How can permaculture-design inform the implementation of regenerative agriculture principles to address global macro-challenges while creating better outcomes for pastoral farming in New Zealand?

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I wish to thank the Kellogg Programme Investing Partners for their continued support. With additional special thanks to Agmardt.

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“There can be no life without soil and no soil without life; they have evolved together”
Charles E. Kellogg, USDA Yearbook of Agriculture (1938)

“The ultimate test of a moral society is the kind of world it leaves to its children”
attributed to Dietrich Bonhoeffer (1906 – 1945)

“The farmer is the only man in our economy who buys everything at retail, sells everything at wholesale, and pays the freight both ways.”
John F. Kennedy, US President (1961-1963)

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The challenges and opportunities that lie ahead in the agriculture sector are significant. I believe the ability to engage in diverse, meaningful, and difficult conversations with an open mind and desire to address the coming challenges will determine how well the leaders of today create New Zealand's agricultural environment of tomorrow.

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Regenerative pasture in mid-winter. Note riparian planting on lake edge and newly planted silvo-pasture just below the poplars in the background on the left of the image (Mangarara Farm, Hawkes Bay)

Executive summary

World agriculture is dependent on and supported by cheap and readily available fossil fuels which have led to huge increases in global population, consumption, and economic prosperity. Unfortunately, this has created undesirable side effects such as resource depletion and environmental degradation, and we may now be reaching the planet's bio-physical limits. Renewables are unlikely to fill the energy void left by declining fossil fuels and agricultural systems need to adapt to face the threats posed by declining net energy, environmental effects, and approaching bio-physical limits. Regenerative agriculture is gaining momentum as a profitable low-input farming system that addresses the current threats by treating the farm as an ecosystem, by delivering benefits to soil health, biodiversity, and plant animal health while reducing the impact on the climate and the environment. When integrated with permaculture principles and implemented through a design process at farm scale, regenerative agriculture can provide better economic, environmental, and social outcomes to pastoral farmers when specific site and operational context is considered. This report makes recommendations including that farmers better understand permaculture, and regenerative agriculture principles and the suggested design process to implement them at farm scale and that farmers create a 100-year plan for their farm based on these principles that considers economic, environmental, and social outcomes including well-being.

Introduction

The view from space

Nature photographer Galen Rowell once called William Anders' iconic photo Earthrise (below) – taken from the Apollo 8 module in lunar orbit – "the most influential environmental photograph ever taken". It shows a beautiful blue-green planet teeming with life rising over the barren lifeless surface of the moon. It is a reminder that Earth is our home and what the consequences of its destruction may look like.

The 'triumph' of modern agriculture

Modern industrial agriculture produces cheap food in abundance through a food production system dependent upon the use of synthetic fertilisers, mainly nitrogen and phosphorus (but also other minerals), to increase the productive capacity of land to feed the world's growing population (Campbell et al., 2017). Coupled with an increase in mechanisation and technology since the industrial revolution and supported more recently by cheap and freely available fossil-based fuels, agriculture (and humans) has boomed. 'Feed the world' was the lofty and well-intentioned goal of mid-20th century pioneers like American wheat researcher Norman Borlaug, winner of the 1970 Nobel Prize and father of the Green Revolution.

Undesirable side effects

But the current agricultural trajectory has undesirable side effects and is now unsustainable. According to a review by Marshall and Brockway (2020), global agriculture is subject to three unsustainable energy trends: it is approaching its biophysical limits, is driver of environmental degradation, and has a growing dependence on fossil fuels. Krebs and Bach (2018) provide a comprehensive review of the evidence that modern industrial agriculture is largely responsible for many environmental problems faced globally, e.g., biodiversity loss, soil degradation, and alteration of biogeochemical cycles and greenhouse gas emissions. Excessive tilling, fertiliser application, pesticide, herbicide, and insecticide use, created increased soil erosion, and soils depleted of microbial life (Zhang et al., 2007; Foley et al., 2017). Further, the value of ecosystem services provided to agricultural production by natural ecosystems, including pollination, biological pest control, maintenance of soil structure and fertility, nutrient cycling and hydrological services is both enormous, underappreciated, and under threat (Power, 2010).

Sustainable development

Sustainable development, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987), has revealed itself to be an oxymoron, akin to trying to 'have your cake and eat it too'. As of 2014, no country meets the threshold for sustainable growth (Holden, et al., 2014). There cannot be infinite growth on a finite planet without encountering the biophysical limits first described by Meadows, et al. (1972) in the Limits to Growth report.

Impact of technology

Technology, often lauded as the miracle by which these biophysical limits were to be overcome (or at least lived within), has simply acted as an enabler, perpetuating business as usual and the myth of sustainability for the last 49 years. Any advances in technology or efficiency (or government policy) designed to reduce resource consumption have led to the exact opposite occurring due to increased demand – the Jevons' paradox first described by English economist William Jevons in 1865 with respect to coal use, (Bauer, et al. 2009).

Impact of policy on the environment

So, despite all the worldwide conventions, frameworks, agreements, government policies, and actions designed to rectify the situation, we humans have made exactly no progress in arresting the decline of the life supporting capacity of our planet by any environmental measure. World Wildlife Fund's (2020) Living Planet Report estimates that we have lost 68% of all vertebrate wildlife populations between 1970 and 2016, two thirds of all birds, mammals, reptiles, amphibians, and fish gone in less than 50 years. During that time the human population has more than doubled, increasing from 3.7 billion to over 7.8 billion today. The recently released 6th IPCC report (more than 3000 pages) makes for pretty grim reading indicating rises in greenhouse gasses, CO_2, and increased climate risks associated with human-impact on the environment (IPCC, 2021).

The New Zealand context

The overall trends in New Zealand are the same. Government and other regulators in New Zealand have tended to see issues in a siloed manner rather than holistically. Current policies are based on fragmented objectives and tend to be driven and incentivised primarily by short-term goals (Bardsley et al., 2020). It is possible that New Zealand's pastoral ecosystems are now reaching the biophysical limits to growth and even sustainability. Bardsley et al. (2020) notes the "recurring issues are well known" and include:

- Land-use competition and inappropriate land use
- Soil degradation and loss
- Water rights and use
- Irrigation and water quality
- Excessive use of synthetic nitrogen and other fertilisers
- Loss of native/endemic species and overall biodiversity decline
- Pollution of aquatic ecosystems from ill-advised land use
- Climate change effects that will reduce productivity or force changes in types of activity
- Biosecurity failures resulting in incursion of weeds, pests, and animal diseases
- Increased detection of pesticide residues (because of better technologies) in New Zealand's markets, possibly leading to the imposition of non-tariff barriers.

So now in the early part of the 2020s, the world finds itself faced with exactly the same increasing challenges it faced 50 years (and more) ago, namely, enhanced human-induced climate change, increasing population, increasing consumption, environmental degradation and pollution, resource depletion, reducing freshwater quality and availability, etc. These are difficult and complex problems not easily resolved, especially while trying to maintain economic growth and civilisational stability.

Regenerative is the new sustainability

Now the zeitgeist is 'regenerative', the new trend gaining momentum in agriculture. According to proponents, Regenerative Agriculture is the pathway to a 'sustainable' future, an agricultural system that treats the farm as a natural ecosystem, promoting diversity, reducing inputs, and claiming benefits that include better environmental performance, animal health, farmer wellbeing, and profitability. While many pastoral farmers in New Zealand say they practice some aspect of regenerative agriculture, there are questions; what does regenerative mean, is it all hype, a trendy idea to repackage and repurpose existing agricultural practices to make products appeal to environmentally conscious consumers? How does 'regenerative' differ from what might be described as 'conventional' farming, are there any regenerative criteria, as with Organics, and if so, what are they? And perhaps most importantly, even if regenerative agriculture is a 'thing', how can it assist us to navigate the challenges and opportunities represented by Marshall and Brockway's (2020) trio of trends (approaching biophysical limits, environmental degradation, and dependence on fossil fuels) currently weighing on agriculture.

Add permaculture design

Another agricultural trend that has been quietly sweeping the world as concerns about the environment and sustainability have increased is permaculture (Fieberg, et al. 2020). Co-founder David Holmgren defines permaculture as "consciously designed landscapes, which mimic the patterns and relationships found in nature, while yielding an abundance of food, fibre, and energy for provision of local needs" (Holmgren, 2002). Originally borne out of the Australian 'back to the land' movement in the late 1970s, permaculture is based on a series of design principles which have only recently found strong scientific support, underlining their applicability in the redesign of agricultural systems towards sustainability (Krebs and Bach, 2018).

Permaculture in its purest form was not designed to work at scale, but does that mean it can't? It was designed to distance itself from large scale industrial agriculture, but does that mean permaculture cannot now assist in its reinvention? Just because a thing was designed for one purpose, does that mean it cannot be adapted for another? Outside of the broad differences, how does permaculture compare with regenerative agriculture in practice? Permaculture principles are implemented through a design process. If there is a broad alignment in both sets of principles, can the permaculture design process be applied to better implement regenerative agriculture?

Perhaps if we can capture 'intention' without getting bogged down in 'definition', if we don't sacrifice 'pragmatism' for 'idealism', then permaculture design may provide an unlikely unifying framework to solve the complex problems and competing agendas of agricultural production.

It is that premise that forms the basis of this report, namely, how can permaculture design inform the implementation of regenerative agriculture principles to address global macro challenges and create better outcomes for pastoral farming in New Zealand.

Key Points

- Human population, consumption, and agriculture have boomed through cheap accessible fossil fuels
- This has created undesirable environmental effects which have never adequately been addressed
- Regenerative agriculture and permaculture principles may provide part of a solution

Objectives

This report attempts to understand how regenerative agriculture can be implemented through permaculture design in a pastoral farming context. Its purpose is to outline the impact of approaching macro trends in agriculture concerning biophysical limits, the environment, and fossil fuel dependency and describe how these may be addressed through long term whole ecosystem farm planning based on permaculture and regenerative agriculture principles.

This topic is considerably broad. There are plenty of opportunities to pursue specific lines of enquiry. It is not my intention to thoroughly address all these avenues in detail but to provide an overview of the issues with suitable evidence and then a suggested course of action. It is my intention to further stimulate discussion and hopefully lead to effective strategies to mitigate what I consider will be seen in the rear-view mirror as the defining issues of our time.

To achieve this objective, this report will:

- Arrive at a 'working definition' of regenerative agriculture
- Outline some of the perceived benefits of regenerative agriculture and examine some of the evidence both supporting and criticising it
- Describe the difference between ecosystem thinking and machine thinking to assist in better understanding the regenerative mindset
- Determine how the principles of Permaculture design may inform the implementation of Regenerative Agriculture
- Examine how regenerative agriculture may be part of a solution to agricultural macro trends regarding biophysical limits, environment, and fossil fuel dependency.
- Provide feedback from regenerative farmers on a series of questions regarding the practical application of regenerative agriculture
- Make recommendations that may assist in the successful adoption of regenerative practices by pastoral farmers

Methodology

A review of the literature was conducted to identify existing material on regenerative agriculture and group this into themes. Merfield (2019) commented in undertaking his own review study, “there is very little literature directly studying regenerative agriculture”, and so published literature is scarce prior to Grelet et al., (2021)’s definitive white paper, which informed a great deal of this work. An extensive review of material available on the internet from regenerative pioneers including Joel Salatin, Gabe Brown, Alan Savory, Charles Massy, and Mark Shepherd was also undertaken.

Permaculture material was sourced in a similar fashion from a literature review, but also via permaculture teacher’s websites including David Holmgren, Geoff Lawton, Darren Dogherty, and Dan Palmer. I completed a Permaculture Design Course (PDC) in 2016 and have both theoretical and practical permaculture experience. As I completed the research, the themes of the report began to emerge, namely the way in which permaculture could assist in the implementation of regenerative agriculture to provide solutions to some of the challenges faced by agriculture.

I conducted further semi-structed interviews with regenerative experts such as Gwen Grelet, Sam Lang, Nicole Masters, and Charles Merfield and scientists including Craig Anderson, Mike Joy, Peter Gluckman, and John Roche, to build up a picture of the relationship between regenerative agriculture and the issues confronting pastoral farming in New Zealand and what some of the solutions might be.

Part way into the research, three energy trends related to agriculture and the challenges they pose emerged. Regenerative agriculture/permaculture made claims that seemed to address these challenges via ecosystem thinking. To understand this better I visited three farmers I knew were implementing completely regenerative techniques on farm. A series of semi-structured interviews were conducted, and I also posed five standardised questions raised in the literature.

Hugh Jellie provided me with considerable assistance in understanding ecosystem thinking. The permaculture design process was the key to translating regenerative / permaculture into a practical application. This provided elegant unobtrusive guidance through ecosystems thinking to address some of the challenges posed to pastoral farming in New Zealand including profitability, environmental compliance and responsibility, farming within biophysical constraints, and farmer engagement and wellbeing.

This report begins by addressing the macro trends facing agriculture before introducing regenerative agriculture, permaculture, and a design process that when implemented at farm scale may go some way to improving desired outcomes.

Three macro trends facing agriculture

According to Marshall and Brockway (2020) global agriculture is subject to three unsustainable energy trends, (1) it is approaching its biophysical limits, (2) is driver of environmental degradation, and (3), has a growing dependence on fossil fuels. The convergence of these trends will provide the future operating context for agriculture in New Zealand, if not already the current one.

The effects of energy on agriculture

A comprehensive review of the role of energy in global systems is beyond the scope of this report, however, the extent to which energy is crucial to the functioning of modern society is both under-estimated and under-appreciated. This section provides a brief overview some of the key concepts of energy and how energy relates to agriculture.

Agriculture is dependent on fossil fuels

Most of the energy consumed worldwide (79%) is derived from fossil fuels; coal, oil, and natural gas (Figure 1), cheap available energy is crucial to the functioning of modern society and our food system, (Pelletier et al., 2011) and the risks associated with its price volatility and long-term availability are poorly understood (Deike et al. 2008; Norton, 2019; Berman, 2021).

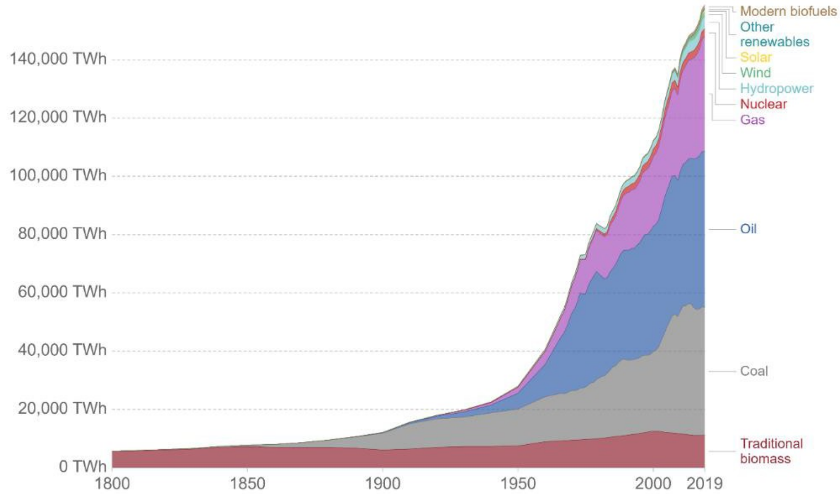


Figure 1. Global direct primary energy consumption (1800 – 2019) (after Smil, 2017; BP, Statistical review of World Energy, 2020)

Agricultural production uses about 28% of the world's energy (Gomiero, et al., 2008; Pelletier, et al., 2011; Rokicki, et al., 2021), about 90% of which is derived from fossil fuels (Harchaoui and Chatzimpiros, 2018a, Marshall and Brockway, 2020). The transition to an agricultural system dependent on fossil fuel was the result of:

- using fossil fuelled machinery 'on-farm' for production practices such as tillage, seeding, irrigation, harvesting etc.
- embedded fossil fuel energy in the production, transport, and application of fertilisers, herbicides, and pesticides (Harchaoui and Chatzimpiros 2018b) and animal feed inputs (Pelletier et al., 2011)
- increasing dependency on fossil fuels for post-production processes such as transportation, processing, packaging, distribution, retail and household preparation (Infante-Amate and de Molina, 2013; Centre for sustainable systems, 2017)

Even by the 1970s the crucial role energy played in agricultural production was evident by this now famous quote from Howard Odum. "The great conceit of industrial man is that he imagined his progress in agricultural yields was due to new knowledge. A whole generation thought that the carrying capacity of the Earth was proportional to the amount of land under cultivation and that higher efficiencies in using the energy of the sun had arrived. This is a sad hoax, for industrial man no longer eats potatoes made from solar energy; now he eats potatoes partly made of oil" (Odum, 1971).

