a 30-year period from 1990 until 2020. Advocates of economic growth currently target a continued economic growth rate of 3% per year. This exponential rate of growth would require the use of as much energy as has been used since 1800 until 2021 over the next 24 years.

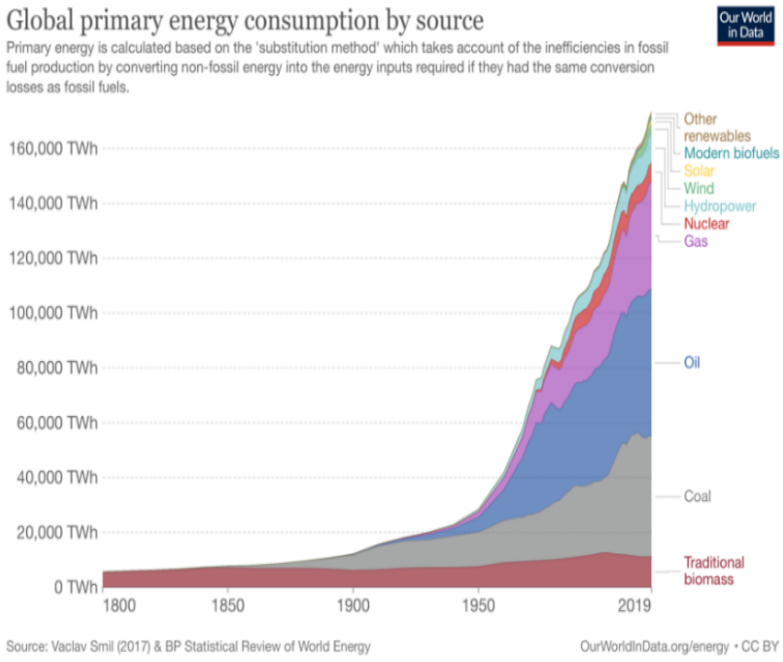


Figure 12: Global Consumption of Fossil Fuels (Our World in Data 2021)

The increase in the rate of population growth from the 1950s to the 1970s was enabled by the green agricultural revolution when traditional farming practices were replaced by artificial fertilisers, pesticides, and farm machinery. In 1971, Howard Odum pointed out that people were effectively eating oil as a result of the green agricultural revolution. This is even more so the case today with subsequent increases in the lengths of supply chains from the farm gate to the plate of each consumer due to the increase in globalisation of food production.

Figure 13: Industrialisation of Food Production

THE BIGGEST SOURCES OF GREENHOUSE GASES

It is now well established and accepted by most that climate change is a reality due to the emissions of greenhouse gas emissions (Myers et al. 2021). There are many different sources of greenhouse gas emissions as shown in Figure 14. Most of these emissions are the result of burning fossil fuels.

Figure 14: The Biggest Sources of Greenhouse Gases (Climate Reality Project 2019)

Each link in a web of supply chains from the original sources of fossil fuels in the ground to the goods and services enjoyed by consumers involves additional greenhouse gas emissions which accumulate in the atmosphere.

TIPPING ELEMENTS AT RISK

A tipping point in our climate system is a threshold which, if exceeded, leads to abrupt and large changes in the state of the system. Some of these changes can be irreversible. Timothy Lenton and colleagues (2008) identified nine tipping points and Will Steffen and colleagues (2018) have identified which tipping elements are most at risk.

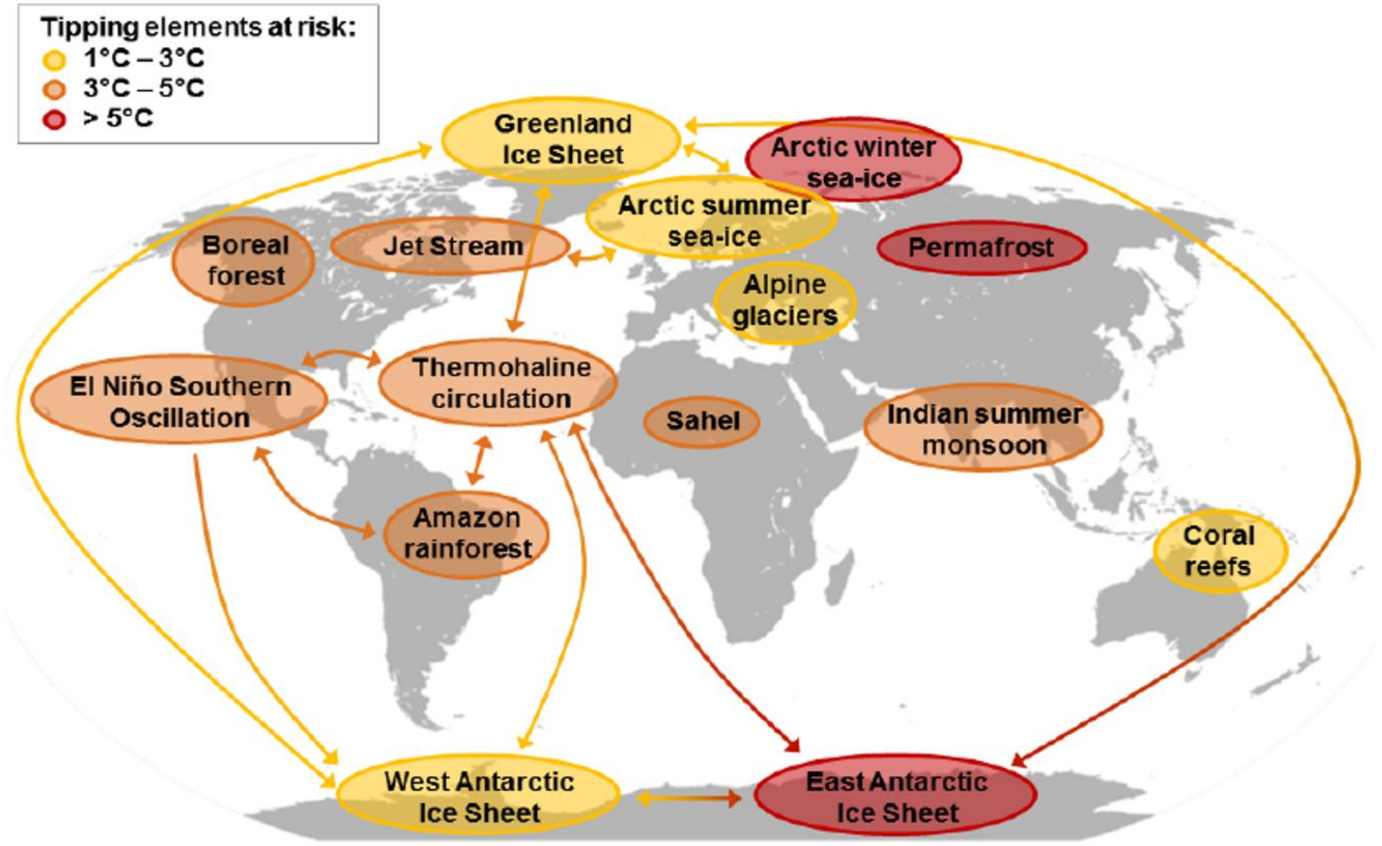


Figure 15: Tipping Elements at Risk (Steffen et al. 2018)

Because different climate systems are interconnected, one system can have an impact on another. The arrows in Figure 15 show the potential interactions among tipping elements. Each increase in global warming risks a domino like cascade where a series of tipping point thresholds are exceeded.

The Greenland ice sheet, Arctic summer sea ice, alpine glaciers, coral reefs, and West Antarctic ice sheets are already undergoing change with a 1.0 degree Celsius increase in global warming above preindustrial levels. Sea ice reflects more sunlight into outer space than uncovered water where sea ice used to be. With each melting of sea ice, the oceans absorb more heat which increases the level of global warming. The melting of sea ice involves a positive feedback loop where the melting of sea ice results in an acceleration in the melting of more sea ice.

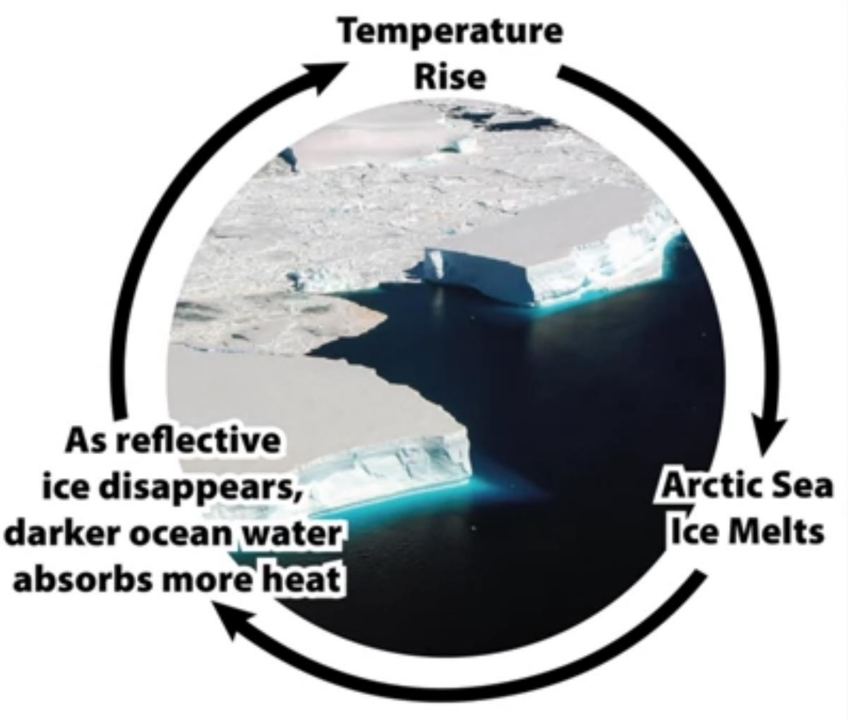


Figure 16: Positive Feedback Loop of Melting of Melting of Sea Ice

An existential life-threatening tipping element is the thawing of permafrost. Tundra is located in a large treeless plain in the Arctic regions where the subsoil is frozen.

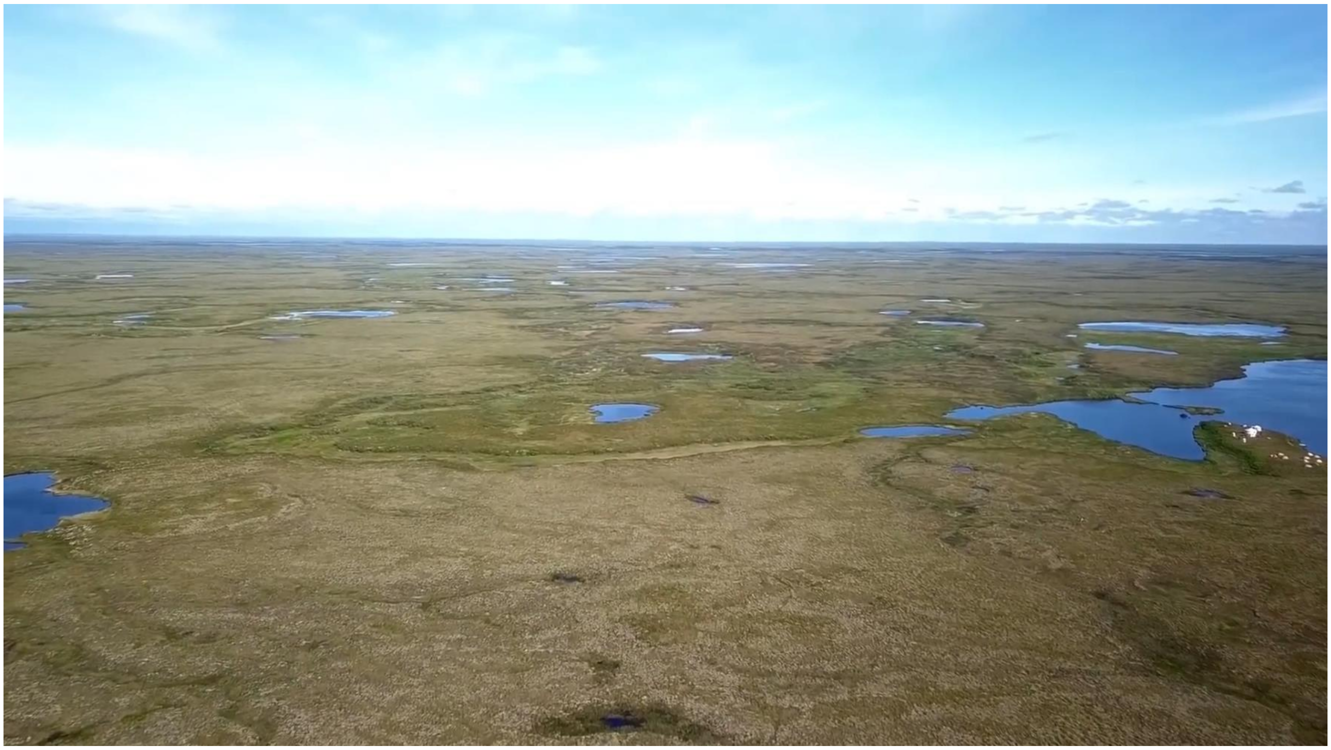


Figure 17: Tundra in Arctic Regions

This frozen subsoil, or permafrost, holds a vast amount of carbon accumulated from dead plants and animals over thousands of years.

The units of carbon stock in Figure 18 are in Petagrams. That is one gram multiplied by ten to the power of fifteen - in other words multiplied by 10 fifteen times. The atmosphere holds about 589 Petagrams and permafrost stores about 1,700 Petagrams. There is much more carbon locked in permafrost than is currently in the Earth's atmosphere.