Some agricultural systems are so energy intense they use more energy in production of food than they produce as a result (Guzman-Casado and de Molina, 2017). From the perspective of previous agrarian societies whose survival depended on producing surpluses of biomass derived energy, this situation would have been untenable (Marshall and Brockway, 2020). Over the last 100 years we have propped up world's entire agricultural food production and distribution system with readily available cheap fossil fuels, and there is a very good reason for this.

Fossil fuels have huge advantages

Human work has been replaced by fossil fuels that are much more 'energy dense' allowing an exponential amount of work to be done, i.e. human manual labour was replaced by steam power which was in turn replaced by petroleum driven internal combustion engines (Hagens, 2021). One barrel of oil (about $US70) does approximately the same amount of labour as 4.5 years of human work. If extrapolated to the approximate current daily global consumption of 100 million barrels, the equivalent energy consumed is equivalent to around 500 billion hours of human labour. When distributed equally among the world's population (which of course it isn't), this would equate to every human having 60 human labourers working for them every day (Morgan, 2013; Hagens, 2021).

As well as being very energy dense, fossil fuels are easily transportable, store energy, are refined into different fuels, provide the feedstock for a vast array of consumer products, are quickly scalable and provide energy where and when required regardless of the weather.

Fossil fuels are running out

The majority of the world's major oil fields were discovered by the 1960s (Figure 2) and are currently in decline (Figure 3) despite demand increasing. World conventional fossil fuel production peaked somewhere between 2012 and 2018 depending on who authored the research.

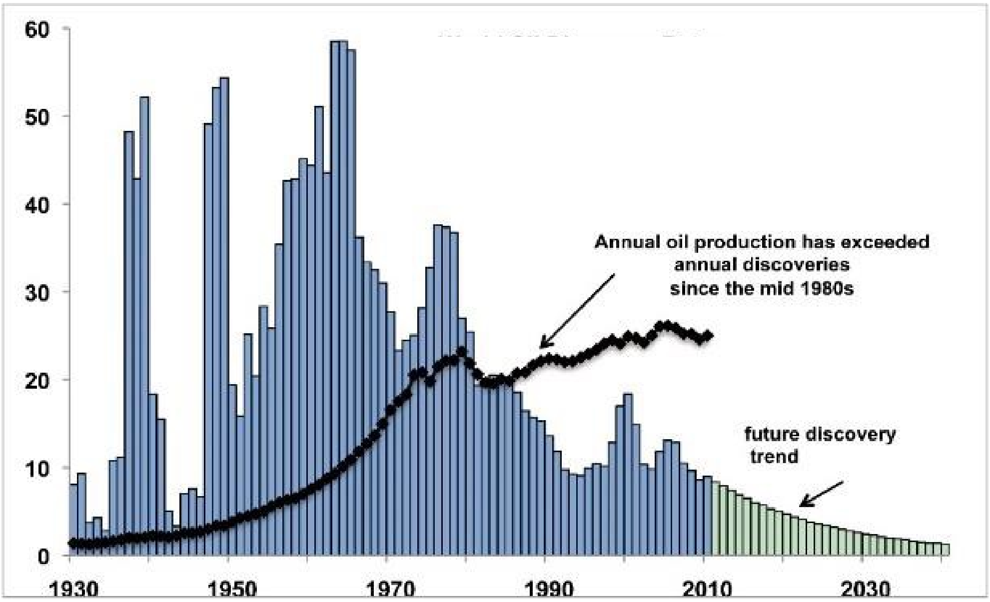


Figure 2. World conventional oil discovery rates (giga-barrels/year) (Day et al., 2009) Future discovery trend (right tail of graph) does not consider tight oil discovery/production which has increased supply.

Fracking of ‘tight oil’ in the US has supported total world production since about 2012 and looks set to peak around 2025. Huge numbers of wells need to be drilled to reach worthwhile levels of tight oil production and production declines rapidly in the range of 38 – 45% per annum from individual wells. For example, in 2017, around 8,500 tight oil wells were completed in the US and nearly 70% of these were needed simply to compensate for declines at existing wells (Gould and McGlade, 2019). So tight oil has extended world oil supply and pushed the peak of the curve (on Figures 2 and 3) out by maybe 10-12 years. Due to increasing consumption as world population approaches 9 billion, improved extraction technology, and more access to debt funding, the rate of decline will likely be steeper on the other side of the curve than it was on the run up. (Hagens, 2021).

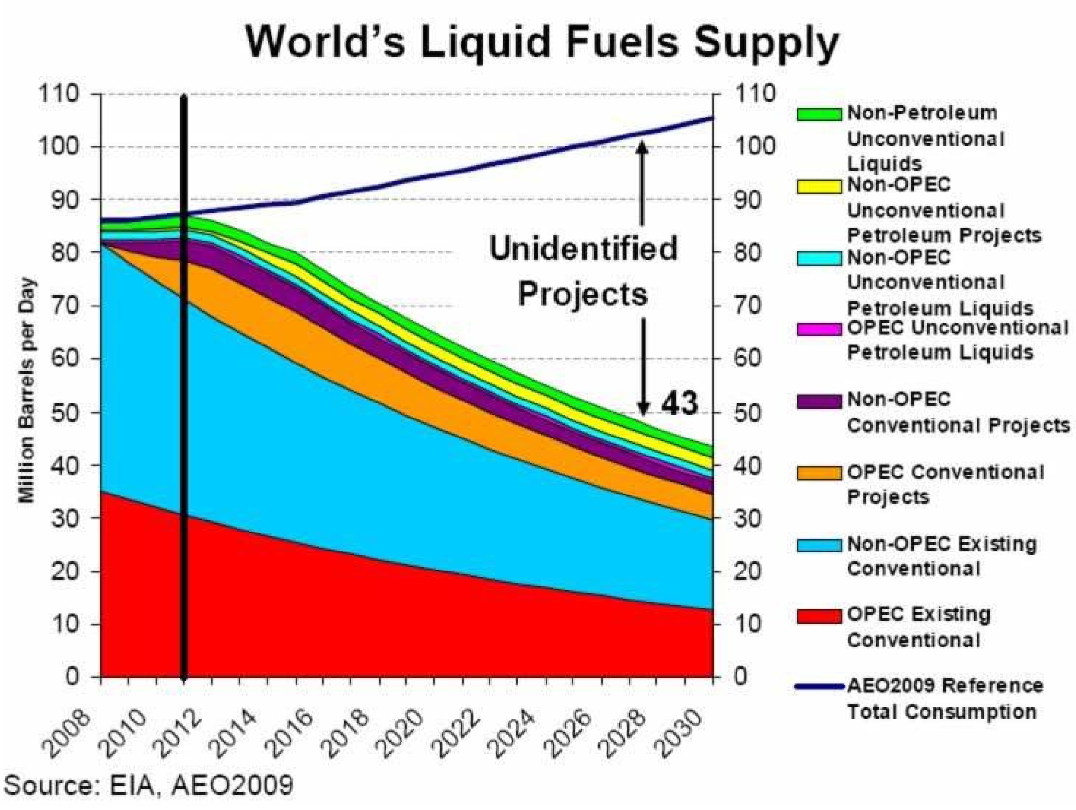


Figure 3. World’s liquid fuel supply (production) (EIA, 2009) The blue line indicates 2009 projections for consumption showing a production shortfall. US tight oil production makes up part of the ‘unidentified projects’ and pushes the peak out to about 2025.

When will oil run out? Nobody knows for sure. There is still a great deal of oil left, but it is more difficult, dangerous, and deep than the oil already extracted (Morgan, 2013). This is important because the energy used to obtain the remaining oil is increasing. Therefore, the net energy return on the energy invested (EROEI) is dropping quickly. It will eventually take more energy to extract, refine, and harness the energy than the energy itself produces, rendering the system net energy negative and therefore pointless (Morgan, 2013). Outside of Venezuela, itself a failed state, most of the world’s remaining oil lies in a triangle with sides a couple of hundred miles across between Saudi Arabia, Iran, and Iraq; a region exposed to significant geopolitical risk.

The demand for energy is increasing

World primary energy consumption has been increasing and is made up primarily of fossil fuels, oil, natural gas and coal (Figure 4) (BP, 2021). Global energy demand is set to increase by 4.6% in 2021, more than offsetting the 4% contraction in 2020, due to the Coronavirus pandemic. Demand for all fossil fuels is set to grow significantly in 2021. Coal demand alone is projected to increase by 60%, more than all renewables combined, underpinning a rise in CO_2 emissions of almost 5%. This expected increase would reverse 80% of the drop in emissions that occurred in 2020 (IEA, 2021a). Global oil demand is set to return to pre-pandemic levels by the end of 2022. "OPEC+ needs to open the taps to keep the world oil markets adequately supplied" and "meeting the expected demand growth is unlikely to be a problem" (IEA, 2021b). It doesn't look like we are ready to back away from our dependence on fossil fuels any time soon.

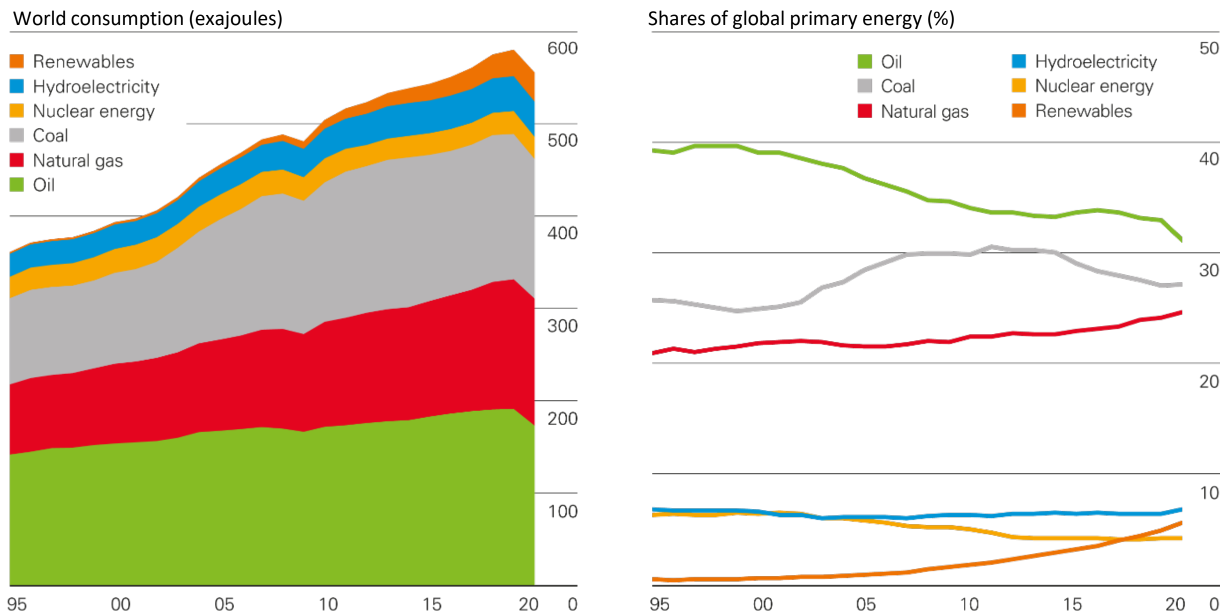


Figure 4. World primary energy consumption 1995 – 2020 (BP, 2021) The left graph: the lower 3 areas (green, red, grey) are fossil fuel consumption for primary energy (84%) of total. The right graph shows a relative increase in renewables and natural gas (and potentially coal) and decrease in oil as a percentage. Percentage share is relative, not absolute as total consumption (left graph) has increased over time. Note also the dips at 2008 (GFC) and 2020 (Coronavirus pandemic).

The economy is dependent on surplus energy

The economy is driven by surplus energy, not surplus money. Growth in output and population is the result of harnessing ever-greater quantities of energy. All resources, food, work, timber, concrete, machinery, oil, natural gas, coal, and renewables are composed of embedded energy – they are essentially the same thing (Morgan, 2013). Energy is embedded in extraction, production, delivery, and consumption. So it follows that energy powers the economy, not money. Money is the means by which this embedded energy is traded, the total of which represents a country's gross domestic product (GDP). Money can be considered therefore as a future claim on energy, as it is either invested or consumed.

Will renewable energy make up the energy shortfall?

Renewable energy sources have proliferated over the last 20 or so years in response to addressing climate change, environmental damage, and declining fossil fuel availability (Hagens, 2016, 2021, EIA, 2021). Renewable energy includes energy derived from solar, wind, hydro, geothermal, wave, and biofuels and accounted for 26% of the energy generated worldwide in 2018 (IEA, 2020). But there is a reality often obscured in the 'transition to renewables' story. Firstly, renewable energy *infrastructure* is not renewable and secondly, the vast majority of renewable energy generation produces only electrical energy, not primary energy.

Renewable energy infrastructure is not renewable

The sun and the wind are renewable, the machines and devices that capture and store it are not. Electricity is not a primary energy source in and of itself. It is generated or captured from a primary source such as sunlight, water, wind, or the burning of fossil fuels and in this process, about a third of the energy value is lost (Energy Resources Aotearoa, 2021). As a manufactured energy, electricity generation relies on the construction and maintenance of dams, batteries, panels, turbines, blades, and other machines that are built exclusively from fossil energy and mineral resources mined from the Earth using fossil fuels, they are maintained using fossil fuels, and eventually dismantled (and perhaps replaced) using more fossil fuels (Oroschakoff, 2018; Forsberg, 2020; Martin and Bloomberg, 2020). Renewable energy is more accurately described as rebuildable (Hagens, 2016, 2021; Berman, 2019). Most of the fossil energy consumption associated with the construction of renewable/rebuildable energy is up front. But despite the embedded fossil energy, a wind farm for example does break even on an energy basis over its lifetime and emits much less CO_2 per kW/h than energy generated by burning fossil fuels (Helman, 2021). Renewable/rebuildable energy sources are a growing and important part of the energy equation, but they are not the solution to fulfilling increasing energy demand.

Renewable energy generation produces mainly electrical energy

Although electricity is useful, it is not as versatile or as energy dense as fossil fuel derived energy. The bulk of the world's electricity (c.f. energy) (73%) is currently generated from the burning of fossil fuels; natural gas, coal, and oil (Figure. 5). To transition this generation to renewable/rebuildable would require a massive shift.

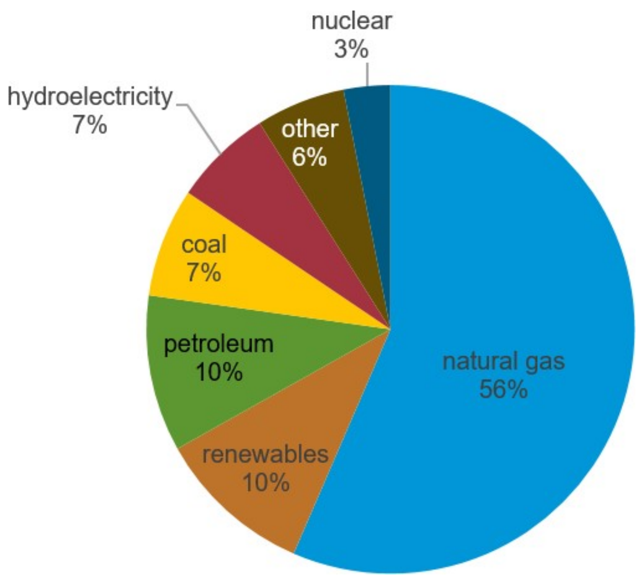


Figure 5. World electricity generation by fuel in 2019 (BP, 2021)

Projections such as those by Norwegian consulting firm DNV (Figure 6) show fossil fuel generation of electricity being replaced by renewable sources of energy (solar and wind).