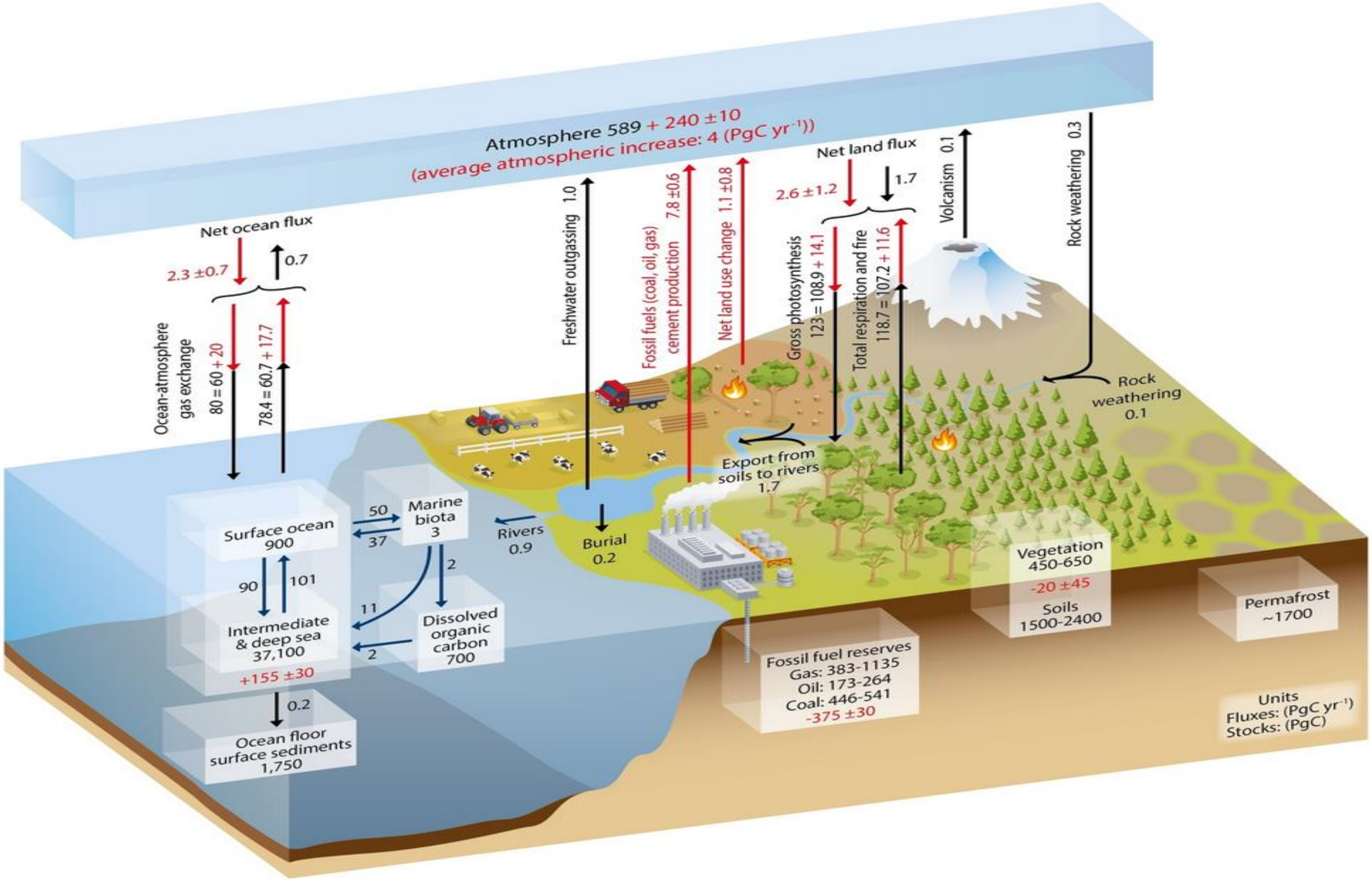


Figure 18 : Location of Carbon in the Biosphere

There is a side issue here. Carbon is also stored in the ground in the form of fossil fuels reserves. These reserves include gas (383 - 1,134 Petagrams), oil (173 - 264 Petagrams), and coal (446 - 541 Petagrams). The carbon locked in these fossil fuels far exceed that of carbon in the atmosphere. A year before the 2015 Paris Agreement, Christophe McGlade and Paul Ekins (2014) cautioned that most of these fossil fuel reserves must stay in the ground. At the 2015 Paris Agreement, nations agreed to restrict their use of fossil fuels and keep within a carbon budget in order to achieve net zero greenhouse emissions by 2050. But many countries have continued to explore for more reserves of fossil fuels. By doing so, these countries contravene the spirit of the 2015 Paris Agreement and use part of the agreed global carbon budget in exploration for more fossil fuels which should be used to transition from fossil fuels to renewable energy and infrastructure.

As the climate warms, permafrost begins to thaw. This brings microbes in the soil out of hibernation, allowing them to break down the organic carbon in the soil. This process releases CO_2 and, to a lesser extent, methane which is a far more potent greenhouse gas than CO_2.

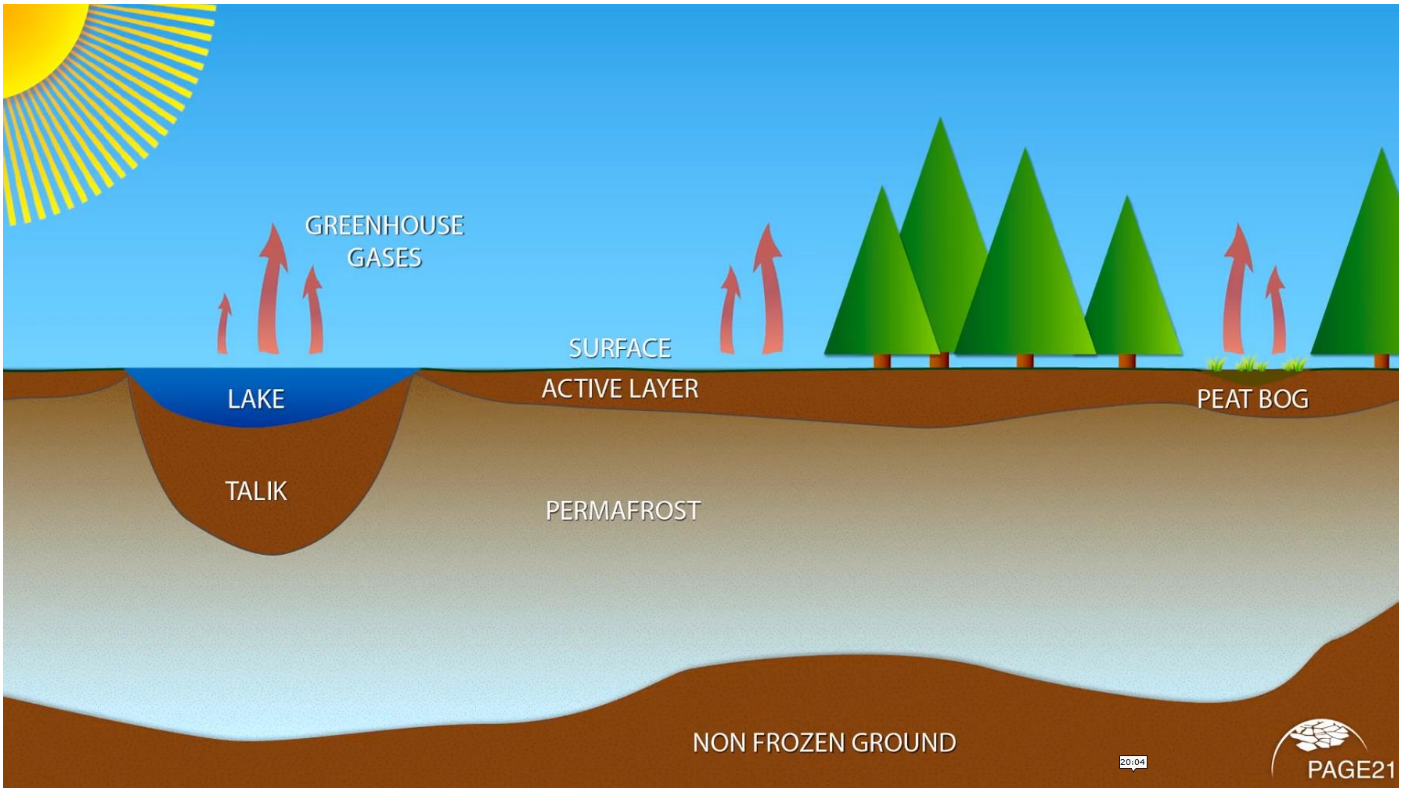


Figure 19: Thawing of Permafrost

There is already evidence of permafrost thawing. Large scale thawing of permafrost would result in irreversible change in climate. The result would be a hothouse Earth where no life forms can survive.

Figure 20: Example of Current Thawing of Permafrost

HOTHOUSE EARTH

In their study of tipping elements at risk, Will Steffen and colleagues (2018) conclude:

> "Our analysis suggests that the Earth System may be approaching a planetary threshold that could lock in a continuing rapid pathway toward much hotter conditions - Hothouse Earth".

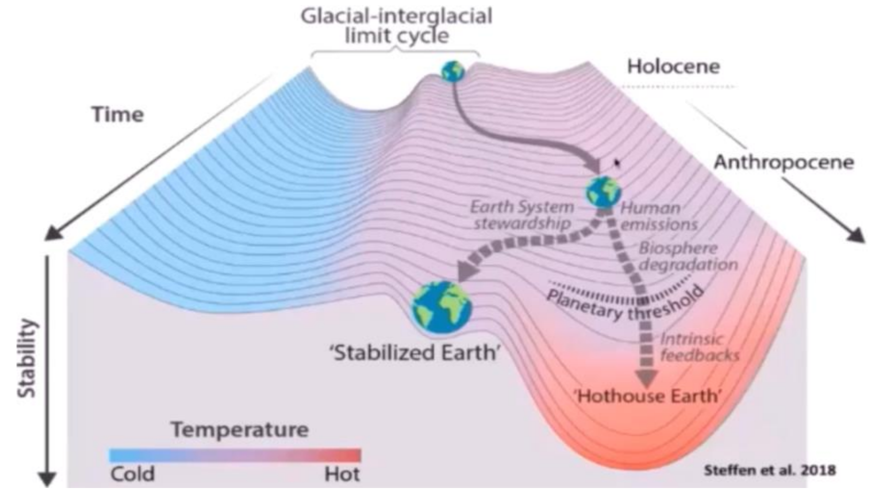


Figure 21: Hot House Earth (Steffen et al. 2018)

In 2021 the International Panel on Climate Change (IPCC 2021) reported that global temperatures are likely to rise by more than 1.5 degree Celsius above pre-industrial levels over the next two decades (IPCC 2021). This would cause widespread devastation and more extreme weather. Only rapid and drastic reductions in greenhouse gases in this decade can prevent climate breakdown. Every fraction of a degree of further heating is likely to compound the accelerating effects of climate change.

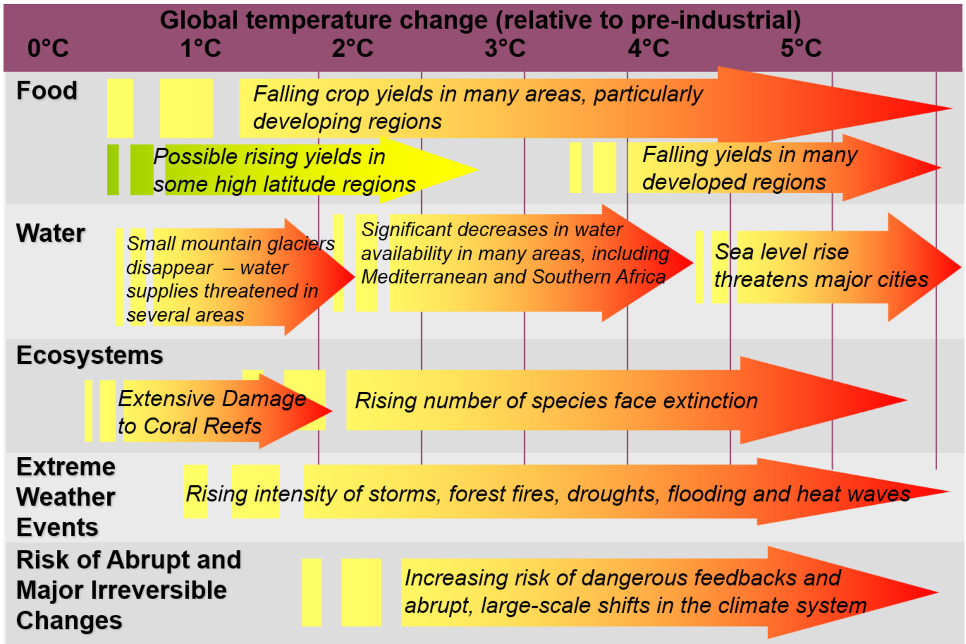


Figure 22: Impact of Climate Change

Climate change scientists have estimated the impact of climate change on food, water, ecosystems, extreme weather events, and the risk of abrupt and irreversible changes. Negative changes are coloured with an increasing intensity of red for each increase in global temperatures above pre-industrial levels. Neutral changes are coloured yellow, and positive changes are coloured green.

Reports by the IPCC are couched in terms of risk and probability because any field of science does not and cannot provide absolute certainty. All knowledge based on science is provisional. What distinguishes genuine science from pseudoscience is its willingness to allow evidence to confirm or challenge its theories.

A strong pattern of climate science has developed over the last number of decades. With each increase in the understanding of our global climate systems, the more dire are the conclusions of climate scientists as to where our global climate system is currently heading due to insufficient action to reduce greenhouse gas emissions.

THE PRECAUTIONARY PRINCIPLE

Taleb and colleagues (2014) summarise the Precautionary Principle as follows:

> "The precautionary principle (PP) states that if an action or policy has a suspected risk of causing severe harm to the public domain (affecting general health or the environment globally), the action should not be taken in the absence of scientific near-certainty about its safety. Under these conditions, the burden of proof about absence of harm falls on those proposing an action, not those opposing it."

"Climate change is now reaching the end-game… the issue is the very survival of our civilisation."
– Prof. Hans Joachim Schellnhuber

Prof Hans Joachim Schellnhuber

For twenty years the Head of the Potsdam Institute for Climate Impact Research, senior advisor to Pope Francis, German Chancellor Angela Merkel and the European Union

WHAT LIES BENEATH
The Understatement Of Existential Climate Risk (2018)
Written by: David Spratt & Ian Dunlop
Foreword by: Hans Joachim Schellnhuber

Figure 23: Climate Change forms an Existential Threat

The action of burning fossil fuels accompanied by greenhouse gas emissions to the atmosphere falls well within the category of applying the Precautionary Principle because failure to cease burning fossil fuels sufficiently quickly would result in an existential threat to all forms of life on Earth. When confronted by a lack of absolute certainty, and especially when risks involve existential threats, the Precautionary Principle as adopted by the United Nations (Tichner et al. 1999) must be abided by all nations, including New Zealand.

We have a choice to make here for the sake of the survival of our own species and all other species on Earth. The choice we have is either a Hothouse Earth where we are currently heading or a Stabilized Earth. Lack of absolute certainty must not be allowed to be an excuse for any further delays in necessary action to mitigate the impact of climate change. The longer we delay action, the greater is the risk of a Hothouse Earth.

In order to avoid the prospect of a hot-house Earth, we need to reduce and eliminate our use of fossil fuels as an energy source. But we are totally reliant on high grade energy and materials for our survival. We have a choice here.

Figure 24: Our Energy Choice

Unless we are prepared to adopt a hunter-gatherer existence, we have no choice but to transition from fossil fuels to high grade renewable energy and infrastructure. We first need to examine fossil fuels in some detail in order to better understand the nature of our true options.

HUBBERT'S CURVE AND PEAK OIL

The production of an individual oil field typically follows that of an initial growth period, a plateau as set by the drilling company, and then a decline in the rate of production as shown in Figure 25 (Hubbert 1956 & 1974).

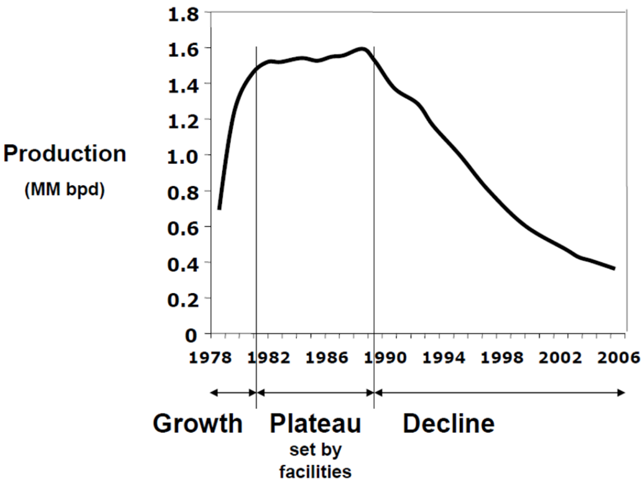


Figure 25: Typical Oil Field History (based on Hubbert 1956 & 1974)

Marion King Hubbert (1956), a geologist, developed what is now known as the Hubbert's Curve as shown in Figure 26 which predicted that the production of all oil fields in the United States would peak in 1970. His prediction was one year out.

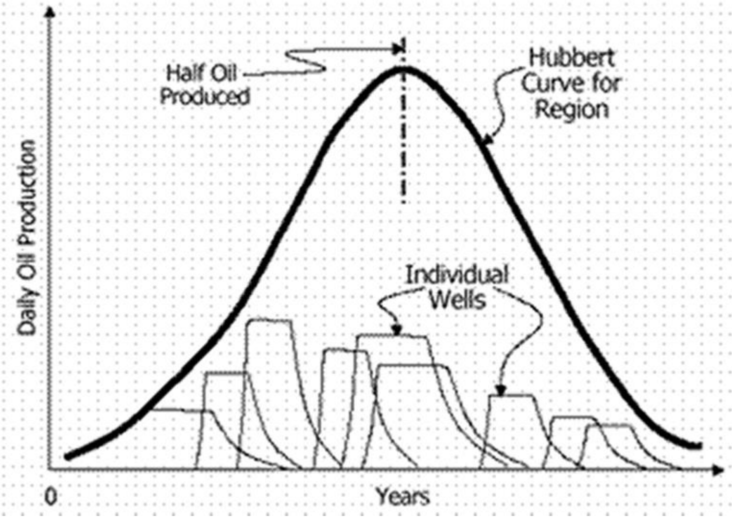


Figure 26: Hubbert's Curve (based on Hubbert 1956 & 1974)

Hubbert based his prediction on the rate and scale of new oil field explorations and the production history of individual oil fields. The Hubbert Curve predicts the peaking of production of oil fields when about half the available oil field reserves had been produced. The rate of oil production subsequently declines.

NET ENERGY

Energy is required to explore and identify where the most concentrated forms of fossil fuels are located. The mining of materials requires the use of energy. More energy is then required to construct the necessary plant and machines to extract the fossil fuels from the ground and to run the plant and machines. The reserves of fossil fuels in the ground which are extracted represent gross energy. Net energy, also known as a surplus, is what is left over for use after extraction (Hall 2016).

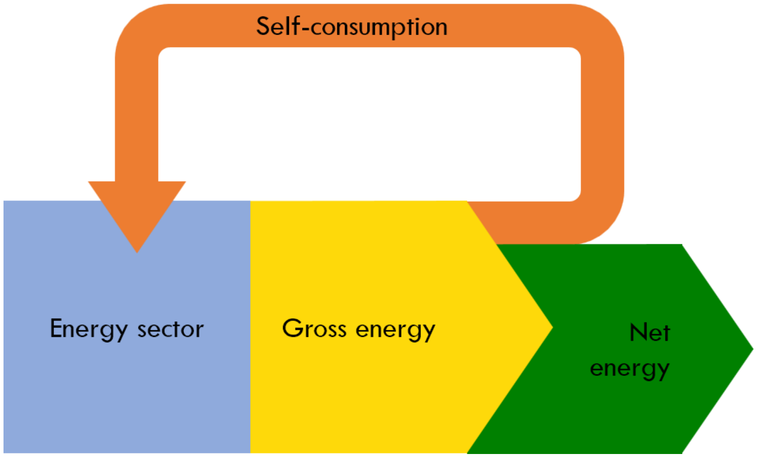


Figure 27: Net Energy (based on Hall 2016)

All life forms require surplus energy to survive. For example, a cheetah chasing down a gazelle expends energy in doing so. The cheetah and its offspring survive for only so long as the energy provided by eating the gazelle exceeds the energy it has expended in catching the gazelle. The cheetah also requires more surplus energy for its own day-to-day metabolism and that of its cubs until its next catch. This would be bare subsistence living. A safety margin would be needed to avoid starvation when gazelles are difficult to catch.

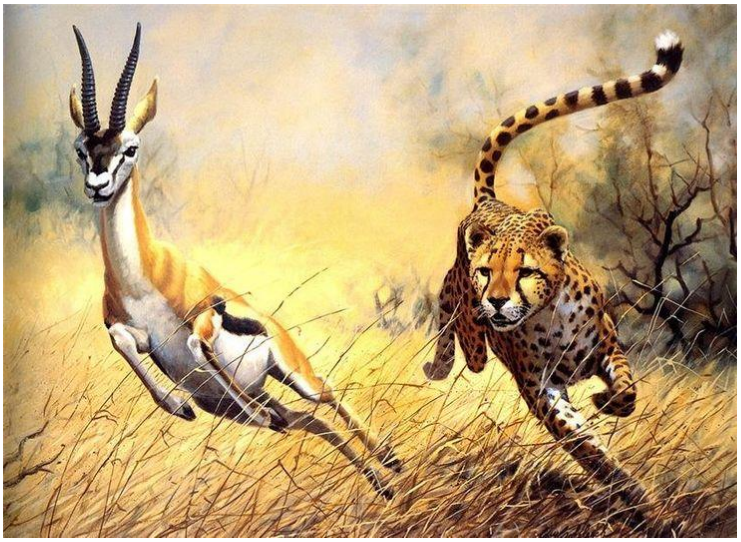


Figure 28: A Cheetah Hunting Down a Gazelle for Surplus Energy

Early humans required surplus energy to sustain their minimum requirements of food, clothing, shelter, tools, and weapons for hunting. We now make use of a much greater surplus of energy to sustain not only our minimum necessities of life, but also our complexes of infrastructure, plant, and machinery and our level of technology which underpin our much higher consumer level of life in the pursuit of happiness and wellbeing.

HIGH AND LOW EROI ECONOMY

To get energy for consumption requires capital created by energy to get energy plus energy to get energy. Energy Returned over Energy Invested, shortened to EROI or sometime ERoEI is a ratio for describing a measure of the energy produced in relationship to the energy used to create it (Hall 2016).

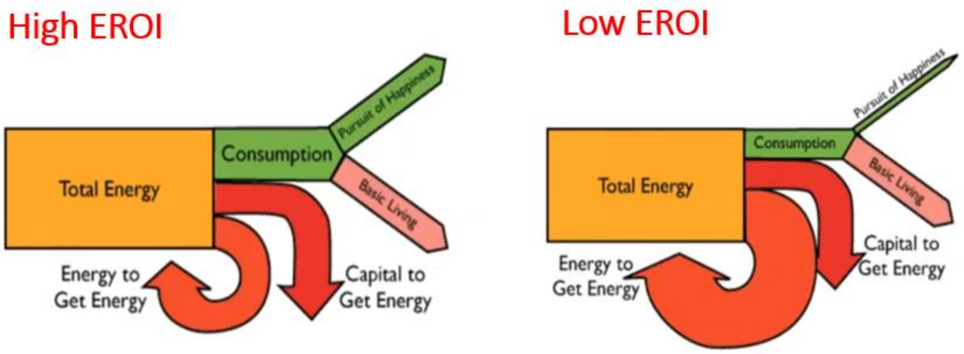


Figure 29: High and Low EROI Economy

The left-hand side of Figure 29 shows a high EROI economy where the energy surplus available for the pursuit of happiness is of the same scale as that required for basic living. Over a large part of the 20th century, we have enjoyed a high EROI economy. The right-hand side of Figure 29 shows a low EROI economy where the energy surplus available for the pursuit of happiness is much less than that for basic living.

Figure 29 is overly simplistic because the energy consumption for basic living is shown to be the same for both economies. What constitutes basic living is largely in the eye of the beholder when life is well above subsistence level. For example, in some developed nations, a family home of 200 square metres might be considered a normal standard. In New Zealand during the 1970s, the size of a standard 3-bedroom house was 94 square metres. What is frivolous consumption in the pursuit of happiness is also largely in the eye of the beholder.

The balance of surplus energy allocated for basic living and the pursuit of happiness can vary from one economy to another when the total surplus is the same. The level of technology that is possible in any economy is largely determined by surplus energy left over after providing for basic living.

EROI BOUNDARIES

In the 1970s and 1980s, net energy studies around the world were undertaken in response to the 1973 OPEC oil embargo which resulted in a four-fold increase in the price of petroleum. The New Zealand government funded several net energy studies under the umbrella of the NZERDC (Isaacs 1993).

Estimates of the EROI of alternative energy sources can vary widely depending on the boundaries of the study (Hall 2016). Figure 30 shows an example of the extent that EROI calculations can differ when different boundaries are applied.

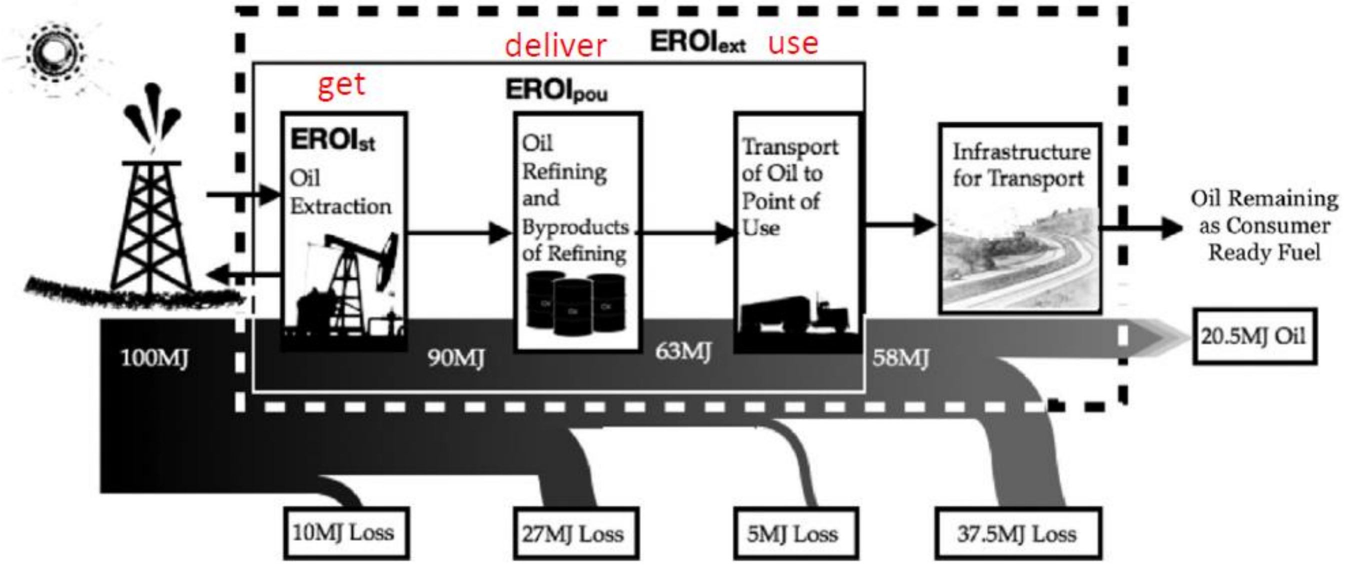


Figure 30: EROI Boundaries (Hall et al. 2014)

There is an enormous difference between the net energy at the point of extraction – 90 MJ at the boundary of oil extraction from the ground compared to remaining net energy of 20.5 MJ as Oil Remaining as Consumer Ready Fuel which takes into account the infrastructure required for transport. Each of the energy losses from the point of extraction of fossil fuels in the ground to the movement of vehicles reliant on the use of infrastructure for transport are heat losses, and each burning of fossil fuels emits greenhouse gases to the atmosphere. The following EROI calculations are based on for every 100 MJ of oil in the ground.

At the point of extraction at the drilling rig, the Energy Return on Energy Invested is 100 MJ / 10MJ which is equal to an EROI ratio of 10:1.

At the point of use at the petrol station after extraction, refining, and transport to the petrol station, the energy returned on energy invested is equal to an EROI ratio of 2.38:1.

Driving vehicles requires infrastructure for transport. The Energy return on Energy Invested to provide fuel for Consumer Ready Fuel. Taking into account the energy cost of providing infrastructure for transport, is equal to an EROI ratio of 1.26:1.

THE NET ENERGY CLIFF

Figure 31 shows the net energy cliff (Hall 2016) with net energy available for consumption as a percentage of gross energy plotted along the Y-axis and the energy returned on energy invested (EROI) plotted along the X-axis.

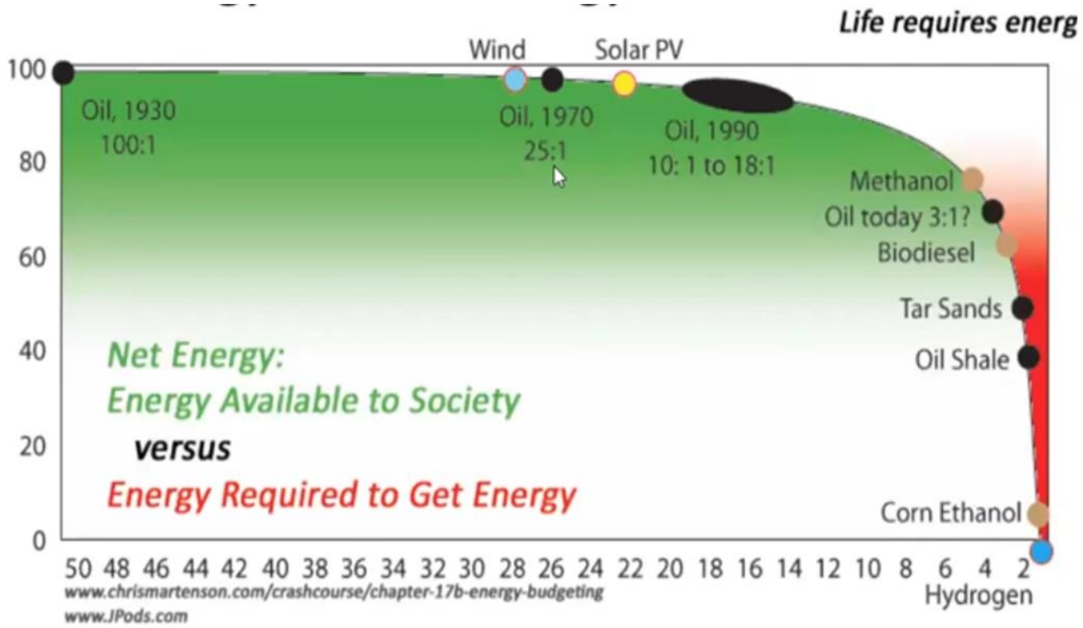


Figure 31: The Net Energy Cliff (based on Hall 2016)

All fossil fuel reserves peak in terms of the maximum rate of gross energy that can be produced over any one year and the gross energy which can be produced each year after peaking subsequently declines over time (Hall 2016).