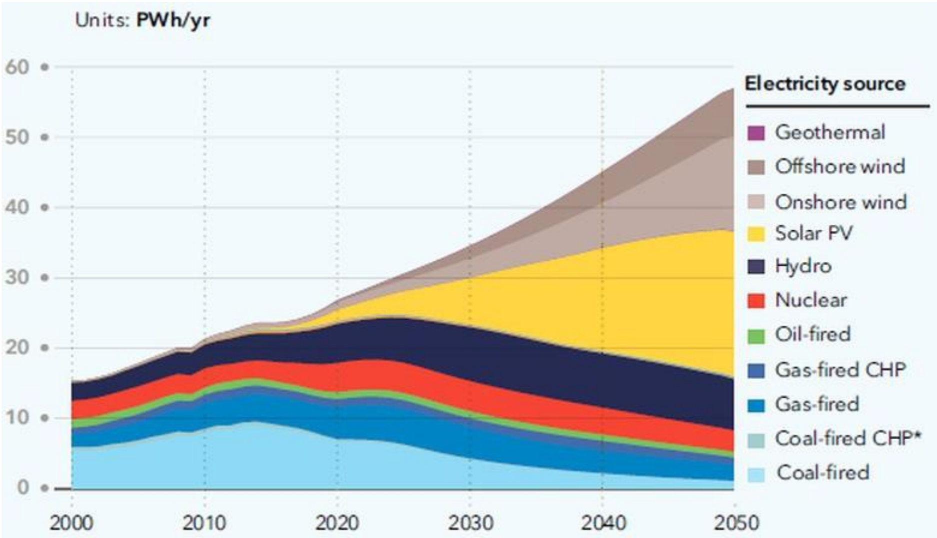


Figure 6. Predictions of a transition from fossil fuels to renewables in electricity generation (DNV 2020 – Norway)

It does make sense to progressively replace electricity generation from more polluting sources like coal with cleaner or renewable sources. But only about 28% of the fossil fuels consumed in the US in 2020 were used to generate electricity, the other 72% being allocated between transport, residential, commercial, and industrial sectors (Sönnichsen, 2021). It is this portion of fossil fuel used to create electrical energy which has the best chance of being replaced by renewable/rebuildable energy. Even if this is transition can occur, which some believe it cannot, (see references to Heinberg and Fridley (2016), Berman (2021), and Friedemann (2021) below), fossil fuels, especially oil have a myriad of other non-replaceable uses in modern society. It is this embedded nature of oil (and other fossil fuels) in the production, manufacture, and distribution of everyday products (concrete, steel, plastics, chemicals etc.) including agricultural products (wire, pipe, plastics, fertiliser, tractors, stockfeed, etc.) that make it such a valuable resource.

Renewable energy in New Zealand

New Zealand has the third highest rate of renewable energy as a portion of primary supply in the OECD (after Norway and Iceland). 40% of New Zealand's energy comes from renewable sources such as hydro, geothermal, and wind to produce electricity, the remaining 60% of energy comes from fossil fuels. New Zealand's total energy consumption makes up 0.15% of global energy consumption. Consumer demand by fuel is heavily weighted towards oil (48%), followed by electricity (24%), natural gas (12.5%), renewables (11%), which is electricity, and coal (4.1%) (Energy Resources Aotearoa, 2021).

New Zealand's agriculture sector directly uses less than 6% of total energy and nearly two thirds of that is diesel. Agriculture is heavily dependent on the industry and transport sectors for processing and distribution, both of which are heavy fossil fuel users (Energy Resources Aotearoa, 2021; MBIE, 2021).

The rise of electric cars embodies the transition to renewables story

Passenger vehicle transition to electric vehicles (EVs) has been seen as the 'low-hanging fruit' in a transition to renewable energy. In 2019, the British Natural History Museum issued a press release authored by a group of leading UK scientists regarding the difficultly posed by energy and resource constraints in meeting the 2050 targets for electric passenger cars and vans only. It stated, "to meet the UK electric car targets for 2050 we would need to produce just under two times the current total annual world cobalt production, nearly the entire world production of neodymium, three quarters the world's lithium production and at least half of the world's copper production."

"If this analysis is extrapolated to the current projected estimate of two billion cars worldwide, based on 2018 figures, annual production would have to increase for neodymium and dysprosium by 70%, copper output would need to more than double and cobalt output would need to increase at least three and a half times for the entire period from now until 2050 to satisfy the demand", for the cars alone.

Further, a 20% increase in UK-generated electricity would be required to charge the current 252.5 billion miles to be driven by UK cars and a further 6% for the energy costs of metal production (Herrington, et al. 2019). Nearly half (46%) of the UK's electrical energy is currently supplied from fossil fuels, mainly imported natural gas from Norway (Department for Business, Energy, and Industrial Strategy, 2020). That's more than 50% of existing energy needs derived directly from fossil fuels in the UK at current consumption without accounting for how a further 20% increase in energy, might be generated, just for electric vehicles.

Even if that extra 20% was to come from renewables/rebuildables, the availability of minerals such as cobalt, copper, and rare earth minerals and volume of fossil fuel energy embedded in the construction and maintenance of wind farms and solar panels etc. over their useful life makes this transition not only unlikely, but virtually impossible (Herrington, et al. 2019). Energy and mineral availability will severely constrain any transition to renewable energy sources (Michaux, 2020). Zaremba (2021) quotes a Bank of America report suggesting the world will run out of batteries for EVs as early as 2025 due to material supply and an inability to meet demand.

For all the carbon 'net-zero' emphasis on EVs, the transportation sector accounted for only 16% of global greenhouse gas emissions in 2020 (Figure 7). The Industrial sector was the greatest source at 29% followed closely by Agriculture at 28%. In addition, transport is not the main use of internal combustion engines. Of the 165 million internal combustion engines manufactured in 2020, less than half (78 million) were for automotive use. Agriculture, manufacturing, power generation, forestry and construction accounted for the other 53%. (Berman, 2021).

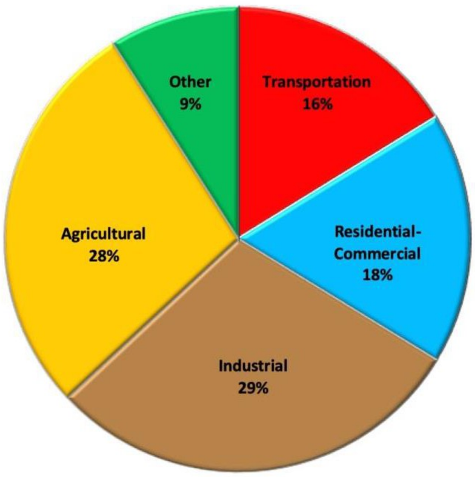


Figure 7. Global greenhouse gas emissions by sector (Berman, 2021)

Renewable energy in agriculture

With respect to agriculture, most renewable energy alternatives globally are associated with functions like heating and pumping water, heating greenhouses and desalinising irrigation water (Acosta-Silva, et al., 2019). The top 5 users of renewable energy for agricultural production in the EU range between 22% for Slovakia and 35% for Sweden; the average is 10% (Rokicki, et al., 2021). Therefore, in the EU, in the best case, 65% of energy for agriculture is provided by fossil fuels; coal, gas, and oil products, whereas on average, 90% of energy comes from fossil fuels. There needs to be a greater recognition of the limits to adoption of, and transition to, renewable electrical energy. Furthermore, it's the embedded nature of the fossil fuels in manufactured farm supply equipment, animal feed, and fertilisers that will be challenging to reduce.

Renewables will not replace the shortfall in fossil fuel energy

Heinberg and Fridley (2016) propose six reasons why renewable energy systems will not seamlessly power the current version of society. We will not be able to simply unplug from fossil fuels and plug into wind and solar. This is a most unpleasant realisation because the implications are significant. A very brief summary of these reasons is:

- **intermittency**: the sun does not always shine; the wind does not always blow. Demand is often not aligned with supply. This creates the problem of storage which is currently addressed by some form of battery.
- **the liquid fuels problem**: electricity does not supply all our energy needs. E.g. most transportation and industrial processes require oil and will be very difficult to substitute due to thermal requirements (e.g. for steel and concrete) and technology constraints (e.g. heavy trucks, ships, and aircraft).
- **other uses of fossil fuels**: there are many uses for fossils fuels in virtually every area of modern society, not just electricity generation. These include manufacturing processes and feedstock for materials which are not able to be substituted.
- **area density of energy collection activities**: Fossil fuels are extracted from large underground reservoirs with small surface areas. Renewables require very large above ground surface area for collection posing significant environmental challenges.
- **location**: Renewable (solar/wind/hydro) are location dependent. Demand is often at distance. Significant energy losses and grid infrastructure costs are incurred in transporting energy.
- **energy quantity**: The quantity of energy able to be supplied by renewables will not replace the current energy demand supplied by fossil fuels let alone any increase in projected demand. This raises questions about whether future economic growth is even possible, let alone desirable.

Fossil fuels are the lifeblood of modern industrial society, and they are steadily being depleted. Eventually, their rates of *production* (c.f. discovery) will cease to grow and will begin to permanently decline, spelling disaster for a civilization dependent on ever-increasing quantities of ever-cheaper fossil energy. Their supposed replacements are totally inadequate, possessing nowhere near the necessary abundance, concentration, versatility, transportability and/or commercial viability. Given how long it takes to build an entirely new energy infrastructure, the time to begin doing so was decades ago. Since we didn't do that, we now face not a continuation of our present lifestyles courtesy of alternative energy sources, but an involuntary "simplification" of every aspect of our lives (Friedemann, 2021).

Defining the energy conundrum is like asking five blind men to describe an entire elephant by each touching only one part of it. The problem looks different depending on whether your perspective is the trunk, the tail, the leg, the ear, or the belly, but each believes they can describe the elephant.

Energy as a component of conventional agricultural production is often ignored in favour of focus on downstream effects such as nutrient losses and gas emissions. Most of that energy is derived from fossil fuels and despite the increasing focus on renewable forms of energy, will continue to be so. Modern industrial agriculture continues to be heavily and inextricably dependent on (mainly) fossil energy inputs at all stages of the supply chain based on an implicit assumption that suitable energy will always be available, it just needs to be priced in (MacKay, 2008).

The economists are wrong. You cannot assume that a resource will always be available, you can't just price it in. There was a time before fossil energy and there will be a time after it (Figure 8). We all live in the anomaly in between. What that future looks like is open to speculation but the energy implications for agriculture and food production are significant based on their current fossil energy indebtedness.

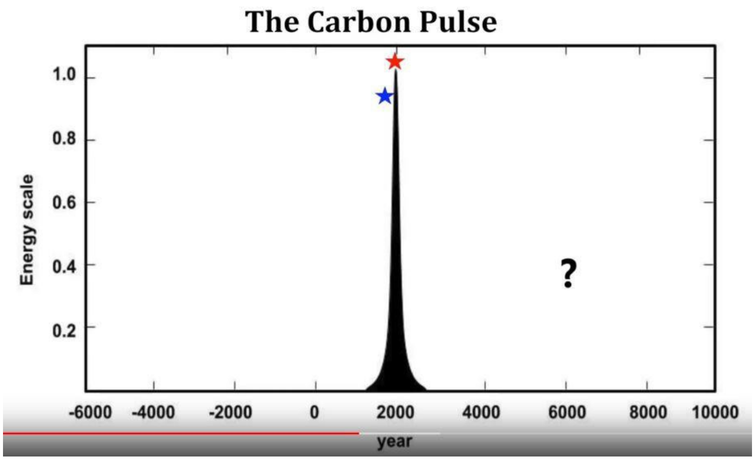


Figure 8. **The fossil carbon pulse** (screen capture from Hagens, 2021) The blue star suggests our current position, the red star, peak production, and the question marks asks where future energy will come from.

Key Points

- Agriculture is dependent on embedded fossil fuels at every part of the supply chain
- Fossil fuels will likely run out before the end of the century, their decline creating significant disruption to a society and food production system wholly dependent on them
- Renewables will not make up the energy shortfall leading to a future with less available net energy

Reaching bio-physical limits

Government responses to curbing greenhouse gas emissions

Many governments and policy makers around the world, including New Zealand, plan to reduce greenhouse gas emissions and reach carbon zero by 2050 in fulfilment of the Paris Agreement on Climate Change. These ambitions in New Zealand have spawned laws and policies (e.g. the Climate Change Response Act 2002, its amendment, the Zero Carbon Act 2019, the Emissions Trading Scheme) and policy direction from major industries including agriculture such as 'Fit for a Better World' (MPI), and the He Waka Eke Noa Primary Sector Climate Action Partnership.

New Zealand introduced the Zero Carbon Act in 2019 to achieve net zero emissions of all greenhouse gases, except for methane emissions from agriculture (which it will address by 2025) and waste, by 2050. Methane made up about 43 percent of New Zealand's gross greenhouse emissions in 2018, with 86 percent of this coming from livestock. Nitrous oxide made up 10 percent. Agriculture contributed 48 percent of our gross greenhouse gas emissions (MfE, 2020) with nearly half (22.5%) coming from dairy farming, according to DairyNZ's website. Methane emissions are covered by a separate target of at least 24-47% reduction below 2017 levels by 2050, with an interim target of 10% reduction by 2030 and this is reflected in MPIs 'Fit for a Better World' strategy (MPI, 2020).

The He Waka Eke Noa Primary Sector Climate Action Partnership between government, industry, and Iwi/Māori was agreed in 2019 to collaborate with and equip farmers and growers to encourage understanding of agricultural emission and sequestration of greenhouse gases, undertake good farming practice that reduces emissions and/or increases sequestration, and provides a financial incentive to do so (He Waka Eke Noa, 2020).

From both a legal, policy, and financial perspective the direction of travel is clear, the net reduction of CO_2 and methane emissions is now enshrined in statute.

Net zero effect for carbon emissions

While these efforts to reduce industrial and agricultural emissions may be noble, at global scale, not one convention, framework, agreement, policy, or action designed to reduce CO_2 emissions has managed to curb what appears to be an exponential increase in atmospheric CO_2, broken only by periods of relative economic contraction (Bioenergy International, 2019) (Figure 9). The forecasted increasing fossil fuel demand (mentioned above) highlights the challenges outlined in the US-based International Energy Agency's 'Net Zero by 2050 - A Roadmap for the Global Energy Sector'. This roadmap notes that most pledges by countries are "not yet underpinned by near-term policies and measures". In the meantime, "oil demand looks set to continue to rise, underlining the enormous effort required to get on track to reach stated ambitions" (IEA, 2021b).

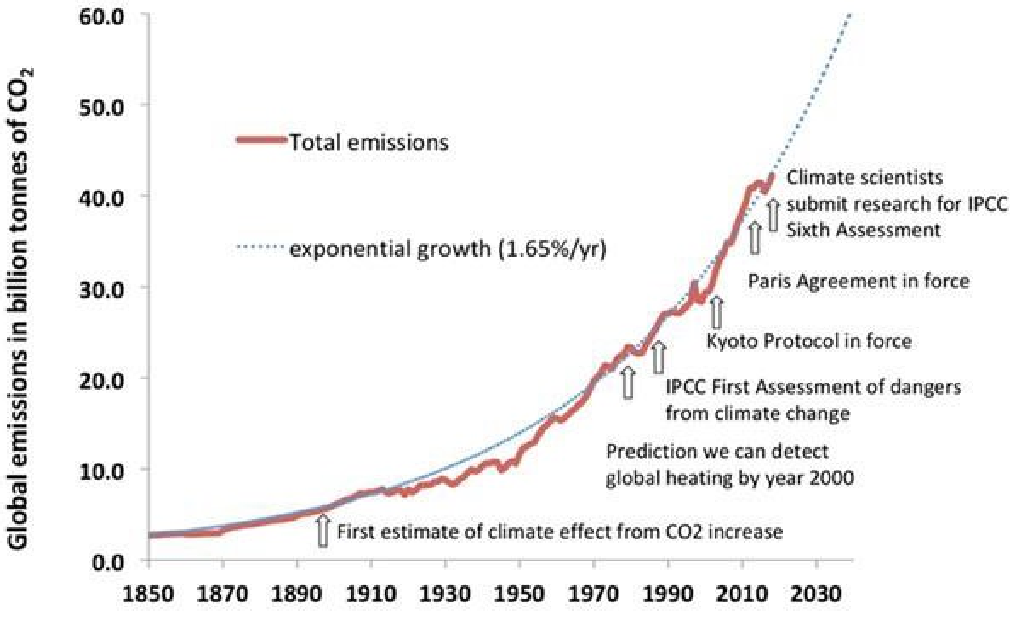


Figure 9. Global CO_2 emissions since 1850. (from Knorr, 2019)

In addition, most emissions linked to energy infrastructure are already essentially locked in. Coal-fired power plants, which account for one-third of energy-related CO_2 emissions today, represent more than a third of cumulative locked-in emissions to 2040. The vast majority of these are related to projects in Asia, where average coal plants are just 11 years old on average with decades left to operate, compared with 40 years on average age in the United States and Europe (EIA, 2018).

Former UK Chief Scientist Sir David King says long-term targets such as Carbon Zero by 2050 are an excuse for procrastination. The short-term matters most: "What we do in the next 3-4 years, I believe, will determine the future of humanity" (Dyke, et al., 2021).

"We have arrived at the painful realisation that the idea of net zero has licensed a recklessly cavalier 'burn now, pay later' approach which has seen carbon emissions continue to soar… The time has come to voice our fears and be honest with wider society. Current net zero policies will not keep warming to within 1.5°C because they were never intended to. They were and still are driven by a need to protect business as usual, not the climate. If we want to keep people safe, then large and sustained cuts to carbon emissions need to happen now" (Spratt, 2021).

But will cuts in global carbon emissions happen now? The evidence would say no. Please see Appendix 1 for required CO_2 emissions reductions required to limit global warming to less than 1.5°C as per the Paris Agreement. Economic growth is the primary driver of energy demand and related CO_2 emissions (Figure 10) (EIA, 2020), and the world needs growth to maintain the current financial system, especially in the wake of the as yet unresolved Global Financial Crisis of 2008 and the Covid-19 Pandemic currently sweeping the globe. Remove energy and you remove growth and then civilisation as we know it (Tverberg, 2012; Friedemann, 2021), and that's a pill that no economist or politician is going to take.

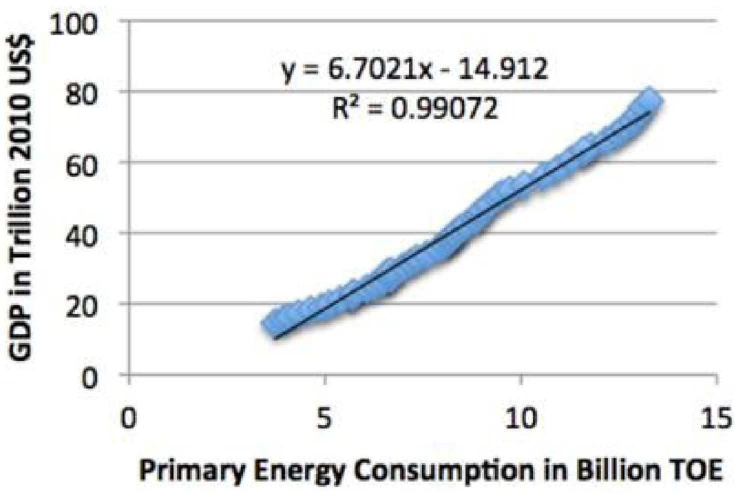


Figure 10. Energy consumption v world GDP in 2010 dollars from 1965-2016. Linear correlation R^2=0.99
(from Gail Tverberg, OurFiniteWorld.com)

Impacts of climate change on agriculture in New Zealand

According to the recently released IPCC report, New Zealand will experience some significant impacts as the result of a changing climate (IPCC, 2021). Predictions for future climate include:

- Mean temperature has increased about 1.1°C since records began ("with human influence the dominant driver") (p3522), more quickly than the global average, particularly around the South Island (p3200), marine heatwaves will become more common and last longer, particularly coming from the Tasman Sea (p3197), with large increases in the frequency of extreme sea-level events (page 3518).
- The south and west of the country will likely get wetter while the north and east will get drier (p3197). Droughts will be more common (p3196) with implications for water supply and irrigation. River flooding and fire weather is projected to increase (p136). There will be between 30 and 50 percent fewer 'frost days' (page 3194).
- Snowfall is expected to decrease with a corresponding retreat of glaciers (p136 / p3198).
- Decreases in snow and ice or increases in flooding will affect winter tourism, energy (hydro) production, river transportation, and infrastructure (p132).
- Landslides will be more likely in the South Island and eastern North Island due to higher precipitation intensity (p3195).

These predictions have significant implications for agriculture as farming land is susceptible to risks associated with changes in temperature and rainfall and more than half (52%) of farmers feel their farm is currently being impacted moderately or majorly by climate change and severe weather patterns (MPI, 2019). These impacts include flooding, coastal erosion, risk to infrastructure, restricted grazing, hail damage, drought, fire danger, soil erosion, insect pest, weeds and disease incursion (Royal Society of New Zealand, 2016). Farmer responses may include more intensive irrigation, flood protection works, use of pesticides / herbicides, all of which have economic, environmental (and probably social) impacts. These measures have the effect of making a farm more energy intensive as additional energy is expended to maintain a suitable growing / grazing environment. Other responses such as retiring vulnerable land or planting trees on erosion prone land are less intensive, but impact on farm management and economics.

Environmental consequences of agriculture on water quality

Between 1990 and 2019, dairy cattle increased from 3.4 million to 6.3 million (82%) with dairy cattle in Canterbury increasing from 113,000 to 1.2 million (973%) and in Southland from 38,000 to 636,000 (1,584 percent). Over the same time period, beef cattle decreased from 4.6 million to 3.9 million (- 15.3%) and sheep were down from 57.9 million to 26.8 million (- 53.6%) (Statistics NZ, 2021).

The increase in the scale and intensity of dairy farming has required increased use of external inputs, especially fertiliser, feed, and water (along with the associated embedded energy) to support these high intensity systems. These external inputs incur considerable environmental externalities as degraded water or excess nutrients that are passed through the system have impacts both economically and environmentally that are borne by wider New Zealand. This is counter-intuitive given the dairy industry itself relies on a 'clean green' image to maximize returns (Foote et al., 2015).

Synthetic nitrogen fertiliser use on farms in New Zealand has increased from 24,586 tonnes in 1990 to 385,000 tonnes in 2019, or 1,361% over 29 years. Nitrogen is highly water soluble and finds its way into waterways creating negative environmental consequences (Figure 11). When combined with animal urine and manure, volatised nitrogen amounts to about 80% of emissions from agricultural soils (Joy and Canning, 2020).

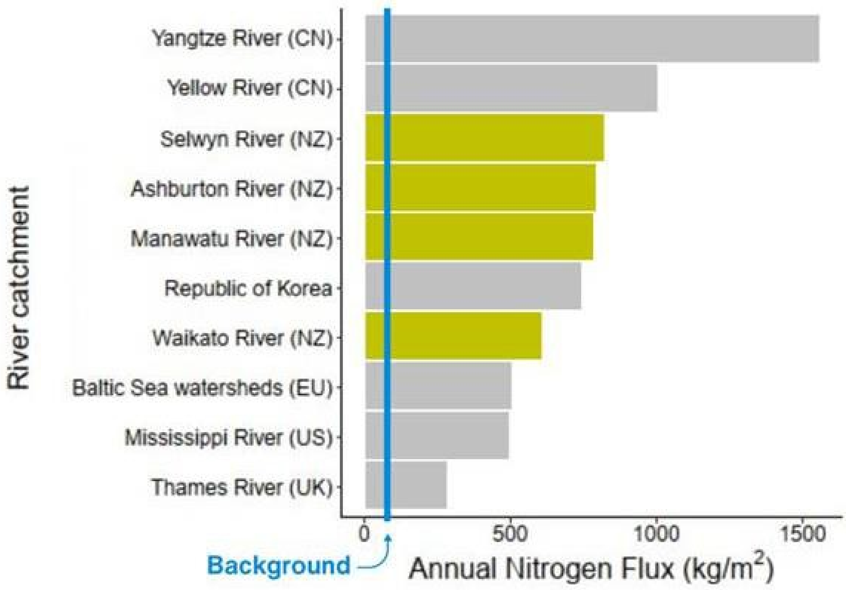


Figure 11. Global comparison of nitrogen flux in rivers (Joy and Canning, 2020)

Farmers are under increasing pressure to ensure their farm meets environmental standards. National regulations already require stock exclusion from many water bodies and control high risk activities such as intensive winter grazing and dairy conversions. Further regulations in 2022 will require certified freshwater farm plans (phasing them in over time) and the National Policy Statement for Freshwater Management 2020 requires Regional Councils to notify regional plans by 2024 that will introduce new water quality and ecology targets. These measures are part of a government focus on preventing degradation of freshwater bodies and improving them within a generation.

A social licence to operate

Currently more than 95% of dairy products and 88% of all sheep and beef goes to export markets earning $19.0 billion and $10.4 billion respectively for the year ending June 2021 and providing many thousands of jobs (Meat Industry Association/Beef and Lamb NZ, 2020; Granwal, 2021; MPI, 2021). The challenge, according to many such as Foote et al. (2015) is, whether the benefits are worth the hidden economic and environmental costs borne by New Zealanders and the environment.

It is this balance of desirable vs. undesirable effects of farming that leads to the concept of a 'social licence' to operate, which according to Brohmer (2011) is what is earned as a result of meeting public concerns or when an industry is able to act in the best interest of the public or protect the common good. Social licence is essentially trust (Moffat and Zhang, 2014).

Social licence is qualitative and driven largely by perception. It is here that dairy farming in particular has had its challenges. In the nine years to 2017, positive perceptions of New Zealand pastoral farming have slid from 78% to 47% for urban and from 83% to 50% for rural respondents. Further, the number one issue was considered to be water pollution and water quality by both urban (52%) and rural (58%) respondents, and the source of the problem; dairy farming [pastoral farming, which was one category in 2008 was split into sheep and beef farming and dairy farming for the 2017 survey] (UMR Research, 2017).

Dirty dairying, it appears, is a 'thing', however the May 2020 Opinion of Primary Industries report (also carried out by UMR Research) showed an increase in positive perception of 9% for both sheep and beef and dairying from 2017 levels, potentially due to the effects of the Covid-19 related measures. With an increasing consumer demand for sustainability (Whelan and Kronthal-Sacco, 2019) and increasing focus on food traceability, transparency, and trust (van Delden et al., 2020), the environmental credentials of 'the brand' matter (Lucci et al., 2019).

While greenhouse gas emissions and declining water quality are two of the highest profile environmental effects of intensive agriculture in New Zealand, there are others. Over allocation and use of irrigation water to farm marginal lands, soil compaction, soil erosion from grazing steep marginal country or tillage of arable land, and the energy use, itself a greenhouse gas contributor, used in the processing and distribution of agricultural products are also major problems in search of solutions.

Issues identified by farmers as affecting the environment

According to a survey conducted by the Ministry for Primary Industries (MPI, 2019), the key issues farmers face in making their farming operation more environmentally sustainable for the future are:

- **Land management**: the use and sustainability of fertilisers, managing how effluent is discharged, knowing how to reduce the amount of nitrogen used, and planting trees for shade, shelter, and riparian reasons to protect waterways.
- **Water**: ensuring the availability of water, managing water and irrigation more efficiently, and protecting the quality of water in waterways.
- **Financial considerations**: the need to be financially viable to have the capability to undertake environmental work, the need for improved profitability to be more environmentally sustainable, and the increasing costs of compliance in becoming more sustainable.

Increasing regulation: increasing compliance requirements, changing requirements and the additional burden (both financially and mentally) these place on their farming operations.

These issues will come as no surprise to those in the agricultural sector and, combined with the other environmental, climate, energy, and emissions related trends, create a challenging agricultural landscape over both the short and longer term, one to which farming systems will need to be resilient.

Key Points

- No emissions agreement, policy, or law has ever had any reducing effect on increasing atmospheric CO_2
- This is because CO_2 emissions are directly corelated with both economic growth and climate change
- Agricultural practices will need to adapt to new emissions laws and be resilient to a changing climate
- Agriculture is having a negative effect on the environment affecting the social licence to operate

Where to from here?

Humanity is indeed faced with a conundrum. Fossil fuels will both decline in availability and energy density but will increase in price. The transition from fossil fuels to renewable energy will occur in a fragmented fashion and will be largely confined to fossil fuel substitution of electricity generation and constrained by energy and mineral availability. Improvements in technology will most likely compound the pressure on resources and ecosystems acting as an enabler of consumption rather than their panacea. Technology will continue to be the trojan horse that justifies relative business as usual buoyed up by political and economic intransience until that narrative can no longer be sustained. In an accounting-led race to net zero carbon, reduction of greenhouse gas emissions, and relative proliferation of renewable energy, we may win the battle but lose the war. Fossil energy will probably run out before the end of the century. Renewable energy sources cannot hope to replace it due to a lack of energy density, 'reallocation' issues, and a lack of suitable resources. With it, the era propped up by cheap freely available energy and everything that depends on it, will either come to an end, or look vastly different. The climate and the environment may be the beneficiaries of this, but we humans will need to reimagine the complex workings of an entire society including a food production and distribution system that runs on much less energy than our current one does.

The life supporting capacity of the environment (biodiversity, water quality, soil quality, ecosystem function, climate etc.) has declined over at least the last 50 years despite the best efforts of governments and policy makers to arrest and improve this. Climatic extremes and unpredictability are rising and will require the development of increasingly resilient farming systems. These environmental trends look set to continue while population and resource consumption increases, economic growth is pursued to maintain and enable an expansionist financial system, and unrealistic projections are made about the transition to a 'green economy'.

I do not believe that any of these statements are exaggerations; if anything, the impacts of these issues are under-reported and under-appreciated by the vast majority of society.

The conundrum is how do we maintain economic growth to preserve a financial system predicated on debt, propped up, albeit temporarily, by cheap freely available fossil fuel energy, while at the same time transitioning to other forms of renewable energy to progressively replace the impending energy shortfall while maintaining a civilised society and not destroying the life supporting capacity of the planet in the process. Perhaps the absurdity of attempting to maintain the status quo while pursuing conflicting agendas that will undermine it creates an opportunity to examine these complex problems in a new light.

What is needed is a more resilient, lower energy, less intensive, profitable farming system that is respectful of the environment. I suggest that the large-scale farmer-led adoption of regenerative agriculture principles implemented through a permaculture design process at farm scale will go some way towards addressing these issues while creating better outcomes for pastoral farming in New Zealand.

I further suggest that because both permaculture and regenerative agriculture are best described through principles rather than practices, they are scalable, and compatible when viewed in the context to which they are being applied. It is through this lens that agricultural practices in New Zealand should be reimagined, reassessed, and checked for the quality of desired outcomes (environmental, economic, and social), rather than perpetuating blind adherence to an energy intensive, high-input, one-dimensional economic model that can make slaves of farmers through debt and the false promise of well-being through increasing profits.

Regenerative agriculture

The origins of regenerative agriculture

The term 'regenerative agriculture' has been used since the late 1970s (Gabel, 1979) but was popularised by Robert Rodale through the US-based Rodale Institute throughout the 1980s in its research and publications focused on the organic farming movement. Rodale (1983) described Regenerative Agriculture as 'one that, at increasing levels of productivity, increases our land and soil biological production base. It has a high level of built-in economic and biological stability. It has minimal to no impact on the environment beyond the farm or field boundaries. It produces foodstuffs free from biocides. It provides for the productive contribution of increasingly large numbers of people during a transition to minimal reliance on non-renewable resources.

Regenerative agriculture practices

Burgess et al. (2019) and Merfield (2019) provide an excellent summary of regenerative agriculture concepts and literature. They state the practices that appear to be universal are minimisation or elimination of tillage (soil disturbance), having a high diversity of plant species, both pasture and crops, maintaining soil cover and growing roots in the soil, integrating livestock and cropping (mixed farming), with the fundamental aim of improving soil health, particularly increasing / maximising soil organic matter (soil carbon) and soil biology (particularly microbiology), increasing water percolation and avoiding the use of pesticides or excess synthetic inputs.

Claimed benefits of regenerative agriculture

Regenerative agriculture has at its core the intention to improve the health of soil or to restore highly degraded soil, which symbiotically enhances the quality of water, vegetation, and land productivity. By using methods of regenerative agriculture, it is possible not only to increase the amount of soil organic carbon in existing soils, but to build new soil. This has the effect of drawing down carbon from the atmosphere, while simultaneously improving soil structure and soil health, soil fertility and crop yields, water retention and aquifer recharge – thus ameliorating both flooding and drought, and the erosion of further soil, since runoff is reduced (Rhodes, 2017). Low-input agriculture practices result in less energy demand compared to more conventional intensive agriculture and could represent a means to improve energy savings and CO_2 abatement if adopted on a large scale (Gomiero, et al., 2008).

Regenerative agriculture is proposed as a solution to reverse climate change (by sequestering carbon into the soil), biodiversity loss, declining water quality, the health of freshwater ecosystems, and the wellbeing crisis in rural and farming communities (Grelet, et al., 2021).

Merfield (2019) (and others) claim that regenerative agriculture is much bigger than a series of farming practices. It is also a social movement, a value system and a philosophy, with the objectives to dramatically change the industrial farming paradigm and repair the environmental damage done by conventional agriculture. This social and environmental facet of regenerative agriculture is certainly evident from its ‘Organic’ origins, in my discussions with regenerative farmers, and in researching New Zealand based regenerative organisations such as Quorum Sense, Ata Regenerative, Calm the Farm, etc. Regenerative agriculture is clearly holistic in its approach.

Machine vs Ecosystem thinking

In researching and preparing this report, I set out to define regenerative agriculture. The irony is I failed, and in doing so I better understood what ‘regenerative’ actually is. ‘Define’ loosely means, ‘bring to an end’. It comes from the Latin verb, definire, composed of de, which means ‘completely’ and finire, which is ‘to bound’ or ‘limit’, from finis, which is ‘boundary’ or ‘end’. This is the exact opposite of the philosophy of regeneration (Soloviev and Landua, 2016).

Modern reductionist thinking attempts to define concepts prior to applying them. This implies that without definition, there is little value. The whole is therefore divided into parts that can be better understood and then reassembled in sequence to create better understanding of the whole. Reductionist science isolates the parts and seeks to understand them in the laboratory, before making some assumptions about how they would behave in the natural world (Lent, 2021). This is virtually impossible as complex systems (natural systems) have complex and variable relationships that occur between the parts and contain feedback loops which may disproportionately and non-linearly affect the system. So, models and scenarios are created to help explain the relationships and approximate complex system behaviour. Climate modelling might be an example of this. Most models are clumsy and fraught as errors carried into the process are multiplied. An attempt is made to calibrate the model to reality and to scale the system therefore making further assumptions about the interactions of its parts.