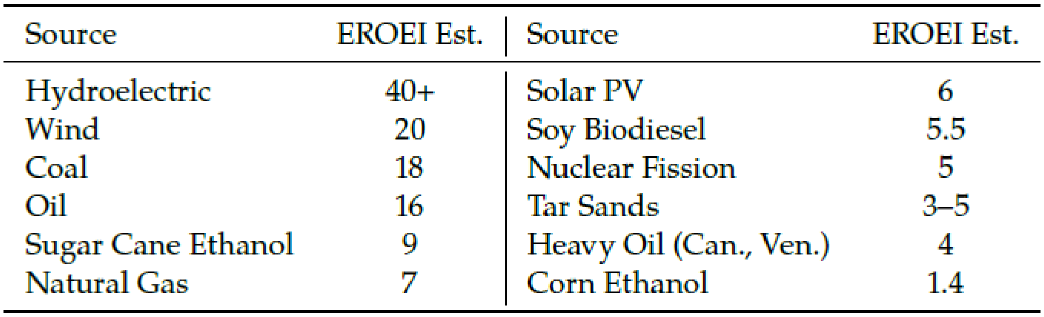
The net energy cliff is where the net energy produced rapidly declines after the EROI of the fossil fuel has declined to a ratio as low as 6:1.

The energy returned on energy invested in all forms of fossil fuels inevitably declines to a ratio of 1:1 where it takes as much energy to produce or procure energy as that produced. There would still be fossil fuels in the ground which could be extracted for their chemical content, but to try and extract further fossil fuels from the ground as an energy source would be an energy drain on society.

A rapid decline in net energy over time does not apply to renewables. Each photovoltaic panel and wind turbine is replaced at the end of their service life and this replacement life cycle is taken into account when estimating their energy returned on energy invested. The longer the service life of photovoltaic panels and wind turbines, the greater is the EROI ratio and the percentage of gross energy returned.

INDICATIVE ENERGY RETURNED ON ENERGY INVESTED

Tom Murphy (2021) has provided indicative energy return on energy invested ratios for a range of fossil fuels and renewables in his 481-page book titled "*Energy and Human Ambitions on a Finite Planet: Assessing and Adapting to Planetary Limits*". The ratios are indicative because net energy analysis estimates of EROI vary depending on which boundaries are applied.



Source	EROEI Est.	Source	EROEI Est.
Hydroelectric	40+	Solar PV	6
Wind	20	Soy Biodiesel	5.5
Coal	18	Nuclear Fission	5
Oil	16	Tar Sands	3–5
Sugar Cane Ethanol	9	Heavy Oil (Can., Ven.)	4
Natural Gas	7	Corn Ethanol	1.4

Table 1: Indicative Energy Returned on Energy Invested (Murphy 2021)

Hydroelectric tops the ranking with an EROI ratio of 40:1 plus. There is limited remaining potential for large scale hydroelectric in most countries. Some countries are blessed with a high percentage of electricity production supported by hydro dams. New Zealand is one of them.

Oil shale has a lower EROI ratio than renewables but, in terms of scale, has so far propped up increases in total net energy while net energy provided by legacy forms of fossil fuels has declined.

We need to transition from fossil fuels to renewables, but what is clear is that the EROI of renewables will be less than that of fossil fuels in the 1970s when field oil peaked. What matters most is the scale of how much net energy can be produced from a combination of different renewables sources. A key question is whether renewable energy with a relatively low EROI ratio compared to fossil fuels in its heyday can scale up to replace and match the level of net energy currently provided by fossil fuels. Scaling up of net energy provided by renewables which have a lower EROI than fossil fuels in its heyday means using more renewables such as photovoltaic panels and wind turbines. That means more materials, the mining of which has a greater impact on the environment.

EROI HIERARCHY OF SOCIETY

Charles Hall and colleagues (2014) have estimated the minimum energy return required for society to fulfil a hierarchy of needs and aspirations as shown in Figure 32.

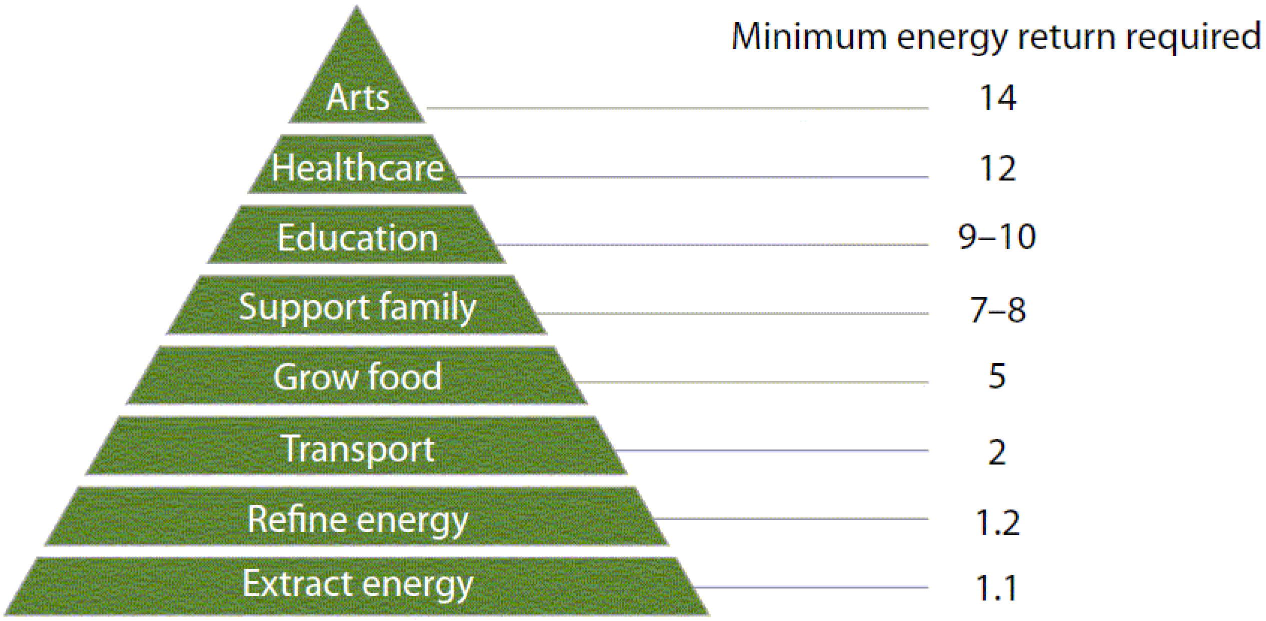


Figure 32: EROI Hierarchy of Society (based on Hall et al. 2014)

It is extremely difficult to provide definitive estimates for each category of needs and aspirations of the hierarchy. However, what is clear is that each category further up the hierarchy requires a greater minimum energy return. The level of technology in any society is dependent on the extent of energy surpluses left over after the necessities of life have been satisfied.

Going back through history, each culture and civilisation achieved the pinnacle of the hierarchy, but not all citizens enjoyed the same life style. Lifestyles for everyone in the past were much simpler than we enjoy now in the developed countries.

We need to transition from fossil fuels to renewables, but the energy return of renewables will be less than that of fossil fuels in the 1970s when field oil peaked. The implications are that a lifestyle dependent on renewable energy and infrastructure could be simpler than what the well-developed nations enjoy now.

ENERGY PRODUCTION OF OIL & GAS FROM 1950 PROJECTED TO 2050

In Figure 33, Delannoy and colleagues (2021) chart the history of oil liquids production from 1950 to 2021. Oil liquids includes natural gas liquids, biofuels, and shale. The Energy of production is plotted along the Y-axis and the date in years are plotted along the X-axis. Delannoy and colleagues then project oil liquids production based on the Globalshift model (Smith 2015) which ignores carbon budgets required to mitigate the impact of fossil fuels. In other words, a continuation of current business as usual.

The cross-hatched light-yellow area at the top of the plotted areas represents the energy required to produce net energy. All stacked areas below this light-yellow area represents net energy available at the point of extraction. The dark grey area at the bottom of the chart represents field oil.

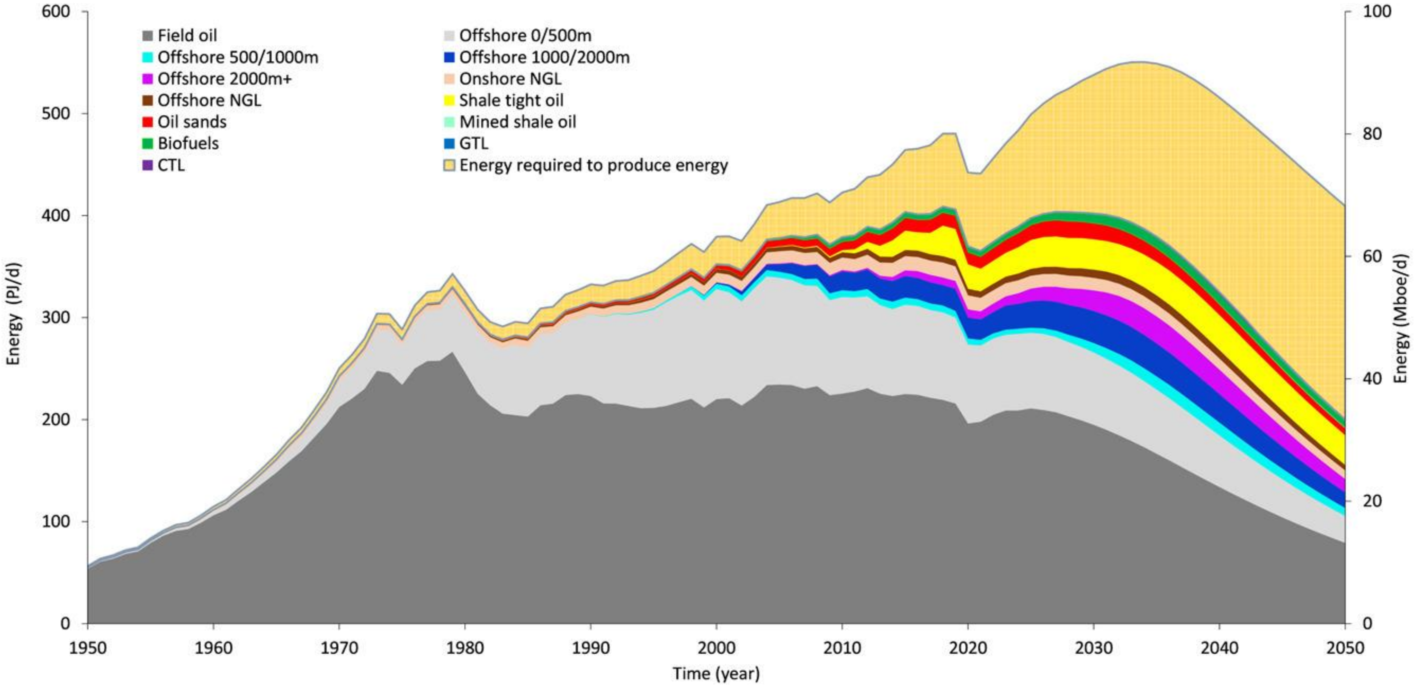


Figure 33: Energy Production of Oil & Gas From 1950 Projected to 2050 (Delannoy et al. 2021)

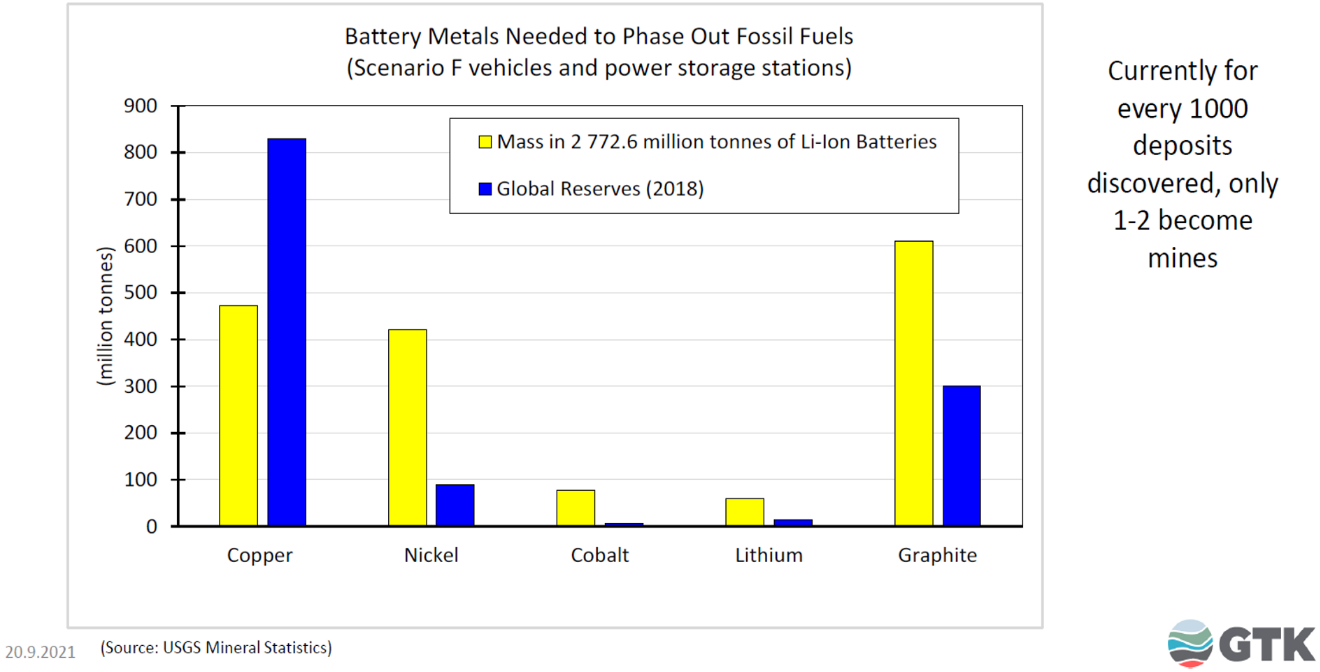
When field oil was drilled in 1950, it required about one unit of investment in energy to provide a return of 50 units of energy, an EROI ratio of 50:1. Net field oil peaked about 1979. The combination of net field oil and off shore drilling to 500 metres coloured light grey peaked about 2004. Off shore drilling to 2,000 metres, shale tight oil, oil sands, onshore natural gas, and biofuel have allowed total net energy to increase until about 2020.

According to Delannoy and colleagues (2021), total net oil liquids will peak about 2024 and then continuously decline until 2050. Other sources of energy include coal, nuclear energy, and renewables. Coal can be converted into a liquid form of fossil fuels, but any conversion involves losses in energy. Time has run out for expanding the use of nuclear energy. New nuclear power stations would be up and running after the next two most critical decades of transition and mitigation of climate change. (Murphy 2021).

MINERALS NEEDED FOR BATTERIES VERSUS RESERVES

We need to transition from fossil fuels to renewable energy and infrastructure, and there is a common assumption by many that renewables can provide the same scale of net energy that fossil fuels have provided so far. Simon Michaux (2019) has challenged that assumption with a study of the minerals and metals required by renewables.

In Figure 34, the global reserves of metals as of 2018 needed by batteries to phase out global fossil fuels are coloured blue and the metals needed are coloured yellow. Copper is currently not an immediate problem, but nickel, cobalt, lithium, and graphite present serious problems. Global reserves of nickel, cobalt, and lithium for batteries are simply not large enough to supply enough metals to scale up renewables to fully replace the global net energy currently provided by fossil fuels.