Reductionist thinking attempts to create linear machine outcomes out of complex systems, e.g. this set of variables will deliver that result. This is not a criticism of science but a distinction between machine and ecosystem thinking. Regenerative agriculture describes an ecosystem, not a machine. Perhaps this is best illustrated by the evolution of life on our own planet, itself a complex system. The prevailing 'Goldilocks' theory (Maunder, 1913) was that Earth was just far enough away from the sun, with just the right combination of mineral and biological conditions to produce life. This was in direct contrast to our closest neighbours Venus and Mars (too hot and too cold respectively) and so Earth was 'just right'.

But when the ancient atmospheres of the three planets are compared (Figure 12), Earth is more similar to the other two planets than it is different. Earth's atmosphere has evolved over time. This can be summarised as 'life creates the conditions for life', or as Lewontin (1991) puts it, "There is no 'environment' in some independent and abstract sense. Just as there is no organism without an environment, there is no environment without an organism. Organisms do not experience environments, they create them." The environment has an effect on life and life has an effect on the environment. It would be difficult (if not impossible) to create a model that could predict the current conditions and lifeforms on Earth using the original conditions on Earth as a starting point. There are too many possibilities due to the complex interactions between the 'parts' over 4.6 billion years. Life is an ecosystem of complicated interactions between dynamic components that is self-organising and non-linear, the outcome of which is more than the sum of those components (Lovelock, 1988).

PLANETARY ATMOSPHERES: THEIR COMPOSITION

	PLANET			
Gas	Venus	Earth without life	Mars	Earth as it is
Carbon dioxide	96.5%	98%	95%	0.03%
Nitrogen	3.5%	1.9%	2.7%	79%
Oxygen	trace	0.0	0.13%	21%
Argon	70 ppm	0.1%	1.6%	1%
Methane	0.0	0.0	0.0	1.7 ppm
Surface temperatures °C	459	240 to 340	−53	13
Total pressure, bars	90	60	0.0064	1.0

Figure 12. Composition of planetary atmospheres (Lovelock, 1988)

Dr. Christine Jones, a well-known Australian regenerative agriculture proponent, echoes this philosophy in describing the basic approach taken by regenerative agriculture in re-establishing biological systems. Minerals are present in soils but are often not available to plants. Conventional farming practices require the addition of inorganic elements to correct for these observed mineral deficiencies, but this is often ineffective. Plant monocultures need to be supported by high and often increasing levels of fertiliser, fungicide, insecticide, and other chemicals that inhibit soil biological activity. The result is even greater expenditure on agro-chemicals in an attempt to control the pest, weed, disease, and fertility problems that ensue therefore creating a negative reinforcing cycle. To address this, we need to consider the biological cause of this dysfunction, not the symptoms (Jones, 2018). The evolution of the species and the evolution of their environment are tightly coupled together as a single and inseparable process (Lovelock, 1988).

So regenerative agriculture seeks to encourage a biological ecosystem within the soil. In doing so, it unlocks a myriad of complex relationships between life forms creating a multitude of possibilities that defy modelling and provide a series of outcomes that exceed the value of the components of the system.

Regenerative agriculture in New Zealand

In a New Zealand context, the Technical Advisory Group (TAG) for Regenerative Agriculture, convened through the Ministry for Primary Industries has arrived at a 'vision' for regenerative agriculture. Regenerating practices are those that "in isolation or collectively can achieve improved outcomes for our productive landscapes, rivers, coastal and marine environments, biodiversity and natural ecosystems, and animal welfare, promote health and wellbeing for humans, and ensure we can grow and consume our food and fibre products sustainably". It is important to note this is not a definition but provides suitable scope and an adequate arena within which to explore nurture, and further refine the regenerative paradigm.

The most recent, wide-ranging, and comprehensive study of regenerative agriculture in New Zealand was undertaken by Grelet, et al. (2021). This landmark study arrived at 11 principles for a 'regenerative mindset' rather than a definition of regenerative agriculture. These are:

1. **The farm is a living system**: Living systems are complex and constantly evolving – understanding how nature functions supports holistic decision-making.
2. **Make context-specific decisions**: Context varies from place to place, person to person and season to season – adapt your system and practices to suit
3. **Question everything**: Be curious, question your beliefs and test different ideas.
4. **Learn together**: Connect with like-minded peers to speed up the learning journey – include perspectives different from your own
5. **Failure is part of the journey**: Push beyond your comfort zone - small failures provide the best learning opportunities.
6. **Open and flexible toolbox**: Try to use practices that help improve ecosystem function while keeping others up your sleeve for if or when you need them.
7. **Plan for what you want, start with what you have**: Transitions take time − clear goals, monitoring and planning are key.
8. **Maximise year-round photosynthesis**: Treat your farm like a solar panel – bigger green leaf area supports greater photosynthesis meaning more food for soil microbes and improved soil health.
9. **Minimise disturbance**: Keep the soil covered and limit disturbance from chemical application, soluble fertiliser, machinery and livestock compaction.
10. **Harness diversity**: Diversity benefits the whole ecosystem – microbes, insects, plants, birds, livestock and your community.
11. **Manage livestock strategically**: Livestock are a powerful tool for building biological function and fertility in our soils, when managed well and adaptively.

The other significant findings of the paper that have an impact on the implementation of regenerative agriculture in New Zealand are:

- The top sought-after outcomes for the Dairy, Sheep and Beef, Arable, and Viticulture sectors are, achieving pride in farming, decisions based on long-term outcomes, increasing profitability and financial expertise rather than merely increasing production, continuous learning and positioning New Zealand as a world leader in Regenerative Agriculture.
- There is some overlap between conventional farming and regenerative agriculture practices, however some conventional farming practices are inconsistent with regenerative agriculture practices.
- New Zealand's farming context is different from other countries in that soils tend to be carbon rich, the native biodiversity is very different from the agricultural species, erosion is prevalent, and therefore New Zealand should develop regenerative agriculture in a way that suits its own context and capitalises on overseas consumers' preferences and their willingness to pay extra for products meeting specific environmental outcomes.
- The paper identifies research priorities for how regenerative agriculture may affect (1) freshwater outcomes, (2) food quality and safety, (3) farmer empowerment and mindset, (4) long-term viability of whole systems, (5) animal welfare, (6) on-farm biodiversity, (7) soil carbon, (8) increase in resilience, (9) accountability in our food systems, (10) access to premium / niche markets, (11) soil health, (12) profitability and production, (13) whole-of-system environment, social and economic outcomes at farm-scale. Professionals are looking for (14) data to de-risk investment and transition to regenerative agriculture, (15) 'conventional-style' practice guides for regenerative agriculture customised for different sectors and New Zealand contexts, (16) an understanding of the 'Regenerative Agriculture continuum" and (17) clarity around the need for a definition/certification for Regenerative Agriculture.

Grelet, et al. (2021)'s findings both outline some of the contemporary issues faced by the agriculture sector and capture the New Zealand context within which regenerative agriculture would be applied, although the last point containing the 17 'research priorities' indicates how much work needs to be done in New Zealand before regenerative agriculture is accepted in the mainstream.

There are detractors

Regenerative agriculture is clearly more than a grazing management practice to those who are implementing it. A review of the comments section below McGuire's (2018) article shows the intensity of feeling. It appears more like an ideology fiercely defended by its proponents and ceaselessly attacked by its detractors. There are also detractors to the application of regenerative agriculture in the New Zealand context. Some of these views are summarised (and well referenced) by Rowarth (2017) and Rowarth, et al. (2020) as:

- soils are already high in organic carbon and therefore there is little value in sequestering more
- less intensive grazing tends to result in a decline in grass quality
- multi-species pastures are difficult to graze optimally due to grass quality and growth rates
- production may be lower per hectare and therefore contribution of greenhouse gases is greater than for well-managed intensive grazing operations

- overseas examples of regenerative agriculture being used to address soil erosion, increase soil moisture and maintain effective pastures year-round are simply not effective in well managed NZ pastures
- claimed self-reported increases in farmer well-being are subjective
- implementing regenerative agriculture may result in increased financial pressure

Further, Rowarth (2017) notes, "New Zealand has already achieved a competitive advantage for animal protein which a change to Regenerative Agriculture could erode". In addition, she states there is "no evidence that Regenerative Agriculture will achieve the goal articulated in Fit for a Better World (MPI, 2020): that 'regenerative farming systems will improve the profitability of farming while leaving behind a smaller environmental footprint'".

Diversity of thought is essential to a healthy knowledge ecosystem. Perhaps, by extension, regenerative agriculture has the best chance of survival by existing in a world of contention, supported by those who accept what it has to offer and demonised alike by those who fear they have the most to lose. It is difficult to believe that organisations (or individuals) who have a vested interest in highly intensive high-input farming would be open to promoting low-input farming systems. As Upton Sinclair once said, "It is difficult to get a man to understand something when his salary depends upon his not understanding it" (Upton Sinclair as quoted in Esar, E. (1949) The Dictionary of Humorous Quotations).

Giller, et al., (2021) argues that for regenerative agriculture to differentiate itself from any other form of 'alternative' agriculture and the practices associated with it from all of those that form good agricultural practice, 5 questions must be considered for any given context. These questions are:

1. What is the problem to which Regenerative Agriculture is meant to be the solution?
2. What is to be regenerated?
3. What agronomic mechanism will enable or facilitate this regeneration?
4. Can this mechanism be integrated into an agronomic practice that is likely to be economically and socially viable in the specific context?
5. What political, social and/or economic forces will drive use of the new agronomic practice?

I asked three New Zealand farmers who implement regenerative principles in their farming operations to provide written responses to the questions. These responses are telling and are summarised by question in Appendix 2. Overwhelmingly they highlight the difference in worldview between *conventional* and *regenerative* mindsets and reinforce that regenerative agriculture to those that implement it is a holistic approach and much more than a series of management practices. Interestingly, two of the farmers I interviewed twice mentioned the use of permaculture principles.

Maybe the research priorities identified by Grelet, et al. (2021) above will go some way towards addressing the concerns of those who are sceptical or do not support the regenerative approach to agriculture. This will take some time although my understanding is some of this research is currently underway (Gwen Grelet, Sam Lang, pers. comm.)

My concern (as already alluded to) is reductionist science is unlikely to provide the required level of comfort, especially when regenerative agriculture both acts as an ecosystem not a machine and is associated with an underlying 'qualitative' social dimension. In addition, based on the conversations I have had with scientists, policy makers, and farmers, there appears to be a tangible disconnect in New Zealand between farmers (and others) working at grass-roots to implement regenerative agriculture and some of those representing farmers and agriculture at either Government or Industry body level.

The economics of regenerative agriculture

A review of the literature reveals few studies on the economic implications of transitioning from conventional to regenerative practices as noted earlier (Merfield, 2019). Examples seem generally confined to North America, focus on corn production, and may include a diverse series of practices including low input farming or organic production.

Nevertheless, the results of these (often older) studies indicate economic performance of farms using what may loosely be described as 'regenerative' practices equals or exceeds that of conventional farms (e.g. Cacek and Langner, 1986, McNeely and Scherr, 2003) and that regenerative farming systems provided greater ecosystem services, resilience, and profitability for farmers than an input-intensive model of corn production. Pests were 10-fold more abundant in insecticide-treated corn fields than on insecticide-free regenerative farms, indicating that farmers who proactively design pest-resilient food systems outperform farmers that react to pests chemically. Regenerative fields had 29% lower grain production but 78% higher profits over traditional corn production systems (LaCanne and Lundgren, 2018). Increased plant species diversity is correlated with an increase in the diversity of insects. As the insect diversity in crops and pastures increases the incidence of pests declines avoiding the need for insecticides (Lundgren and Fausti, 2015). Further, a study on the effects of nitrogen applied at rates of 0, 100, and 200 kg N/ha/yr to 278 experimental grassland communities of increasing plant species richness (1, 2, 4, 8, or 16 species) found that plots with high plant diversity and zero fertilizer produced better yields than low diversity fields with 200 kg N/ha/yr. (Weigelt et al., 2009). Although an overseas study, these results may have implications for New Zealand grass production based on high nitrogen inputs. If so, being able to maintain the same yield while reducing nitrogen inputs will result in a reduction in costs.

In the New Zealand dairy setting, Neal and Roche (2019) found well managed low input feed systems provide a better chance for farmers to meet financial commitments, although they fail to maximise profitability when the milk price is high (e.g. >NZ$7.50/kg MS). Maximising pasture harvested, minimising reliance on supplementary feed, and maintaining effective cost control (low input operations) return greater profits and are more resilient to low milk prices (<$6.50/kgMS) and volatile markets than higher input systems. These low input systems do however fail to capitalise on the premium when milk prices exceed $7.50/kgMS. So higher input systems may produce more milk, but lower input systems are more profitable and resilient to price volatility (Ma, et al., 2017). Anderson and Ridler (2010) also found well managed herds with low inputs were able to increase profitability while reducing methane emissions, leached nitrogen and fossil fuel requirements for feed supplement and feeding on dairy farms.

None of these studies points directly and implicitly to regenerative agriculture being inextricably tied to better financial performance in all situations, although they certainly hint at it. These studies provide evidence that a less intensive, lower input 'regenerative' approach to farming can be more profitable over the long term, especially in a world of economic (and perhaps climatic) volatility. In addition, the increased 'ecosystem services' provided through the diversity created in regenerative systems leads to lower input costs, as in the Lundgren and Fausti (2015) example above. A reduction in spraying leads to a reduced need for spraying equipment. This can be equally applied to other machinery, balers, silage feeders, fertiliser spreaders etc. as inputs reduce, based on site context.

It is also important to remember these studies have only considered the financial performance of regenerative agriculture and none of the environmental, ecosystem, amenity, and well-being measures. Farmers often have both strong economic and social motivation for supporting biodiversity conservation, e.g. protect their social licence to farm, comply cost-effectively with environmental regulations, conserve biodiversity and ecosystem services critical to their own livelihoods, access premium markets that require biodiversity-friendly production systems, or conserve species and landscapes of special cultural, spiritual or aesthetic significance to them (McNeely and Scherr, 2003). It does seem ironic that any discussion about the merits of regenerative agriculture leads first to financial justification, especially where farm debt is high.

Even so, the claimed benefits of regenerative agriculture do appear to play out in the real world. I interviewed a regenerative dairy farmer who farms 550 cows on pumice soils between Taupo and Rotorua for this report. He initially drilled a small area of his farm with 14-seed multi-species pasture as a trial. His results were so encouraging that over the next 4 years he put half of the farm into the same pasture and grazing regime. He mob-grazed and moved rotations out to 30-40 days. Grass root depth went from 45-180mm, soil pH from 5.4-6.1 with no addition of lime. He has applied no phosphate fertiliser for 5 years and only 20-30kg of nitrogen/ha. Available phosphorus (Olsen P) and Potassium have increased while fertiliser costs have dropped from $160,000 to $70,000 per annum. Animal health costs have dropped from $117 per animal to $28. His highest profit year was off his lowest production and he and his family are enjoying farming again (Miah Smith, pers comm). I suggest these are good outcomes in a dairy farming context.

Increasing consumer demand for regenerative products

Regardless of the lack of suitable definition, consumer demand for foods identified as being produced regeneratively is growing and large food producers are making the shift driven by the demands of their international customers.

Silver Fern Farms, New Zealand's largest meat processor, recently announced it is committed to regenerative farming and would work alongside its farmer suppliers to embrace key regenerative agriculture principles aimed at reducing the carbon footprint of the farms, as well as improving soil health, biodiversity, water quality and habitats, ecosystems, animal welfare and communities (Morrison, 2021). Although not keen on a strict definition of regenerative agriculture, because they don't want to be prescriptive, Silver Fern Farms are currently testing potential key regenerative principles to see how their supplier's production systems stack up against them.

The McCain label will implement regenerative agriculture practices across 100% of its 150,000ha of potato growing worldwide. McCain chief executive Max Koeune says, "Everybody can argue the semantics of regenerative agriculture and of course farmers want detail, but this is customer-driven, a clear indication from the marketplace." Perhaps what is even more telling is that McCain's commitment to regenerative agricultural practices is underpinned by a belief that this can be met economically at scale by farmers (Scott, 2021).

Key Points

- Regenerative agriculture is best described by a series of principles that treats the land as an ecosystem
- Despite much opposition, there is scientific evidence supporting regenerative agriculture claims
- Farmers implementing regenerative agriculture report better economic and environmental outcomes
- Consumer demand and Industry policy direction are driving adoption of regenerative agriculture in New Zealand

Permaculture

The origins of permaculture

Permaculture was founded in Australian fringe academia by Bill Mollison and his graduate student, David Holmgren in 1978. It was the conjunction of 'permanent agriculture', was developed as a system of perennial agriculture based on traditional societies, was not suited to a large commercial enterprise or conventional farming, but had greater relevance to those who wish to develop all, or part of their environment to near self-sufficiency to supply the essential needs of a large family, a small settlement, or a city (Mollison and Holmgren, 1978). Permaculture appeared to be rapidly adopted (or perhaps co-opted) by small-scale, self-sufficiency oriented, more socially minded alternative 'life-stylers', and this may have inhibited its debut into the more mainstream arena. Arguably, this may have been intentional. The original audience for permaculturists was " Australians with no farming background who had acquired degraded land of low commercial value with the idea of developing an agriculture for self-sufficiency, whilst working off-farm on income-generating jobs". Permaculture was originally developed as a way of moving away from industrialised agricultural production (Fiebrig, et al. , 2020). The permaculture principles are shown in Figure 13 and also listed below for clarity:

1. Observe and interact
2. Catch and store energy
3. Obtain a yield
4. Apply self-regulation and accept feedback
5. Use and value renewable resources and services
6. Produce no waste
7. Design from patterns to details
8. Integrate rather than segregate
9. Use small and slow solutions
10. Use and value diversity
11. Use edges and value the marginal
12. Creatively use and respond to change

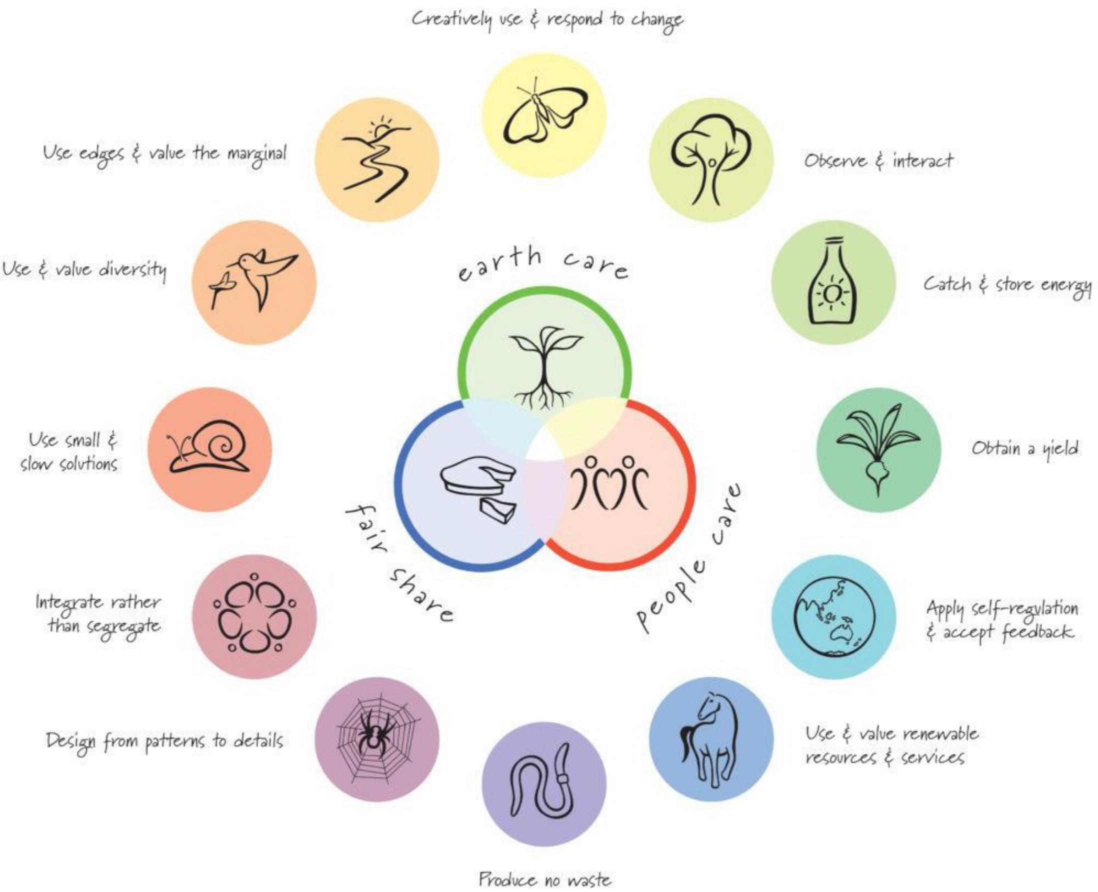


Figure 13. Permaculture principles and ethics (Holmgren (2002, 2011, 2020)

Underpinning permaculture principles are 3 ethical considerations:

1. **Earth care**: rebuilding natural capital of the Earth. Earth care can be taken to mean caring for the living soil, freshwater, biodiversity etc.
2. **People care**: Look after self, families, and the community. Begins with ourselves and expands to include our families, neighbours, and wider communities. The challenge is to grow through self-reliance and personal responsibility. Self-reliance becomes more feasible when we focus on non-material well-being.
3. **Fair share**: Set limits and redistribute surplus. Taking of what we need and sharing any extra whilst recognising that there are limits to how much we can give and how much we can take.

In addition to the permaculture principles and ethics, consideration must be given to a relative scale of permanence of the context into which the design is to be implemented. The scale of relative permanence (Figure 14) was developed by Australian Percival Yeoman and considers the sensible order in which to design for elements, starting with climate and moving towards soils, the easiest and fastest element to change. From a design perspective, the first element upon which humans can have an effect is how water is managed on site. From there, the sequence of planning moves to roads and track, then planting of trees, building of structures, erecting fences and creating management areas, then influencing soil (Yeomans, 1958).

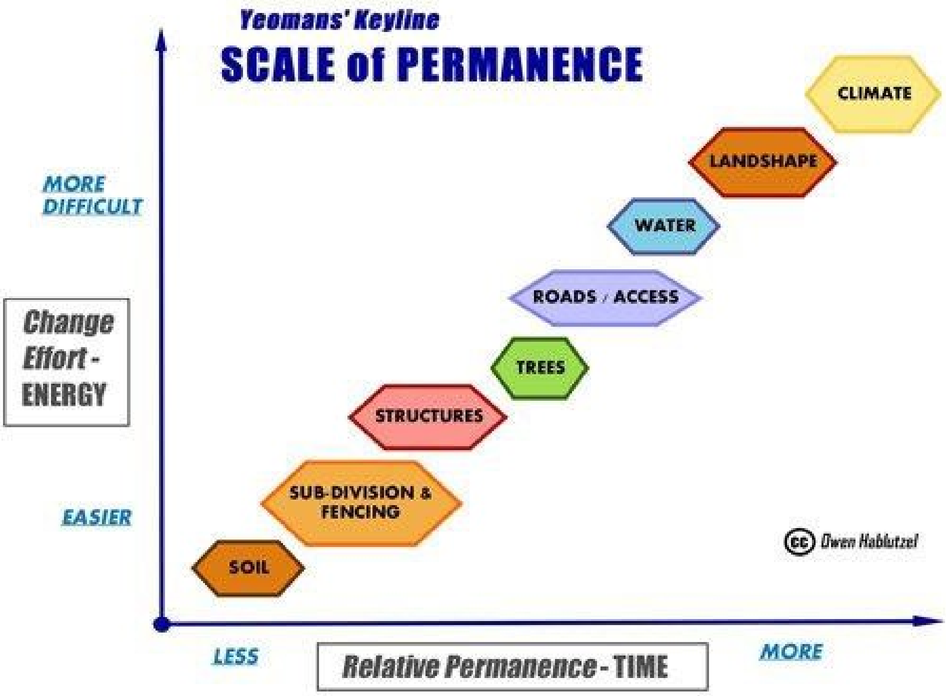


Figure 14. Yeomans' scale of Permanence (after Owen Hablutzel)

Permaculture was originally based on the behaviours of indigenous societies (Mollison and Holmgren, 1978), who saw themselves as more a part of an ecosystem rather than imposing their will on it. The founders soon realised that 'permanent agriculture' as a concept needed to be expanded to 'permanent culture' to accommodate elements of this human / ecosystem interaction. This expanded permaculture beyond just regenerative land use and extended it into many more aspects of sustainable human lifestyle. Permaculture embraced a more social or cultural aspect including well-being (Holmgren, 2002, 2011, Fiebrig, et al. 2020; Solkinson, et al. 2021), see Table 1.

Table 1. The Key Characteristics of Permaculture (after Solkinson, et al. 2021)		
Does not impose solutions	Is adaptable to edges and marginal lands	Intensive rather than extensive land use
Involves the integration of agriculture, animal husbandry, forestry, foraging, and landform engineering	Makes use of the naturally inherent characteristics of animal, plant, and land relationships	Supports landscape planning, site specific design and design of specific components of a site
Develops goals, strategies, and methods, not cookie cutter approaches	Promotes diversity in species, cultivars, yields, microclimates, habitats and functions	Emphasizes personal responsibility and skill building
Thinks at a strategic level about all the possibilities before arriving at a solution	Permaculture design is an iterative process, a repeating cycle of operations and analysis. At each step you may have to go back to a previous step to repeat, assess, evaluate, adapt and redesign the process	Encourages friendships and meaningful connections using social design
Favours multi-functionality	Focuses on long term sustainability	Values appropriate technology
Behaves like a natural ecosystem	Helps make people self-reliant	Uses wild and domestic species
Designs involve right relationships and beneficial connections	Roles and leadership are interchangeable and revokable	Enables surrounding ecosystems to still function
Seeks to create self-managed systems	Is regenerative	Encourages succession

In a New Zealand context, the ecosystem-based permaculture principles may have general alignment with the Te Ao Māori (the Māori worldview) in which Māori see themselves as part of an interconnected natural system. If accepted, this alignment may provide an opportunity for Māori to implement the permaculture principles into long term regenerative designs for Māori land as long as the process by which this occurs can be agreed.

Scientific support for permaculture

There is scientific evidence for all twelve permaculture principles despite the lack of representation of permaculture in scientific literature (Ferguson, 2015, Krebs and Bach, 2018), which considering its origins, is not surprising. In addition, there is evidence that permaculture has the potential to contribute to the sustainable transformation of agriculture (Krebs and Bach, 2018). Urwin and Jordan (2008) state permaculture is “arguably the most comprehensive sustainability concept devised so far”. Permaculture advocates not only for sustainable practices but intends to create resilient livelihoods, following a design process for regeneration and embodying a lifestyle in line with, or beyond, intergovernmental sustainability agendas (Fiebrig, et al., 2020).

Mainstream resistance to permaculture

Will permaculture (or regenerative agriculture for that matter) provide answers to all the issues facing agriculture? It's possible, but unlikely. A complex and dynamic problem landscape coupled with an entrenched solution focus will create resistance as alluded to above. To introduce a framework that was predicated on creating local, small-scale, diverse, decentralised ecology-based solutions that mimic nature to a system dominated by long supply chains, high inputs, high energy, and business models that have evolved towards intensive single-product operations is bound to encounter resistance. In addition, the inclusion of the word 'local' in Holmgren's (2002) definition of permaculture hints at the limits of provenance. In the case of New Zealand, with the vast majority of primary products heading offshore, applying the word local to an export-dominated sector may be a stretch for most perma-purists.

Holmgren (2020) suggests there are many reasons why ecological development solutions reflecting permaculture design principles have not had a greater impact over the last few decades. These reasons include:

- the prevailing scientific culture of reductionism is cautious, if not hostile, to holistic methods of inquiry
- the dominant culture of consumerism, driven by dysfunctional economic measures of progress
- political, economic, and social elites (both global and local) that stand to lose influence and power, through the adoption of local autonomy and self-reliance.

Perhaps Holmgren's views betray his (and Mollison's) original intention for permaculture, perhaps not.

Permaculture design process

There are now at least three schools of thought within permaculture, best characterised by either Bill Mollison's, David Holmgren's, or Darren Doherty's approach, the latter of whom adapted permaculture for use at farm scale (see http://www.regrarians.org/). Although the permaculture principles could be effectively implemented on their own, especially while considering Yeomans' scale of permanence (above), various design methodologies have been developed to further assist implementation. Once again, diversity of opinion is as abundant and necessary as diversity in nature and leads to a healthy functioning ecosystem. Only the 'fittest' ideas will survive by adapting to and influencing their environment. Although some purists may be challenged by this, diversity in all forms is consistent with permaculture principle 10, "use and value diversity".

Building on the work of David Holmgren and Darren Doherty, permaculture teachers Dan Palmer and Alan Grubb have created a popular and useful design process (Figure 15). Implementing this process leads logically through a series of questioning about purpose, site and human context, and consideration of site factors, before revealing the concept, and then more detailed designs based on observation and feedback. An example of a permaculture design for a house and small orchard is shown as Appendix 3. Significantly, I believe it is this design process that may also be useful in implementing Regenerative Agriculture principles in the New Zealand farming context.

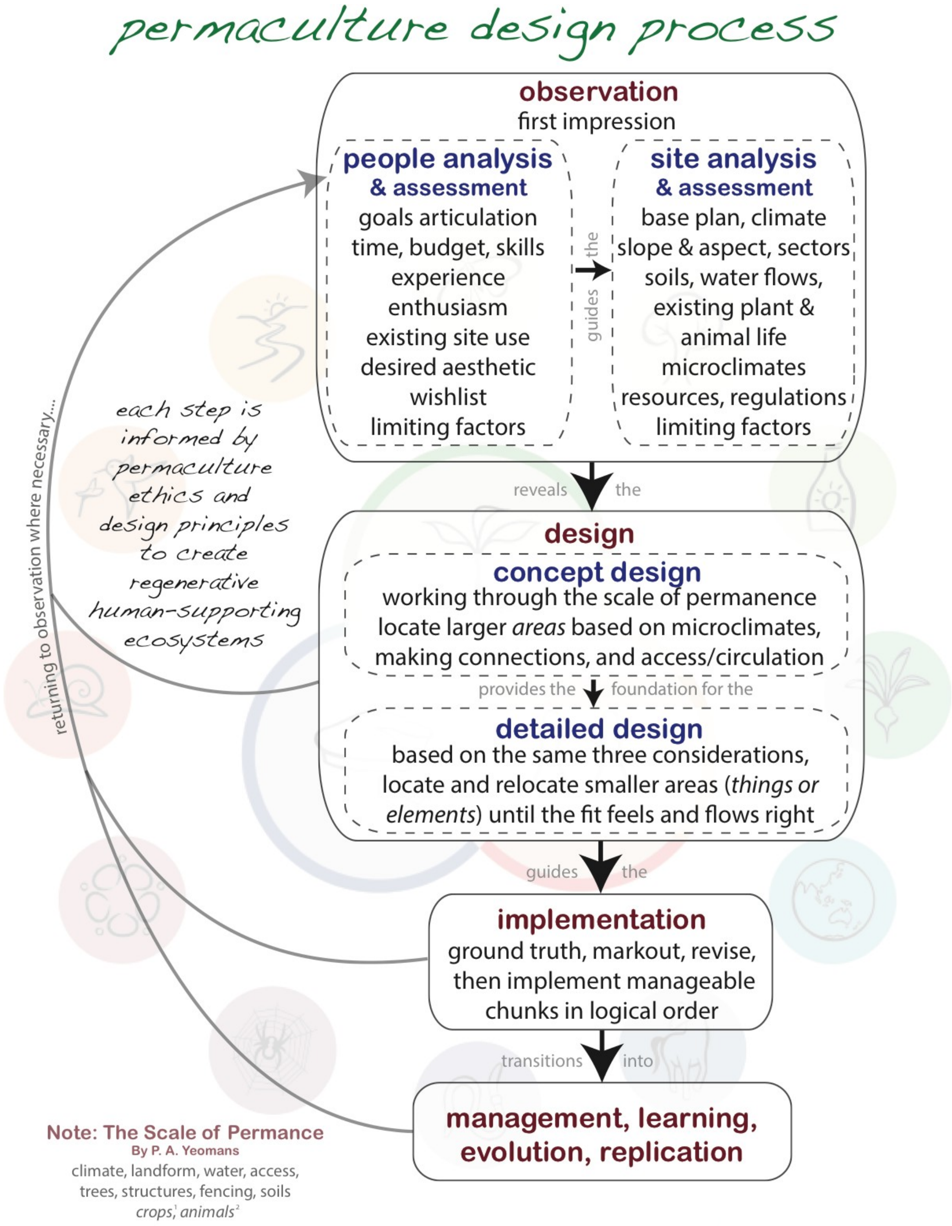


Figure 15. Permaculture Design Process (Palmer and Grubb)

Alignment of permaculture with regenerative agriculture

There is strong evidence of an alignment between the permaculture principles, those practices accepted as being associated with regenerative agriculture, and the principles identified as regenerative by Grelet, et al. (2021). Regenerative agriculture is a combination of existing agro-ecological practices (Figure 16.)