Currently for every 1000 deposits discovered, only 1-2 become mines

20.9.2021 (Source: USGS Mineral Statistics)

Figure 34: Minerals Needed for Batteries versus Reserves (Michaux 2019)

PRIMARY MINING SOURCES WITH SUPPLY RISKS

Michaux (2019) concluded that alternative minerals will be needed for batteries. These include zinc, sodium-sulphur, and hydrogen fuel cells.

In Figure 35, abundant elements are coloured green and those elements which pose a serious supply threat over the next 100 years are coloured red. The reserves of zinc present a serious supply threat over the next 100 years while sodium and sulphur are abundant.

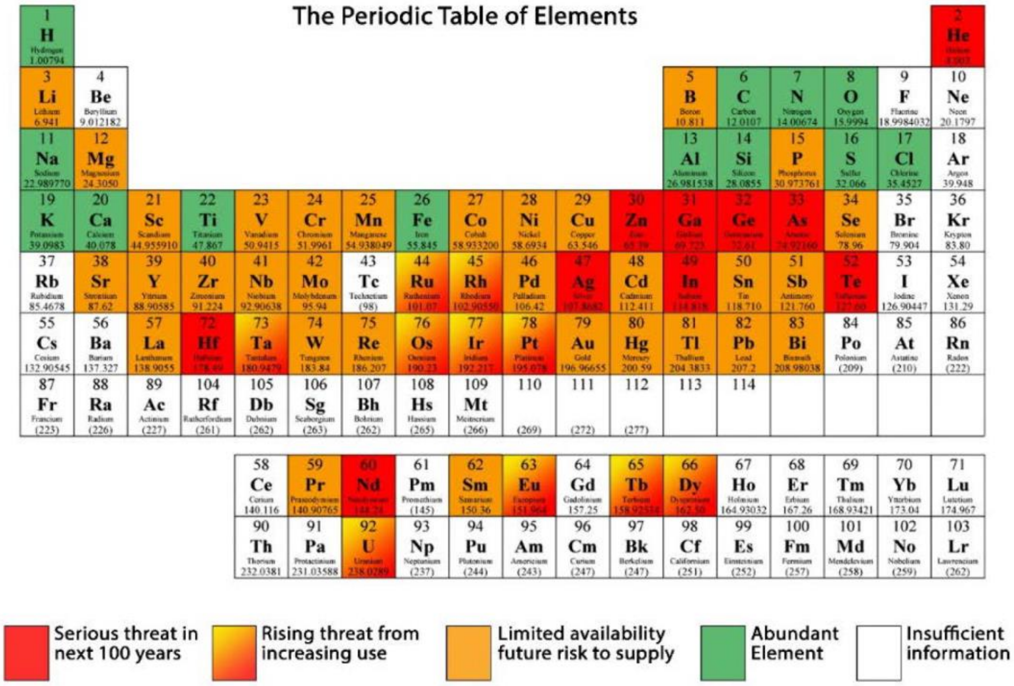


Figure 1. Some primary mining sources for a number of metals have clear supply risks (Source: Report On Critical Raw Materials For The EU May 2014) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

Figure 35: Primary Mining Sources with Supply Risks (Michaux 2019)

There are risks involved with handling sodium and sulphurs due to the volatile nature of both reactants. Liquid sodium can become explosive when coming into contact with water in the atmosphere. Sodium-sulphur battery factories and installations that use them have been the site of several fires. Another drawback to sodium-sulphur batteries is the high operating temperature of 300 °C, which is needed to liquefy the sodium. These high temperatures can damage the ceramic membrane separating the anode and cathode components of the battery and exacerbate the volatility of the reactants in the battery. (Moseley & Garche 2014).

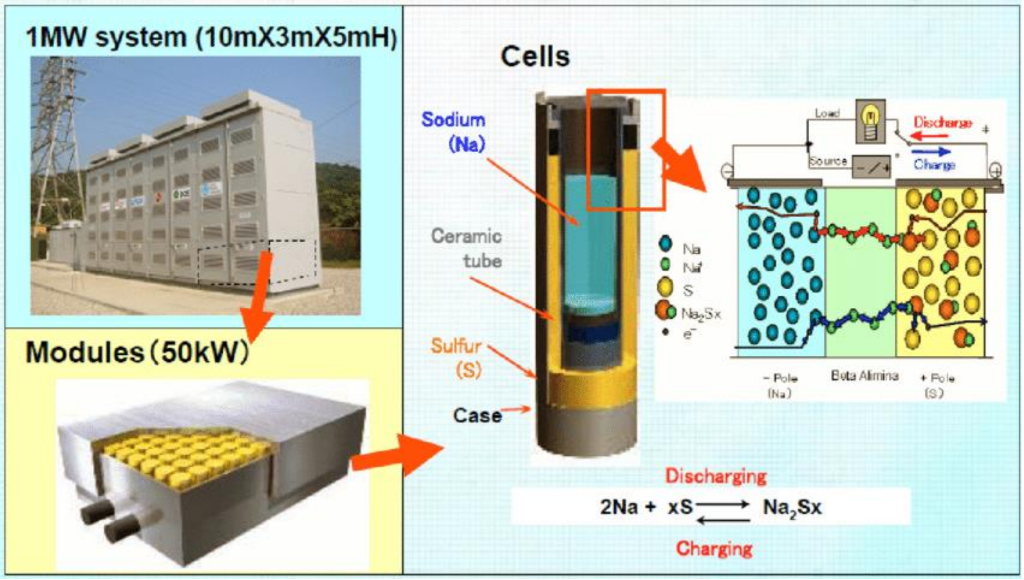


Figure 36: Sodium-Sulphur Batteries

Hydrogen is highly flammable and can react explosively if not handled correctly. Hydrogen is an energy carrier and not a direct source of energy because the production of hydrogen is 65-80% efficient. In other words, it takes more energy to produce hydrogen than the energy contained in the hydrogen that has been produced. There are further energy losses in compression of hydrogen and loss of energy in a fuel cell when supplying energy to an electric motor to undertake the mechanical work of motion. Fuels cells are about 65% efficient in supplying the energy of hydrogen to an electric motor. Electric motors also have a loss in energy due to friction when used to undertake mechanical work of motion. (Murphy 2021).

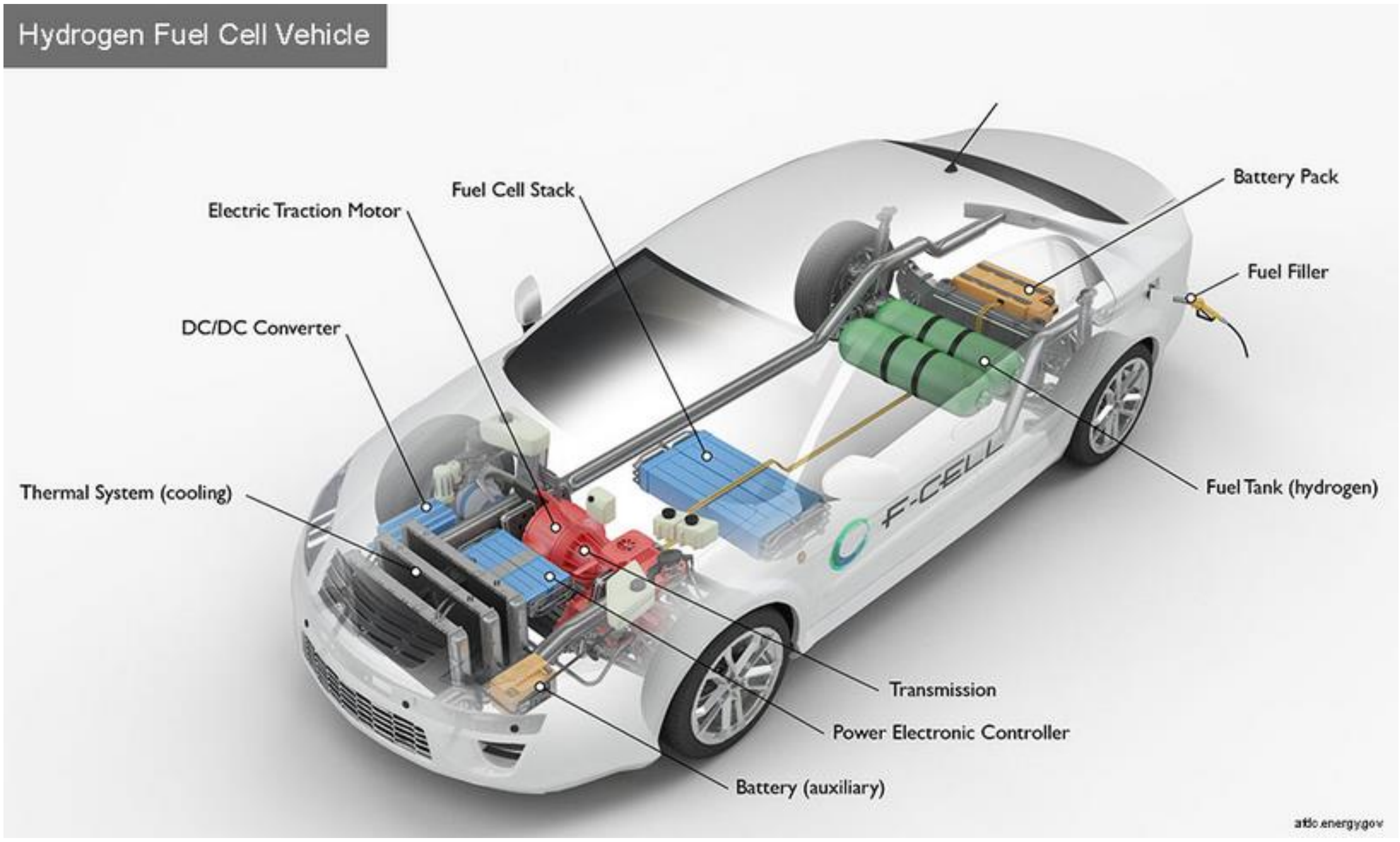


Figure 37: Hydrogen Fuel Cell Vehicle

RECYCLING RATES OF METALS

Photovoltaic panels and wind turbines need to be replaced periodically and, for this reason, some researchers refer to these renewables as being replaceables. If photovoltaic panels and wind turbines provide sufficient energy to replace themselves, then one could refer to them as being renewables should recycling of the materials be 100%. But 100% recycling of any material is impossible. In nature, dispersal of minerals is essential to enable the sustainability of an ecosystem. Humans in an industrial society, as opposed to a hunter-gatherer society, require concentrations of materials, and that requires the use of energy. Higher recycling rates require progressively more energy which ultimately limits the practical level of recycling. (Mills 2020)

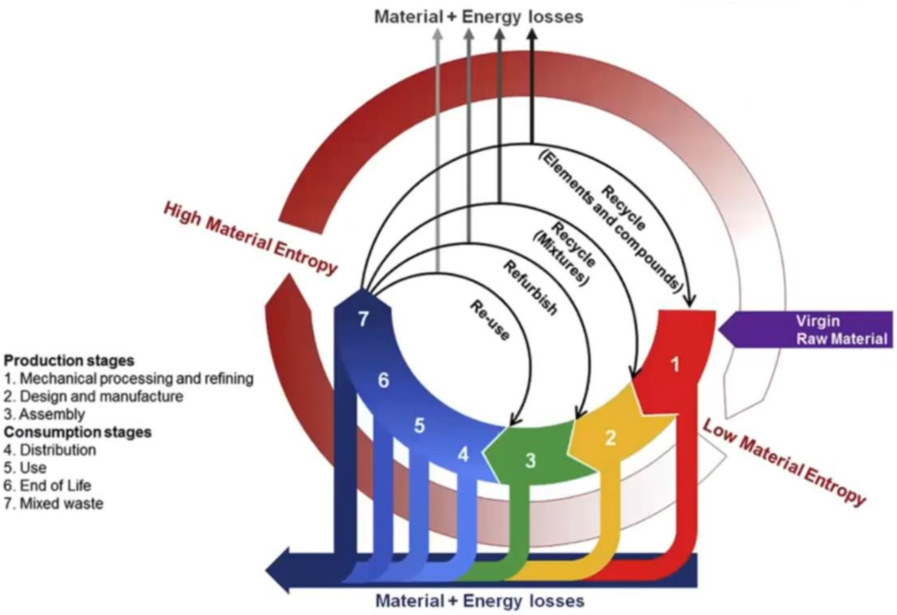


Figure 38: Recycling and Inevitable Energy & Material Loss to the Environment

Figure 39 shows the current recycling rates of metals. Only a few metals have a recycling rate of over 50%. According to the United Nations Environmental Programme (UNEP), “existing data of an end-of-life recycling rate of 70-90% can be estimated for iron and steel. This value is one of the highest end-of-life recycling rates among all the industrially-used metals” (UNEP 2011).

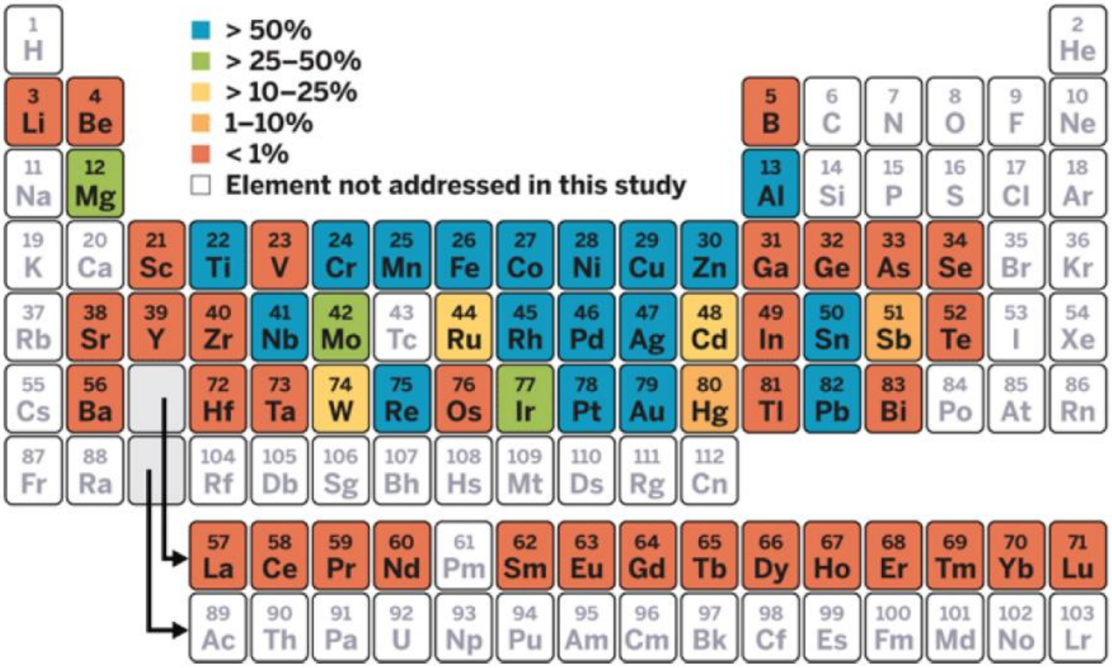


Figure 8. Recycling rates of metals (Source: United Nations Environment Programme, Recycling Rates of Metals (2011) / C&EN May 30, 2011) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

Figure 39: Recycling Rates of Metals (Michaux 2019)

Assume that all metals have a recycling rate of 90%. After only 6 and 7 cycles of recycling, only 53% and then 48% of the original material is available for reuse. The current rates of recycling of many metals nowhere match 90% and higher rates of recycling do not bode well for the long-term future because higher rates of recycling require progressively more energy than lower rates. Some metals require more energy to recycle than other metals at any chosen rate of recycling.

A balance of longevity in use and the rate of recycling is necessary to reduce the energy costs of keeping minerals and metals in use during each generation of the population. This balance needs to weighed up against the energy costs of mining for new minerals and metals and the extent of their scarcity. All minerals and metals which are ultimately dispersed to the environment after mining and use represent the loss of resources for distant generations. The dispersed minerals and metals are too energy costly to concentrate for use (Georgescu-Roegen 1971).

Figure 40: Balancing Rate of Recycling & Longevity Against Mining for Minerals & Metals

DECREASING GRADES OF MINED MATERIALS

The grades of mined materials have steadily decreased, especially since the 1930s as shown in the Figure 41. Without extraordinary advances in mining and refining technology, the 10% of world energy consumption currently used for mineral extraction and processing would rise as lower grade and more remote deposits are mined (Mudd 2009).

Very low concentrations of minerals and metals are too energy costly to concentrate for use. All minerals and metals which are mined and concentrated for use in our industrial society are ultimately dispersed to the environment when the energy costs of higher rates of recycling becomes prohibitive. The energy costs of recycling will eventually exceed that of mining low concentrations of metals and minerals still in the ground

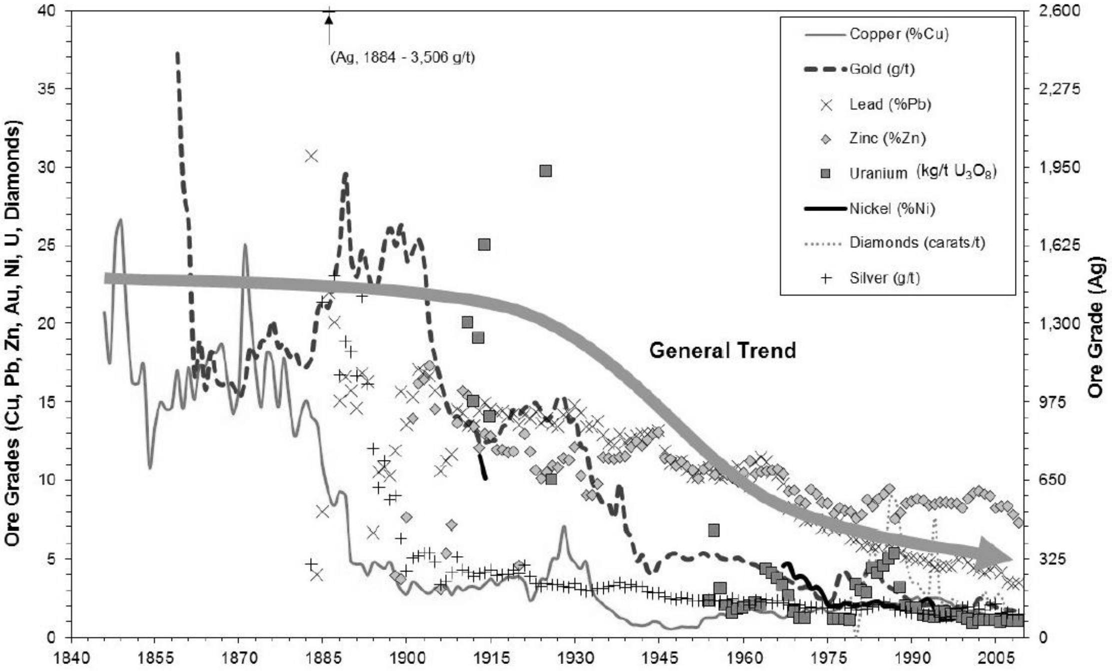


Figure 16. Grade of mined minerals has been decreasing (Source: Mudd 2009- updated 2012, Analyst- Gavin Mudd)

Figure 41: Decreasing Grades of Mined Materials (Mudd 2009, updated Mudd 2012)

Metals and minerals which are ultimately dispersed to the environment after use represent the loss of resources which cannot be used by future generations. If our species of humankind should continue to exist in the far distant future, then future levels of technology will inevitably decline due to the inability to concentrate dispersed minerals and metals. Our focus is on the shorter-term future, and especially the next number of decades, where our actions or lack of actions will largely determine the future of our children’s grandchildren. Figure 42 shows the waste hierarchy of human settlements. Actions further up the hierarchy reduce impacts on the environment and ensure a higher quality of life for future generations.

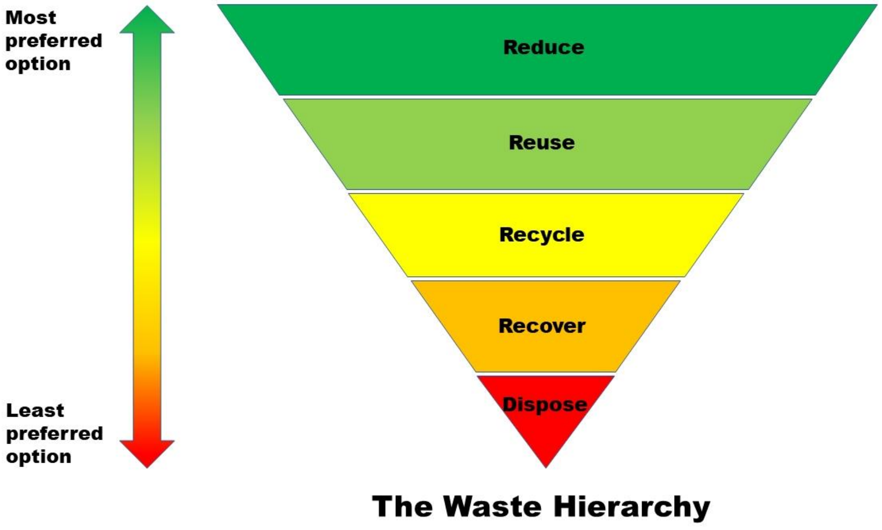


Figure 42: The Waste Hierarchy

CIRCULAR VERSUS LINEAR ECONOMY

Previous leading economic textbooks, for example *Economics* first published by Paul Samuelson in 1948 followed by decades of editions, depicted the economy as being circular. These text books were based on an abstract human construct of what comprises an economy and did not recognise or acknowledge the real-world physical role of energy and materials which flows into the economy and the unavoidable disposal of waste and heat which flows out.

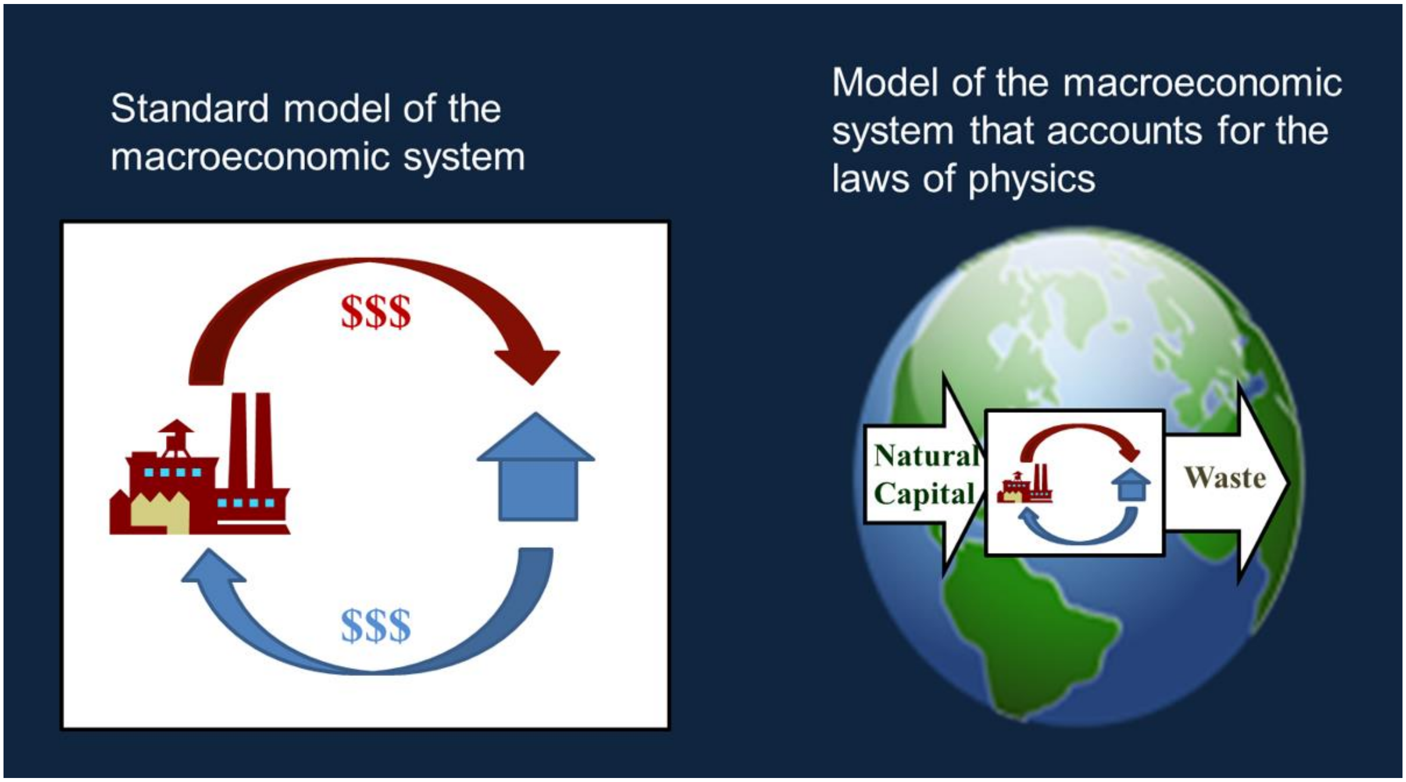


Figure 43: Natural Capital and Waste in a Real-World Economy

More recently, there are those who extoll the virtues of a circular economy on the basis that high rates of recycling are possible (Keblowski et al. 2020). Yes, by all means recycling of materials in our economy should be encouraged and promoted. But to refer to such an economy as being circular promotes the misconception that an economy can be like a perpetual motion machine.

In any economy, materials and high-grade energy flow in from the environment and unavoidable waste and low-grade heat flow out into the environment. Waste is unavoidable in an industrial economy. If we want to continue with an industrial economy, then we need to ensure our waste can be assimilated by the environment and does not overload it. The scale of waste into the environment will depend on the scale of our populations. When the true boundary of an economy, the environment, is taken into account, it is clear that the true nature of a real-world economy is linear and not circular.

THE MYTH OF GREEN GROWTH

Proponents of what has been named “green growth” argue that technological progress and structural change will enable a decoupling of consumption from adverse impacts on the environmental and promote “green” growth (World Bank 2012).

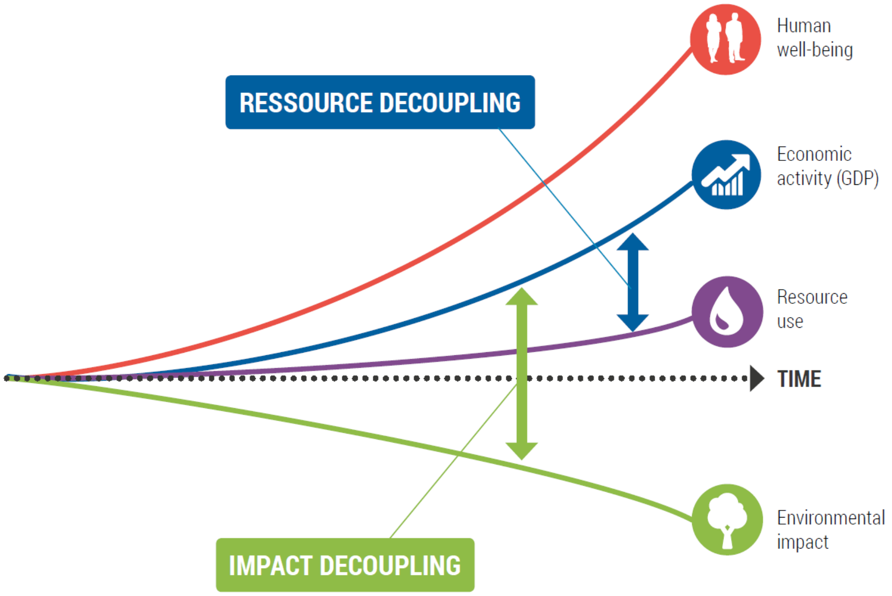


Figure 44: Claimed Decoupling of Natural Resources from Economic Activity

In 2019, Timothee Parrique debunked the extent that decoupling has taken place in some countries in a comprehensive 872-page publication. Many claims did not take into account the embodied energy of goods imported from another country.

Relative decoupling of GDP from energy and materials is possible, but there is a limit as to how much is possible. For example, it is possible to use less energy and materials more efficiently to provide goods and services. Recycling helps to reduce the use of additional materials. But there are thermodynamic upper limits to the possible efficiencies of both energy use and recycling. With improved technology, we have already closely approached many of these upper limits. Photovoltaic panels and wind turbines are good examples.

Improvements in energy efficiency do not necessarily lead to reductions in the use of energy due to the rebound effect, also known as the Jevons Paradox. The rebound effect occurs when greater efficiency in the use of resources results in greater consumption of that resource due to an increasing demand. An example is the increase in the efficiency of the steam engine in the 1800s which resulted in a greater demand for more steam engines. Although each new improved steam engine used less coal, the combination of more steam engines using less coal resulted in a greater consumption of coal (Jevons, 1865). The rebound effect can take place when demand is unrestricted, such as in a growth economy.

Steve Keen (2021) has plotted annual changes in world energy and world GDP since 1970.