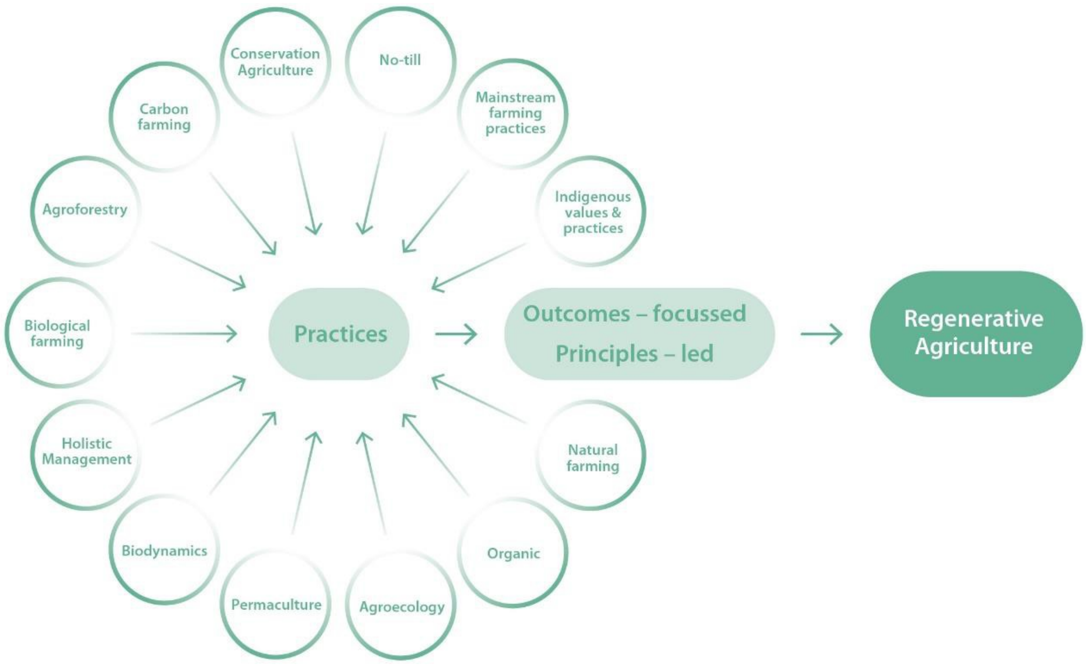


Figure 16. Regenerative agriculture draws on many agro-ecological principles and practices (Grelet, et al., 2021). Note that Organics (5 o'clock position) is 'inputs' focused. Permaculture is in the lower (6.30) part of the figure.

Looking after farmer well-being

The review conducted by Grelet, et al. (2021) finds social well-being is the factor most strongly associated with 'regenerative' than any of the other 15 variables canvased; soil health was second. A business should be configured to meet the needs of the owner, whether those needs be financial, or social (and plenty of others that are context specific). Farming is a business and engagement will likely decline and stress will increase if the needs of the farmer are not met, even to a just base level.

The current record Fonterra milk solids forecast payout of $8.25/kgMS has meant many farmers have taken the opportunity to pay down debt. Although Ma, et al. (2020) found no clear relationship between increased debt and economic performance of dairy farms due to on-farm variables such as stocking rates, intensity, irrigation, and farm practice, the Reserve Bank warns a third of dairy farms face negative cashflow if milk solid prices drop back below $5.50/kg. They further state the agriculture sector also faces several longer-term headwinds, including increased variability in climatic conditions, surplus overseas milk production, the growth of milk alternatives, bovine and crop disease outbreaks, heavily concentrated export markets, geopolitical trade tensions and the full entry of the sector to the Emissions Trading Scheme from 2025 will likely raise compliance costs and weigh on profitability (Milne, 2021).

A feeling of overwhelm and isolation are dangerous risk factors for farmers. Farmers have higher rates of suicide and lower rates of engagement with mental health services than the general population and this is also the case internationally (Goffin, 2014). In my opinion, farmers should take care to ensure they are operating their farming businesses in a way that meets their social and emotional needs rather than pursuing a singular production focus which risks undermining farm resilience, financial and environmental performance, and their own well-being.

Key Points

- Permaculture is a series of principles based on ethics that treats the land as an ecosystem
- There is scientific evidence supporting permaculture and it aligns with regenerative agriculture
- Permaculture principles are implemented through a design process which considers context and goals
- Farmer well-being is identified as a significant issue as compliance and financial pressures increase which a more holistic to farming may address

Application of permaculture to regenerative agriculture at farm scale

In accordance with diversity, there may be many ways to design a regenerative pastoral farming operation in accordance with permaculture principles. This would require following a design process or framework rather than just taking concepts associated with regenerative agriculture and implementing them. When the regenerative agriculture principles are viewed through a permaculture lens to create a farm plan the design should emerge from the landscape as opposed to a being based on a series on practices imposed (or not imposed) on farm. Each of the permaculture principles has an individual application, but when they are applied collectively through a conscious design process, they create the mutualistic and symbiotic relationships we are attempting to mimic in the farm ecosystem. This is not romantic idealism but natural pragmatism.

Implementing regenerative agriculture within the permaculture design principles

The application of regenerative/permaculture co-joined principles may challenge our assumptions of living in 21st century civilised society. We are accustomed to living a 'just in time' and 'on-demand' lifestyle. If we have a clothes dryer, then just use it instead of just hanging out the washing; need some food, just call Uber Eats® and get it delivered rather than going to the effort of cooking. These (and other) behaviours have led to a breakdown in the relationship between people and nature; between what is fiction and what is real. From this disconnected perspective, permaculture principles look like a step back in time, an unsophisticated, folksy nostalgia. But I believe many people have an increasing desire to re-establish that connection to nature and from a farming perspective the key is to treat the farm more like an eco-system than a factory, and then invite people in. Permaculture principles implemented through good design can assist.

The following examination of David Holmgren's permaculture design principles in the context of regenerative agriculture, may provide some insight to their applicability at farm scale.

1. Observe and interact

Careful observation is required to understand what is happening within the farm ecosystem and how the landscape responds and changes. It is a questioning process, are there patterns, what is the function of a particular element, what is the effect of seasonality, climate, wind? What needs do you have as the manager of the ecosystem, and how will you fulfil your needs while safeguarding the life supporting capacity of the ecosystem. What are the things that already exist and how do those things join together? Observing and interacting with the landscape through seasonality builds experience, allows connections between elements to be made, determinations about energy requirements and flows to be drawn, and prevents rushing in to make decisions that may have unforeseen and unintended consequences. Interaction with people is a vital part of the system. Sam Lang founder of Quorum Sense and 2016 Nuffield Scholar says those who had a supportive community were consistently more successful in transitioning to regenerative systems.

2. Catch and store energy

Growing plants provide the ultimate vehicle to catch and store energy. They are the basis of the primary production system. Grasses capture energy by converting sunlight into sugars and moving it into the soil via roots to feed the soil micro-biome. Healthy pastures with good soil structure capture and retain more water than degraded poorly structured soils, providing resistance to drought and increased water holding capacity. Placing a well-constructed (compliant) dam or pond in an ephemeral flow path or expanding a wetland captures water higher in the landscape to increase infiltration into the soil. Solar panels on buildings capture sunlight to heat water and provide electricity. Running hens through a pasture 3 days after cattle have been through harvest fly larvae and spread out manure, while providing eggs or meat. A woodlot of trees provides shelter for animals while growing and firewood for heating buildings. Knowledge gathered over a lifetime provides valuable insights into present day decision making. All are capturing and storing energy.

3. Obtain a yield

Nature requires an energy yield that exceeds the energetic requirements of obtaining it. Ensure the farming operation is profitable and regenerates the ecosystems' capacity to support profit/yield in the long term. This amplifies the system, rewarding the effort that goes into maintaining it. Investing in growing diversified perennial pastures that retain moisture in the soil provide better feed for cattle that encourage more of the same practice while renewing themselves. Fewer well managed mob grazed stock which preserves pasture, reduces inputs, decreases human work (e.g. once a day milking), may reduce overall production, but may increase profits while creating a better quality of life for animal and farmer over the long term. By creating a wishlist of human needs (yields) and then moulding a system of production to enable them to be delivered within environmental and energetic constraints without relying on outsourcing of effects or excess energy consumption, we do a service to ourselves and the environment.

4. Apply self-regulation and accept feedback

Failure is a human concept. Actions create a series of results. The ability to be open to feedback from those results allows better decision-making. Feedback creates an opportunity to check assumptions and apply self-regulation to limit inappropriate behaviour. Watching a stream run dry in summer leaving no habitat for stream life while we are irrigating pasture from a groundwater bore is an opportunity to apply self-regulation. If the goal is a self-maintaining system, then each element within that system needs to be resilient. Breeding out or culling of inferior stock or plants may seem brutal but provides feedback in regulating and improving the resilience of the whole system. US Permaculture pioneer Mark Shepherd uses the principle of Sheer Total Utter Neglect (STUN) to (self) select which trees make it through to next season. In learning to walk, the child must fall (experience feedback). In seeking to remove natural feedback we make ourselves (and our ecosystems) vulnerable and less resilient.

5. Use and value renewable resources and services

Renewable resources are those that are renewed or replaced by natural systems over reasonable periods of time without major inputs of fossil fuels and mined minerals (Holmgren, 2020). These may include the ecosystem services of insects and animals, sunlight, rainwater, soil life, trees, and the wind. Each of these requires a balance to be struck with the natural world that allows it to renew and flourish so that it may be of service to us. This implies a mutual symbiotic relation with the eco-system; we are part of it, and it is part of us. The idea of separateness leads to a belief we can (and should) control the eco-system. We spray for pests and inadvertently kill bees rather than allowing a predator-prey balance to occur in a resilient diversified crop. Planting deciduous trees in pasture provides shade for stock and retains soil moisture in summer (and carbon credits), without sacrificing grazing in winter. Farm operations that have little imported grain feed, no bailing of hay or cutting of silage, and a reduction of fertilisers lead to reduced direct and indirect fossil fuel use. These connections need to be designed into systems intentionally, not abruptly. Others are very simple. Using a solar/wind clothes dryer (washing line) is very effective and renewable compared with the materials and energy used in an electric clothes dryer. It also creates a simple connection between ourselves and nature.

6. Produce no waste

There is no waste in nature. Waste is a human concept and should be seen as a resource. If by-products of production are harnessed in the design, they create resources in another part of the system. But central to this principle is the careful use of energy and resources to create as little wastage as possible. Reduction of synthetic inputs and stimulation of natural cycles in the soil lead to a healthy functioning microbiome and reduce excess fertiliser entering waterways. A diversified pasture re-establishes a functioning web of insect and invertebrate life that constantly recycles animal manure and trampled grasses into the soil after stock have passed through. Systems that produce no waste focus on creating circular relationships rather than linear ones.

7. Design from patterns to details

Patterns emerge from the landscape through observation and interaction (Principle 1). Rather than focusing early on the details, take a broad view of these patterns and boundaries of a system and consider the inputs, outputs, and how the system relates to others. This broad understanding of function allows details to emerge that make sense and create a natural organisation in design. As the system evolves in complexity, additional detail is revealed. Complex systems designed this way work efficiency and require less energy to maintain. Creating a farm base map, incorporating external sectors, delineating zones before identifying functional areas and detailed structure is how permaculture design works (see Creating a 100-year farm plan, etc. below). The context of the design will yield the content, not the other way around.

8. Integrate rather than segregate

Nature values diversity, with elements drawn together in mutually beneficial symbiotic relationships that improves the function of the whole; each benefit from and uses the products of the other creating natural connections. One regenerative beef farmer interviewed for this report is incorporating trees into his grazing land (silvo-pasture). Planting 70 stems/ha at $3.50/stem means the establishment cost is $245/ha. At $30/tonne of CO_2 sequestered, he will double his profit/ha, improve shade and water retention in his pasture during summer providing for improved animal health without losing any production (Greg Hart, pers comm). A series of stacked, complimentary land uses provides more ecosystem services, improves yield, results in better animal and plant health, increases diversification and resilience, reduces external energy requirements, provides opportunity for greater social engagement (multiple seasonal harvest times and opportunities for collaboration), and emphasises the interconnectedness of natural systems.

9. Use small and slow solutions

Plan for transitions over time. Start slowly with new pasture mixes on smaller trial blocks and measure results, accept feedback and implement lessons learned (Principle 1). Systems can be designed on the smallest scale possible to reduce risk and then expanded. Walking through the farm rather than taking a motorbike allows time for observation and planning and creates time for personal reflection. Animals are calmer in the absence of noise and mechanical disturbance and respond better than when they are chased around. Good results from smaller amounts of fertiliser does not necessarily mean that plants will respond better to more. Lowering the inputs of off-farm nutrients leads to a greater focus on maintaining and managing feed on-farm. Smaller slower solutions are often low-tech and therefore more resilient and scalable than high tech solutions.

10. Use and value diversity

There are a variety of landscapes within a farming environment defined by topography, soil type, drainage, vegetation, land class, slope etc. Each introduces diversity in the environment and is better suited to a different use. Wetlands provide services to biodiversity, nutrient and sediment capture, and water storage. Draining that same area for pasture would yield lower quality pasture prone to pugging and weed infestation and would likely require higher maintenance. The same can be said for retiring steep land; class 6. A regenerative farmer I interviewed for this report has fenced and retired all class 6 land and planted it in native trees. He calculated the cost of maintaining that land in production (beef) exceeded the profit per hectare it generated. He is creating a diversified landscape based on dry stock farming, native trees, wetlands, and production forestry (John Burke, pers comm). Multi-species (high species diversity) landscapes are more resilient to pest incursion, disease, and drought and therefore require less chemicals and energy in management. Left on its own, nature will always tend towards species diversity. Multiple revenue streams protect the farmer from market fluctuations or reliance on a single market. Valuing diversity also extends to the diverse experience and opinions of people.

11. Use edges and value the marginal

The world is full of edges and boundaries, rivers, streams, forests, fence lines, and buildings. The interface between areas provides opportunities for exchange of inputs and energy. One might say Permaculture lives outside the mainstream at the margins of agriculture and society. The answers to challenges tend to lie at the margins. If they were in the mainstream, there wouldn't be any challenges. Change occurs first at the margin and then moves toward the centre. Margins tend to be undervalued, but riparian planting for example improves the biodiversity, stream bank stability, and water quality. The surface of the soil is the margin between the soil and the atmosphere across which energy, nutrients, and water is passed. If that soil is well maintained, deep and fertile, then a multitude of species can flourish. Shelter trees may be planted along fenced edges and create shade and habitat without occupying grazing space. Buildings located towards edges create useful spaces for storage between them rather than occupying the open ground. Marginal land is better repurposed as wetland or forest or bush than maintained for pasture and is the preferred habitat for wildlife

12. Creatively use and respond to change

We are either the agents of change or changes are imposed upon us. The first relates to creating change, the second adapting to it. We can either view change as an opportunity to be discovered, or as a departure from and loss of desired stability. In nature change is constant, life is either growing, or dying, and both represent opportunity, one in the form of fruit, the other as fertiliser. We are reminded of the first and ninth principles; observe and interact and use small and slow solutions. In this way, the opportunity reveals itself and we are able to proceed with lower risk. Change creates durability as a system is constantly renewing and improving itself. We see this in the succession of grassland to scrub to bush to forest. Changes in policy around emissions, carbon, nutrients, and freshwater, will be imposed upon us and will require adaptation, whereas we create a decision to transition to regenerative agriculture. Both create opportunity.

Creating a 100-year regenerative farm plan using the permaculture design process

Using the Palmer-Grubbs design process (Figure 15, above) a 100-year farm plan can be created that meets the economic, social, and environmental needs of the landowner, farmer, the farm ecosystem (including animal livestock), the environment (including environmental regulations), customers, and those same needs of future generations.

There are four main phases in the design process. The first is observation, getting an understanding or feel for how things are now. The second is design, coming up with a possibility or an idea about the future which expressed in the design. Then the design is created. Implementation is the third step where the design is implemented in the landscape. The last phase is the ongoing management, learning, and feedback from the system as it evolves.

Phase one: Observation

Observations consist of both the landscape (farm) and the people interacting with it.

Firstly, we consider the people. A series of questions will uncover what the needs of the people are, what they want to achieve, how they wish to live, how they want it to look/feel, the level of income they might receive, what budget or cashflow do they have, will there be any change in the composition of those living on the site over time, the physical input possible from people living there, and many more people centred questions. This is a crucial phase as it sets up the context from the people perspective. The outcome of this part of the process is a statement of intent, a vision centred on the wants and needs of the people living as part of this landscape.