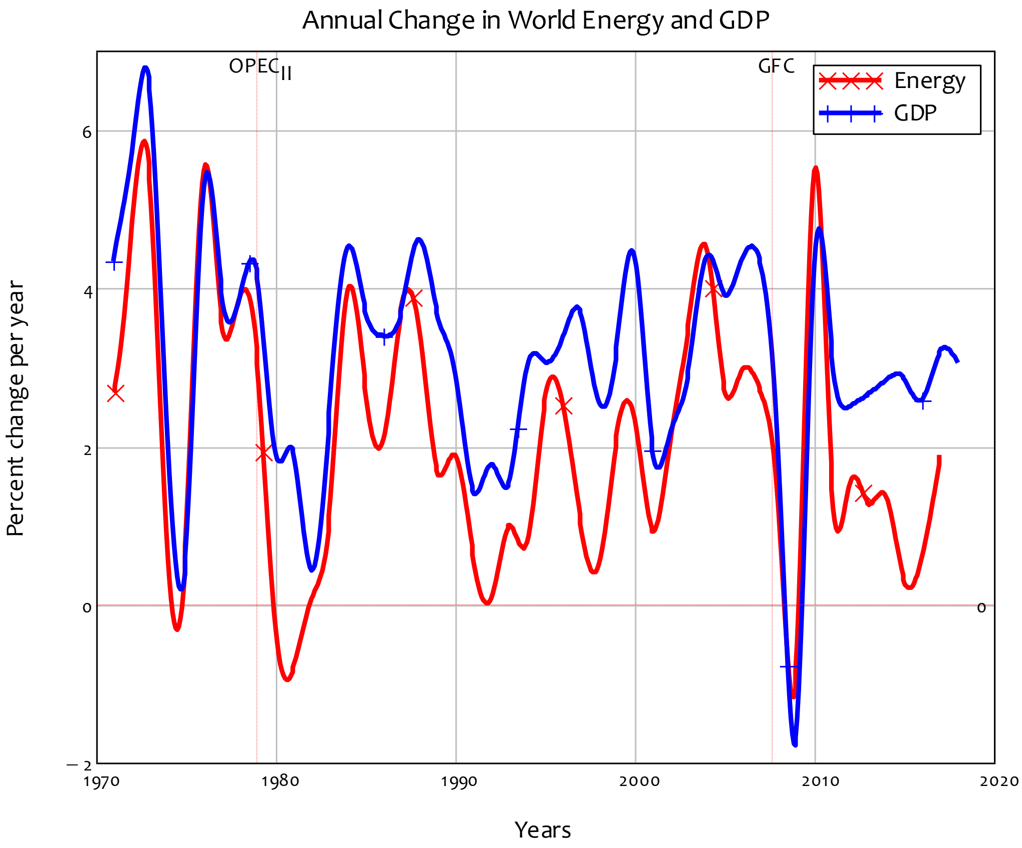


Figure 45: Annual Changes in World Energy and GDP (Keen 2021)

The percentage change per year is plotted along the Y-axis and the date in years are plotted along the X-axis. There is undoubtedly a close visual relationship between annual changes in world energy and world GDP. The correlation coefficient of these changes is a high 0.83. The reason why is because any form of activity or process requires the use of energy and materials. Any claims of absolute decoupling of energy and materials from an economy are absolute nonsense. Claims of absolute decoupling are on a par with claims of the possibility and existence of a perpetual motion machine.

OUR CURRENT PREDICAMENT

In 1977, William Ophuls cautioned that the time for concern about the potential exhaustion of a resource comes when no more than 10% of the total has been used up. This applies especially when the rate of extraction of a resource is exponential.

There is an expression of “Don’t eat your seed corn” which refers to the age-old farmer’s strategy of saving some of the harvest of the current year as the seeds for the next. Our main energy sources have been fossil fuels, and they have produced very few seeds for the next harvest in the form of renewables. The inevitable peaking of fossil fuels has been ignored since cautions in the 1970s to make wise use of a proportion of fossil fuels to enable a smooth transition from fossil fuels to renewable energy and infrastructure.

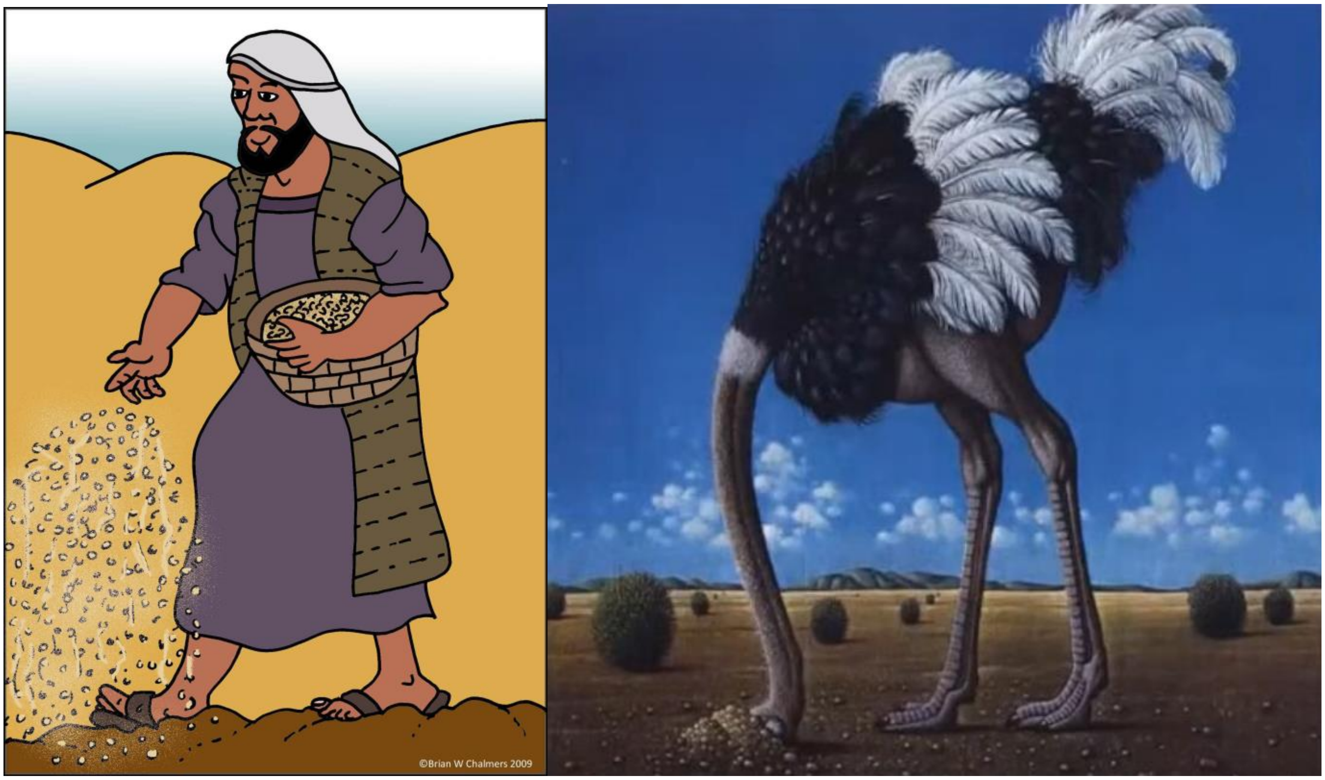


Figure 46: Early Warnings to Use Proportion of Fossil Fuels for Transition to Renewables Ignored

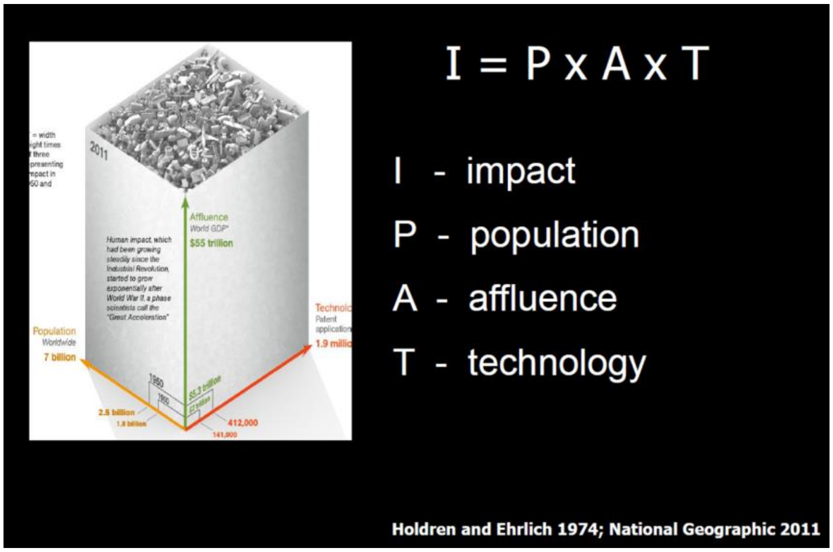
We now have a situation where the energy provided by the current limited scale of renewables such as photovoltaic panels and wind turbines is insufficient to bootstrap the manufacturing of more renewables. Manufacturing of renewable energy sources requires the use of fossil fuels. But a transition from fossil fuels to renewables and infrastructure is now more difficult because the net energy of oil liquids, a convenient and key form of fossil fuels necessary for the production of renewables, is on the decline.

The longer we delay in using what remains of net energy provided by oil liquids, the less likely we will be able to make a transition to renewables. At the same time that we should be transitioning from fossil fuels to renewables, we also need to reduce our consumption of fossil fuels to mitigate the impact of climate change. We have a double whammy here.

The only way out of our predicament is to divert the use of fossil fuels away from unnecessary consumption to that of investment in renewables and infrastructure and do this on a limited and reducing carbon budget to ensure we mitigate the impact of climate change

IMPACT OF HUMANS ON THE ENVIRONMENT

John Holdren and Paul Ehrlich (1971) provided a broad-brush measure of the impact of human activity on the environment in the form of an equation where the impact equals the level of the population multiplied by the level of affluence multiplied by the level of technology.



I = P x A x T

I - impact

P - population

A - affluence

T - technology

Holdren and Ehrlich 1974; National Geographic 2011

Figure 47: Impact of Humans on the Environment (Holdren & Ehrlich 1971)

As mentioned already, the current world population in 2021 is 7.9 billion. Population growth still remains the elephant in the room. It is a taboo subject and it is politically incorrect to suggest that any country should limit the size of its population. For some people, the right to have as many children as you want is sacrosanct.

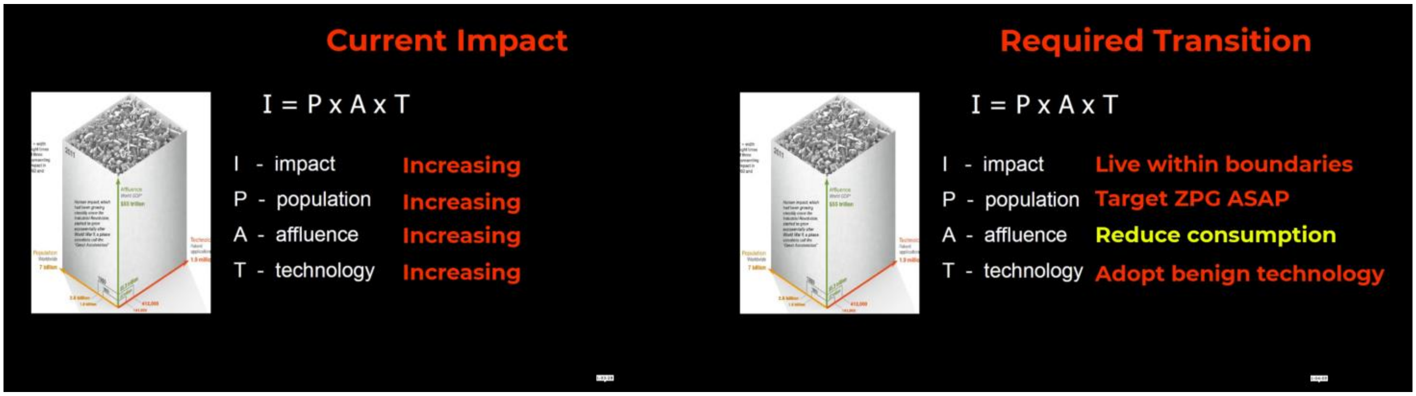
Even if all countries were to adopt a Zero Population Growth policy overnight – an average of two children per family - the world population would continue to grow due to inbuilt population momentum. The United Nations Population Division expects the world population to level out at 10.9 billion people by the end of the century. There are no guarantees this will happen. Population growth is not on the agenda and continued population growth is inevitable unless war and/or nature intervenes.

A measure of affluence is the consumption of energy and materials per capita and GDP is a good proxy of consumption. GDP per capita has been increasing exponentially, especially in the well-developed countries. The impact of technology on the environment has undoubtedly increased in parallel with increases in consumption. Increases in pollution is just one of many examples

A measure of affluence is the consumption of energy and materials per capita and GDP is a good proxy of consumption. GDP per capita has been increasing exponentially, especially in the well-developed countries. The impact of technology on the environment has undoubtedly increased in parallel with increases in consumption. Increases in pollution is just one of many examples.

Given that the world population will continue to increase over the next number of critical decades, the only way we can mitigate the impact of climate change and avoid exceeding planetary boundaries is by reducing our current levels of consumption and the impact of our technology on the environment. In a transition from fossil fuels to renewable energy and infrastructure and beyond, we need to live within our planetary boundaries. It is imperative that we target Zero

Population Growth as soon as possible otherwise all our efforts will be in vain. We need to reduce our levels of consumption, especially in the well-developed countries. We also need to adopt benign technology which has a lower impact on the environment. The level of unavoidable waste we generate needs to be such that it can be safely assimilated by the environment



Current Impact

I = P x A x T

I - impact	Increasing
P - population	Increasing
A - affluence	Increasing
T - technology	Increasing

Required Transition

I = P x A x T

I - impact	Live within boundaries
P - population	Target ZPG ASAP
A - affluence	Reduce consumption
T - technology	Adopt benign technology

Figure 48: Current Impact on the Environment and Required Transition

DISPROPORTIONATE CONSUMPTION BY THE WEALTHY

Carbon dioxide emissions are a good proxy for consumption of fossil fuels used to provide goods and services. Figure 49 shows that the richest 10% of people in the world, and that includes New Zealanders, are responsible for 49% of CO2 emissions. The poorest 50% of people in the world are responsible for only around 10% of total lifestyle consumption emissions.

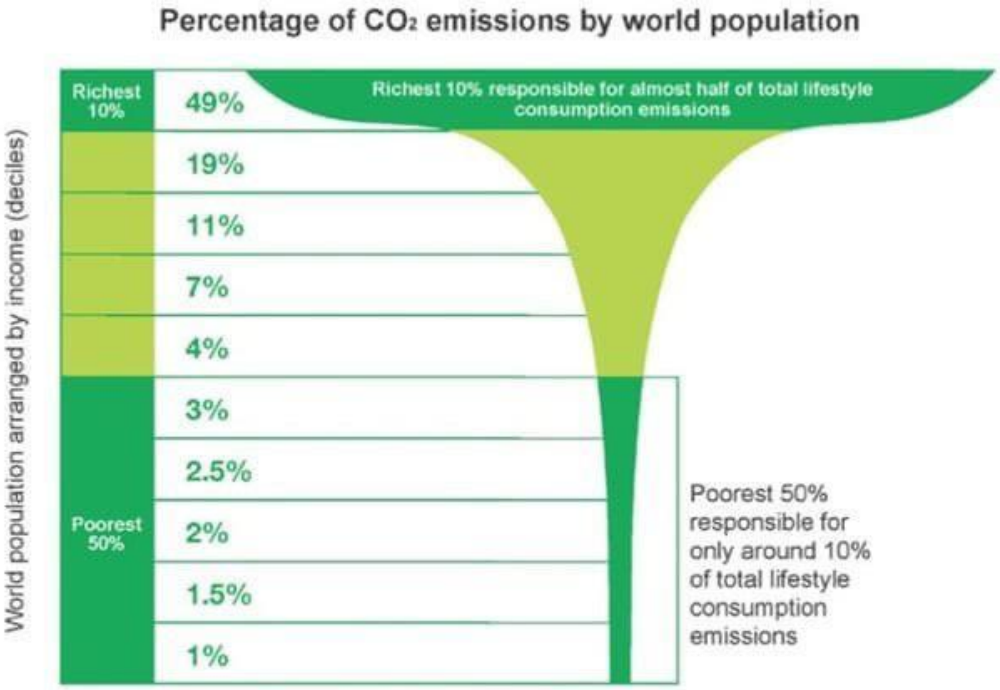


Figure 49: Disproportionate Consumption by the Wealthy (Oxfam 2015)

The need to reduce consumption levels in order to mitigate the impact of climate change applies especially to the well-developed countries. An immediate 50% reduction in emissions by the richest 10% in the world would reduce global emissions to 75% of current levels. A 75% reduction would reduce global emissions to 62.5% of current levels.

HAPPINESS AND GNP ACROSS COUNTRIES

Figure 50 shows happiness and satisfaction with life for people within each country plotted along the Y-axis ranging from 30% to 100% of the population with GNP plotted along the X-axis in United States 1995 dollars.

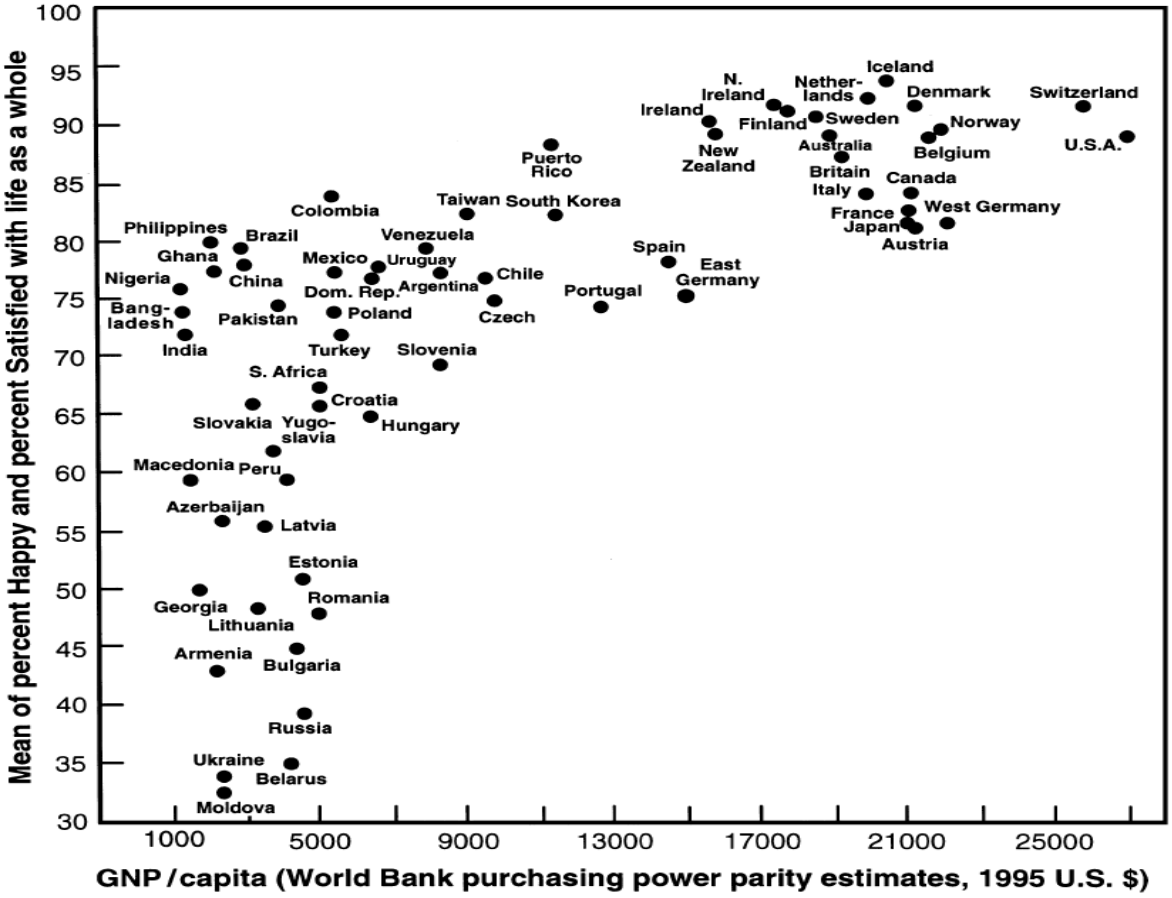


Figure 50: Happiness and GNP across Countries (Inglehart & Kingman 2000)

About 88% of New Zealanders are happy and satisfied with life with a GNP per capita of $16,000 compared to about 90% of those in the United States with a GNP per capita of $27,00. About 78% of Brazilians are happy and satisfied with life with a GNP per capita of only $3,000.

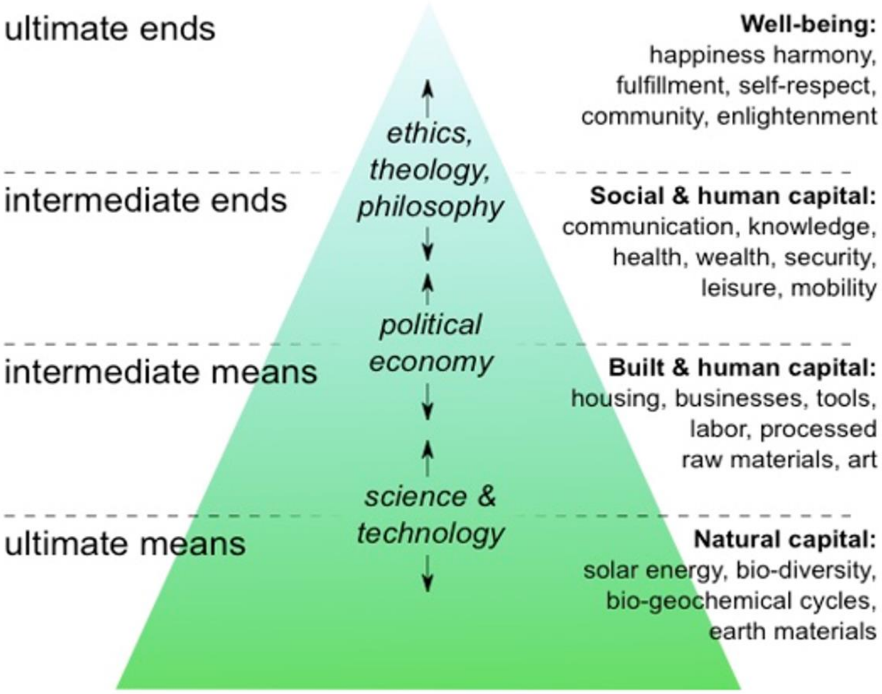
Do not forget that inequity of GNP per capita between countries also exists within countries. The small percentage of extremely rich people in each country raises the average or mean GNP per capita above that enjoyed by 50% of the country. Many people in each country on less income than the average for that country are nonetheless happy and satisfied with their lives.

Several studies, including that of Wilkinson & Pickett (2009) reveal that once people are above a minimum threshold of income, happiness and satisfaction with life does not necessarily improve to any greater extent with substantial increases in GNP or GDP per capita. It is possible to have happiness and satisfaction with life on an income lower than the average for that country. A dramatic reduction in consumption by the rich countries will not necessarily result in a dramatic decline in welfare and happiness, but a transition to a less materialistic lifestyle will be difficult for some.

Many of the actions recommended by the SCAN Framework to mitigate the impact of climate change and reduce our impact on the environment will improve the quality of life for families and enhance and promote a greater sense of community. It is as communities we will continue to thrive.

THE BASIS AND PURPOSE OF OUR ECONOMY

Transitioning from fossil fuels to renewable energy and infrastructure requires a re-assessment of the basis and purpose of our economy. The ultimate purpose of our economy is the well-being of current and future generations. Continued growth in built capital and populations is unnecessary to achieve this. Attempts to continue to grow can only but accelerate the same dire consequences that we currently face. To attain well-being of all generations, both current and future, we need to look after the primary basis of our economy which is natural capital. From now onwards we must be responsible stewards of all natural capital. Well-being follows on by looking after and preserving the primary basis of our economy.



http://steadystate.org/an-economics-fit-for-purpose-in-a-finite-world/

Figure 51: The Basis and Purpose of Our Economy

KEY MESSAGES

Humanity is in ecological/planetary overshoot. It is critical to understand that climate change is but one of many symptoms of a wider ecological overshoot manifested in biodiversity loss (for example, massive declines in pollinating insects), collapse of ecosystems, pollution, resource depletion, and soil depletion. We have already exceeded Earth's carrying capacity and our current ecological footprint exceeds our global bio-capacity by at 56% (Wackernagel et al. 2021). We are rapidly eroding our own ecosphere, the life-support system upon which we all depend. We have already crossed several critical thresholds, and are dangerously close to many others (Rockström 2009; Seibert and Rees 2021).

The dominant ethos of our Western culture over the past 200 years has been economic growth made possible by fossil fuels which are a convenient and energy dense form of energy. Abundant and cheap fossil fuels have enabled exponential growth in world population and economies as measured by GDP.

The burning of fossil fuels and emissions of greenhouse gases has resulted in human-induced climate change. We must reduce fossil fuel consumption to put a brake on the already disastrous impacts of climate change which, if left unaddressed, is an existential threat to all forms of life on Earth (Lenton et al. 2008; Steffen et al. 2018).

Renewable energy (non-fossil fuel energy such as wind, solar, hydro, and geothermal) cannot bootstrap the formation of renewable energy infrastructure by itself. Continued use of fossil fuels is required to enable a transition at the very same time we need to immediately reduce consumption of fossil fuels. But the energy returned on energy invested (EROI) to extract fossil fuels from the ground is declining. There are strong indications that conventional oil production has peaked, the maximum rate of extraction has plateaued, and the net energy available from global fossil fuel production has peaked and will now decline (Hall et al. 2014; Chapman 2014; Delannoy et al. 2021; Bihouix 2021; Rech et al. 2021). Declines in EROI can only but accelerate.

In New Zealand, about 75% of our electricity was generated by 'renewables' (hydro, wind, geothermal, solar) in 2017, but only 32% of NZ total energy use was from 'renewables'. The remaining 68% of total energy use was from fossil fuels (LLNL/US Dept Energy/IEA 2021). If we wanted to 100% electrify our economy, then we would have to triple our electrical generation capacity.

Renewable energy has a much lower EROI than conventional oil in the Twentieth century when the EROIs of fossil fuels was much higher than it is now (Seibert & Rees 2021; Capellán-Pérez et al. 2019). Battery storage of renewable energy is less energy dense and portable for transport purposes than fossil fuels (Seibert & Rees 2021).

It is impossible to scale up renewable energy to meet current energy per-capita levels because renewable energy is critically dependent on the use of scarce and rare minerals (Michaux 2021; Bihouix 2021). Reaching "net zero" globally by 2050 – far too late to avoid climate catastrophe - would require six times the amount of mineral resources used today (IEA 2021). We would have to use fossil fuels to mine these materials and build, implement, and replace this enormous renewable energy infrastructure. At the same time, the net energy available from fossil fuels will soon peak and then will begin to decline (Delannoy 2021). We simply cannot quantitatively replace current energy consumption provided mainly by fossil fuels with energy from renewables (Michaux 2021; Krumdieck 2021; Seibert & Rees 2021; Bihouix 2021).

High EROIs of fossil fuels enabled exponential growth in populations and economies in the Twentieth Century. In the Twenty First Century, we now face a future where there will be less energy per capita. Continued increases in consumption per capita will be impossible. Less energy per capita means less consumption per capita. Priorities as to what constitutes non-essential consumption over and above essential consumption will need to be examined and revised.

Any attempts to continue business-as-usual economic growth while also avoiding climate change through a transition from fossil fuels to renewables will only but lead towards increasing ecological overshoot and collapse through biodiversity loss, ecosystems breakdown, soil depletion, resource depletion, and all the other symptoms of overshoot. Whether it is powered by fossil fuels or renewable energy, continued economic growth – the expansion of the human enterprise in a finite world - can only lead to ecological and social decline and collapse (Demaria 2018; Herrington 2021; Seibert and Rees 2021).

We need to rapidly reduce our emissions of greenhouse gases, starting immediately, to mitigate the impact of climate change by reducing our use of fossil fuels. At the same time, we still need to use fossil fuels to enable a transition from fossil fuels to that of renewable energy and infrastructure (Seibert and Rees 2021). The only way out of this conundrum is to radically reduce our current levels of consumption and divert the use of fossil fuels away from extravagant and unnecessary consumption to a limited renewable energy system that can support a lower-energy society.

Reducing our consumption of fossil fuels means keeping most of our fossil fuel reserves in the ground to avoid exceeding critical climate change threshold (McGlade & Ekins 2014). Further exploration of fossil fuels would be a waste of energy and reduce our budget of fossil fuels which we need to enable a transition. If we squander our limited budget of fossil fuels on foolhardy explorations for more fossil fuels and frivolous consumption, then we will lose our last chance to make a global transition to renewable energy and infrastructure.

It is logically impossible for perpetual economic and population growth to occur on a finite planet. Sustainable economic growth is an oxymoron and empirical evidence on resource use and carbon emissions does not support green growth theory (Hickel & Kallis 2020). Either we have a planned, orderly contraction (de-growth) of our economy or else a far more chaotic contraction will be forced upon us by nature, likely within a decade from now (Herrington 2020).

Climate change is but only one of many symptoms of ecological overshoot. We can only address climate change by fully addressing ecological overshoot (Heinberg 2017; Herrington 2020).

SHORT SUMMARY

- We currently face a wicked problem that has no easy solution.
- We need to reduce our use of fossil fuels in order to mitigate the impact of climate change and avoid the risk of triggering tipping points which would result in an irreversible cascade of climate change leading to a hot-house Earth.
- In an industrial society, we are totally reliant on high grade energy for our survival, so we need to transition from fossil fuels to high-grade renewable energy and infrastructure.
- High-grade renewables cannot bootstrap themselves into existence, so we need to continue using fossil fuels to manufacture renewables such as photovoltaic panels and wind turbines.
- Reducing our use of fossil fuels is imperative in order to mitigate the impact of climate change.
- We have no choice but to divert use of fossil fuels on a limited and reducing budget from unnecessary and frivolous consumption to investments in renewables and infrastructure.
- This applies especially to the well-developed countries like New Zealand.
- Renewable energy cannot scale up to the same energy levels per capita that we currently enjoy in the well-developed countries.
- We will need to learn how to live well on a much-reduced budget of energy during and after a transition from fossil fuels to renewables.
- It is possible to do this because much of our current consumption of energy in the form of goods and services does not lead to greater well-being.
- It is as supportive communities that we can continue to thrive.
- What is possible will not happen unless we face up to realities and respond to the urgent need to reduce our greenhouse gas emissions without delay.
- We need to adopt the Precautionary Principle and target net zero emissions by 2030 instead of by 2050.
- The longer we delay, the greater will be the accumulations of greenhouse gases in the atmosphere and the subsequent increasing risk of irreversible climate change.

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