Secondly, we consider the landscape (farm) itself. We embark on a similar questioning process, but this time directed towards the landscape. A base map is constructed and then the influence of physical factors are added such as prevailing seasonal winds, sun angles, water flows, topography, view shafts, roads and tracks, streams, wetlands, existing buildings, limiting factors, etc. A series of overlays on transparent drafting paper are added to the base map to build up a complete picture of the existing physical nature of the farm. I suggest these overlays at least include Land Classes, soils, and existing vegetation including wetland and bush areas.

By taking at least a 100-year timeframe and then breaking it down into shorter blocks of time, consideration can be given to the long-term functioning of the land as well as observing changes over a shorter term. This allows for a 'no-surprises' approach where elements may be phased in or phased out as the result of the ongoing management, learning, and feedback phase.

Phase two: Design

This phase is broken into concept design and detailed design.

Concept design is characterised by locating areas on the plan which exhibit similar character, functional area, or are based on an intended use. These are roughly identified by 'blob' like areas on the base map. Linkages are created between 'blobs' to indicate movement or logical groupings and they often overlap at this stage. Areas will naturally emerge out of the design as being better for one purpose than another based on location and site factors. Yeoman's scale of permanence (Figure 14, above) provides a hierarchy to inform the order of elements from the wish list or design brief. At all times it is important to reference the statement of intent, what are we trying to create? There may be several attempts and variations created in this initial design phase. It is important to allow time in this part of the process and constantly seek feedback to improve the concept design.

In the detailed design phase, the blobs begin to take on form as they are tested and specified as areas or given functions, e.g., new orchard, stock yards, irrigation ponds, regenerating wetland, retired erosion prone land, etc. The detailed design requires constant checking to ensure the design will implement the statement of intent and all work together, e.g., a sheltered tree-lined walking path from a newly built dam to the house represents a series of elements with linkages. The path cannot be located until the dam is located (Yeoman's scale of permanence).

Phase three: Implementation

By now there is a holistic plan considering the interactions and needs of all the elements and how they relate to each other. Implementation involves the scheduling of activities to implement the detailed design. It must consider the budget, farming cycles, growing seasons, commitment required from people and any plan to transition from one farming system to another, e.g., higher input fertiliser and feed to lower input system. Advice should be obtained to assist in the implementation of farm system transitions.

Phase four: On-going management, learning and feedback

Over time, and by accepting feedback from the results of the implementation, the detailed design will become established in the landscape. As it evolves, new decisions will be made as we check the original statement of intent for fit. Are we on track, what has changed, and what needs to be done? Plantings and trees will grow, pastures will evolve, animal movements will become established or change as new methods are tried, and new ideas will enter the system for consideration. By monitoring the health of the farm ecosystem that has been created and learning as you go, the system will improve and respond naturally.

Key Points

- Regenerative agriculture can be implemented through Permaculture design principles at farm scale
- Permaculture and regenerative agriculture may provide desirable economic, environmental, energy, and well-being outcomes to farmers when implemented through a design process with a sufficiently long timeframe and within a specific farming context

A new beginning

Although the solution is often contained in the problem, that problem cannot be solved using the same thinking that created it. By collecting up iterative thoughts and piecing them together, we arrive at a 'logical' outcome. But what is required is a change in the direction of thinking; the ability to think 'from' a whole instead of 'towards' it. This is why context is so important in the design process; it defines the whole from which the solutions emerge. This is perhaps the greatest challenge, the necessary change in thinking.

But humans seem unable or unwilling to change voluntarily, tending rather to adapt when change is imposed. We collectively seem unable or unwilling to back away from existential threats, mainly because we have difficultly perceiving or comprehending them in light of the current relative stability. We tend to default to logic based on the past to justify actions that reinforce the status quo even when intuitively we know change is needed. We are not nearly as clever as we think we are. We are animals covered with a thin skin of civility, all competing to seek and preserve relative advantage. As with any other animal, we will maximise the utility of our environment to serve our perceived short-term needs with a limited ability to regulate our own behaviour. In the end we are held hostage by our own beliefs and behaviours that seek to maintain the status quo based on our illusion of security.

Even if we do have the capacity to contemplate change, are we actually addressing the problems we think we are, have we got the context wrong, are we just so wedded to a traditional world view we have become incapable of considering alternatives, or more frighteningly, do we know what we need to do, we just collectively lack the courage (or political will) to change?

It seems that Dyke, et al. (2021) is right and the scramble to implement policies like those leading to zero carbon by 2050 achieves two things, namely, provides evidence that we are at least 'doing something' while simultaneously kicking the can down road to perpetuate business as usual. This seems akin to picking up coins in front of a steamroller, effectively making the most of the relative normality while postponing meaningful change.

Despite perhaps the best of intentions, the siloed nature of policy creation and decision making within government appears to have hindered rather than helped. Without apportioning blame, when political expediency, reductionist science, and vested self-interest are added to the mix, the ladder may in reality be leaning against the wrong wall.

The complex global issues we face are outside of political ideology (left vs. right) but rather informed by bio-physical reality. Therefore, any solutions (or designs) need to be created outside of any political agenda of Blue vs. Green vs. Yellow vs. Red etc. To paraphrase British politician David Penhaligon, who in 1977 said, “No turkey ever votes for Christmas to come early”, it is unlikely the current political system will ever deliver the change required to adequately address these challenges. We are therefore destined to try and make omelettes without breaking any eggs.

Is there any hope? Yes, I believe there is. But only if we begin understanding the whole rather than a short-term focus on dominating the parts – maybe think of the omelette rather than the eggs. There cannot be infinite growth on a finite plant. We have made some false assumptions about the capacity for our world to accommodate our future lifestyle aspirations. These assumptions will be thrown into stark relief as we approach the bio-physical limits that define our world. When change is forced upon us, we will adapt, but there will be a price to be paid. What that price is remains to be seen. And now we have come full circle. We are back where we started, we all inhabit the same greenish-blue planet.

Conclusions

Modern industrial agriculture produces cheap food in abundance but has undesirable side effects that are negatively impacting the environment and threatening the life supporting capacity of our planet. Fossil fuels have supported a dramatic increase in population resulting in commensurate increases in resource extraction and consumption. To date, no policy approach has been successful in arresting this decline and improved technology has merely acted as an enabler reinforcing these trends.

Industrial agriculture requires large amounts of fossil energy to maintain the existing methods of production and distribution. Fossil fuel energy reserves are decreasing worldwide. Renewable energy sources rely heavily on fossil fuels for their construction, maintenance, and replacement and battery and panel production is energy intensive and constrained by mineral availability. The energy generated from renewable sources is often intermittent, less dense, difficult to store, and often in the wrong place at the wrong time, and therefore renewable energy will not replace the energy deficit created by the depletion of fossil fuels.

Although declining energy is unlikely to have a substantial effect on agriculture in the fossil fuel rich short (10-20 year) term, there are significant implications for the agricultural economy and the effective functioning of society in the medium to long term, especially where food consumption is at distance from food production in export lead countries such as New Zealand. Lower intensity farming systems will only go some way towards addressing New Zealand’s reliance on fossil fuel inputs to the agricultural system.

A new approach to food production and living on the land is necessary to provide for the needs of future generations without destroying the environment and to create a future worth inheriting. Permaculture and regenerative principles are both highly compatible and scalable and if implemented through the permaculture design process will assist in the transition towards food production and land management that treats the land as an ecosystem. This will ultimately create beneficial outcomes for farmer engagement and well-being, farm profitability, ecosystem services, biodiversity, and resilience due to lower input costs and income diversity.

Regenerative agriculture implemented through a permaculture design process can address global macro-challenges while creating better outcomes for pastoral farming in New Zealand.

Recommendations

Based on the research carried out in the preparation of this report and the findings thereof, I would make the following recommendations:

Recommendations to Government, policy makers, and agricultural industry groups

As representatives of the people of New Zealand and of farmers, my recommendations are:

- Conduct a thorough and realistic investigation into the energy implications for agriculture in New Zealand of declining fossil fuel availability
- Better promote and support an ecosystem-based low-input regenerative approach to pastoral farming to create better resilience and outcomes for farmers and farmland
- Better recognise the extent to which the current food production system (and governance thereof) creates obstacles to the widespread adoption of low input regenerative systems

Recommendations to pastoral farmers

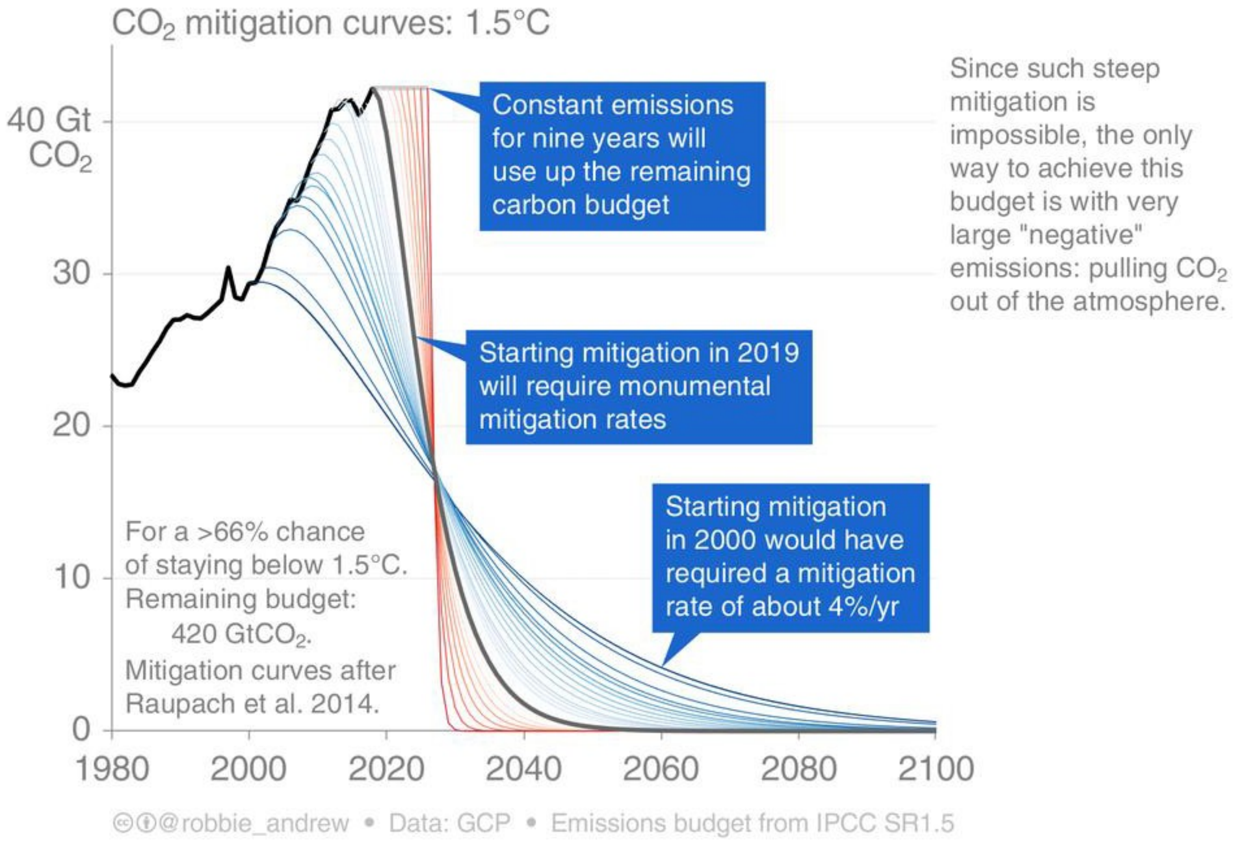
The information presented in this report may be interpreted as a roadmap to transition from more conventional to more regenerative farming system, but it does not constitute specific advice. While I would strongly recommend exploring the merits of permaculture and regenerative agriculture, care should be taken to consider motivation, goals, site characteristics, and the degree to which any transition might impact on farm viability, in consultation with a suitably experienced advisor. My recommendations are:

In consultation with family and farm stakeholders:

- Examine what you would like your farm to be providing in terms of environmental, social, and economic outcomes and create a 100-year vision for the farm.
- Conduct a thorough investigation of permaculture principles, regenerative agriculture principles, and the permaculture design process and educate yourself as to how these may assist your farmer stakeholders to achieve the farm vision.
- Consider creative ways to reduce farm debt to create full control over farming operations. This may include selling a portion of the farm to a like-minded shareholder.
- Transition from a focus on revenue generated through a reliance on high-intensity high-input system to a lower-intensity, lower-input system that focuses on resilience and longer-term profit.
- Establish a plan (with guidance) to manage the farm as a natural ecosystem that exceeds coming regulatory requirements for emissions and freshwater standards rather than managing the farm as a mechanical production system that begrudgingly meets them.
- Consider stacked enterprises and diversification (e.g. silvo-pasture, laying hens, cropping, tree nursery, market gardening, introducing other animals such as milking goats etc.) to increase resilience and reduce reliance on one export dominated income stream, as long as this fits with the farm vision.
- Connect with the appropriate help, advice, and support from like-minded advisors and participating farmers and contribute to this community.
- Consider supplying high value local markets rather than commodity-based export markets.
- Consider the effect a dramatic rise in fuel prices (or lack of fuel supply) would have on your farming operation over the 100-year timeframe including the cost of farm inputs with a fuel component and make plans to address this.

Appendices

Appendix 1: CO_2 mitigation curves and start dates for required reductions in CO_2 emissions to keep global warming to 1.5°C in line with The Paris Agreement. (from Dyke et al., 2021)



Appendix 2: Summary of NZ Regenerative farmer responses to the 5 questions regenerative agriculture needs to answer to differentiate itself…, as posed by Giller et al. (2021)

1. What is the problem to which Regenerative Agriculture is meant to be the solution?

> Regenerative Agriculture is not about solving problems it is about working with natural processes to create productive landscapes that mimic processes that have been occurring throughout time. Our current food production system is absolutely reliant on abundant cheap fossil fuels and long supply chains including bringing fertilizer from the other side of the world. Food produced through the industrial system particularly the use of some chemicals is contributing to a serious decline in human health. Intensive pastoral and arable farming land use systems involving high stocking rates and synthetic fertiliser inputs (particularly N) have caused environmental damage by way of soil erosion (sediment & P loss) and nitrification of aquifers and waterways. Intensive farming systems and soil tillage also degrades soil structure, reducing potential water holding capacity and resilience to drought and increasing demand for irrigation in the face of climate change. Improvements to the problems caused by conventional agriculture are a by-product of regenerative agriculture, not the focus.

2. What is to be regenerated?

Soil is regenerated through a management system that increases soil carbon storage, promotes nutrient recycling, and restores, and maintains a healthy soil biome. In this way, landscape functions, such as water infiltration and improved water storage are restored. This process can regenerate everything, individual farmers, soils, biodiversity, water quality, community, even civilisation.

3. What agronomic mechanism will enable or facilitate this regeneration?

Restoration and enhancement of the natural carbon and nitrogen cycles through re-engaging the photosynthetic plant-microbe bridge essential to healthy and well-structured soils – this is achieved through multi-species pasture, changing grazing management to maintain high covers, soil armour and significantly reducing or eliminating synthetic fertiliser inputs (particularly N which is toxic to beneficial fungi). The exact combination of methods employed will depend on the landscape and farm context. Observational skills are required to provide feedback as the landscape function changes over time. Practices will include minimum tillage, cover crops, diversity in species, rotational grazing, holistic type grazing, fallowing, using permaculture principles, planting of trees etc. Full cost accounting and the developing local resilient food systems should be a focus.

4. Can this mechanism be integrated into an agronomic practice that is likely to be economically and socially viable in the specific context?

It can and is. There are many agronomic practices already in place in NZ and across the world where regenerative agriculture is succeeding backed by scientific analysis. Everything is going to be different in a post peak oil world as climate change starts to bite and finite resources dwindle. The science is clear, we are in overshoot and if we want to leave a world worth inheriting to future generations we have to localise and sequester carbon and restore biodiversity. Our economic system must change and we need to have strong resilient local communities.

5. What political, social and/or economic forces will drive use of the new agronomic practice?

Regenerative Agriculture has been built on a peer-to-peer learning at farm manager level and will not work top down as this takes away the focus from creating and enhancing landscapes to fixing problems real and imagined. The shift (if it is to happen) will be an evolutionary leap of consciousness as humans remember our interconnectedness with each other and nature. This is what regenerative agriculture is, working with nature rather than trying to dominate and control nature. Regenerative agriculture is building on a wide range of founding principles such as holistic grazing, biological farming, permaculture, rotational grazing and husbandry practices used over thousands of years. Adoption will be driven by consumer demand for more naturally produced nutrient dense food, the opportunity differentiate NZ produce and provide integrity to our “Taste Pure Nature” story (tastepurenaturenz.co.nz), environmental requirements to reduce sediment and nutrient pollution of NZ waterways, the quest for greater farm resilience and reduced stress by NZ farmers.

Appendix 3: Example of a permaculture design for a home and small orchard

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