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Energy use in New Zealand's primary food production chains and a transition to lower emissions

The role of Energy Return On Investment in our success

Solis Norton

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Nuffield New Zealand
PO Box 85084
Lincoln 7647
admin@ruralleaders.co.nz
+64 21 139 6881

Executive Summary

This report explores and applies a novel methodology of standardising and quantifying energy flows within New Zealand's primary food production chains and more widely within New Zealand itself in relation to the Zero Carbon bill. Then demonstrates the method as a critically important adjunct to economics in planning and navigating our transition to low emissions food systems and society more generally.

The looming challenge of maintaining the success and growth in global food production enjoyed over the last century is heightened by the fact that underpinning a huge amount of this progress was cheap, flexible and incredibly energy dense fossil fuels. Given that managing our human population seems an impossibly thorny maelstrom, our only option is to mitigate its impact while trying ever harder to meet its needs.

Tension within our food systems between increasing production and reducing environmental impact is creeping steadily upward. Many 'wicked' issues are involved. Proposed solutions based on economics often seem to compound them further yet, while confounding our leaders and causing frustration amongst the public. We need to strip away all that is superfluous and get down to the very basics of how to produce food in a genuinely sustainable fashion. I sought to explore this from an energy perspective.

In my Nuffield Scholarship I investigated and applied a method of describing systems, food systems for example, in terms of their energy use and their energy production. From this understanding their, strengths, weaknesses, risks, and opportunities can be quantified, especially with respect to reducing energy related emissions. Even the comparatively high-level calculations reported here illustrate the very very critical risks inherent in plotting a path to low emissions food systems and for society more generally based solely on economic analysis.

The method is known as Energy Return On (Energy) Investment (EROI) and lies within the field of Biophysical Economics.

It has traditionally been used to quantify the net energy returned from fossil fuel or other energy sources. In so doing it consistently shows that fossil fuels have a higher EROI than almost all the non-fossil alternatives. In essence, the fossil options are a more lucrative energy source. This presents a tremendous challenge to maintaining current levels of prosperity during our shift to other energy sources that is not immediately visible economically.

EROI has immense potential in a diverse spectrum of other applications. For example food systems, transport, industries, or any element of our society, even society itself. The key point is any system that we want to reduce energy use within and emissions from. My report shows that it is an ideal adjunct to our economic approaches to adapting New Zealand's primary

food production chains and our society more widely toward goals set out in the Zero Carbon Bill.

Key outcomes are that:

- Energetically, organic and less intensive farm systems tend to have proportionally lower inputs and outputs than their conventional counterparts, often by a considerable margin, eg 15-25%. Hence a nation-wide shift to low intensity food systems will reduce our total production.

- Energetically, producing food from plants is far more efficient than producing it from animals. Many other environmental and emissions related benefits link to this point.

- Despite advances in our agriculture, forestry, and fisheries over the last 30 years, the energy required by this sector to produce a dollar of GDP has not changed.

- Fonterra's projected energy requirement in 2050 under the Zero Carbon Act will increase 5% even with the simplistic assumption that their production levels remain static between now and then. All similar industries will experience much the same increase in primary energy requirement as they transition away from fossil fuels, more so if they want to grow between now and then. This is a fundamental challenge to our low emissions transition.

- Critically, there is very little understanding of energy use in our primary food production system from a **chain** perspective. That is, right from the creation of farm inputs through to the shipping of processed product to consumers. Without this, transition weaknesses and opportunities cannot be prioritised effectively.

- Under the 2050 Innovative Scenario modelled in the Low Emissions Economy final report, energy used by our energy supply system (primary energy) increases from 5% of our national consumption today to 9% in 2050. This is a drop in EROI from 20.3 today to 10.0 in 2050. But concurrently GDP is projected to double.

- In this same scenario, anticipating population growth within New Zealand and a transition to both less energy and renewable energy sources, energy delivered per capita per year drops 37% from 16.5GJ to 10.4GJ, equivalent to what we used per person in the late 1970s.

- In my view the proposed Zero Carbon bill is an exceptionally forward thinking and valuable document to guide a transition to lower emissions. It identifies all the critical elements. But it needs an energy perspective alongside its economic one for success.

What to do?

The Zero Carbon Bill presents the perfect opportunity to bring EROI in to optimise our transition to lower emissions systems.

Development of this methodology, for which the vast majority of expertise and logistics are readily available, should be undertaken by a 'Transition Institute' that links initially to the Interim Climate Change Committee and then to the independent Climate Commission.

In a little more detail, we need to deepen our understanding of New Zealand's primary production systems from an energy stock and flow perspective. First by creating an overarching perspective of energy use in the different components of our systems, then by filling knowledge gaps. The rural transport sector typifies such a gap. Fonterra show notable foresight in making key data in this regard publicly available but their results emphasise the importance of both EROI and economic approaches to future projections. Nationally and within the sphere of primary industries this is not a huge undertaking. But the benefit would be immense if it brought an energy perspective to those leading our transition.

On recognising the merits of EROI, I feel it is a natural it would then be applied beyond our primary industries to other aspects of New Zealand's Zero Carbon transition.

Furthermore, it could easily be adapted to other food systems around the world. It provides a standardised means of comparison mercifully unbiased by the usual blizzard of economic and political instruments. Consequently it could play a major role in optimising the full range of food systems from subsistence through to super high tech, all of which will play some role in 2050. In doing so, New Zealand would be truly forging ahead globally in the process of optimising a low emissions transition. We would actually be making a major contribution to adaptation and mitigation efforts against the impact of climate change.

Sure our land mass won't feed everyone but our ingenuity, practical mentality and pioneering spirit absolutely could. See the recommendations on page 62 for how.

Kenyan roadside fruit stall

Scholar bio

I am 43 and married to Emily, we live near Port Chalmers in Dunedin with our daughter Olive.

I practice martial arts, am a keen hunter and gardener and pursue a simple, balanced lifestyle. I work part time as a contract hunter for the Department of Conservation.

In 1996 I completed a Bachelor in Agricultural Science at Massey, continuing with a Masters Degree in Applied Science, then PhD in veterinary epidemiology.

In the early 2000s I became interested in the Peak Oil concept, which lead to the field of Energy Return On Investment. Interest became fascination at the incongruity of living in biophysical harmony with the environment against anticipating a projected nine billion people in 2050.

Joining the University of Otago's Centre for Sustainability and the Otago Energy Research Centre, I worked with the Agricultural Research Group On Sustainability. After good progress, opportunities for more work dwindled.

I left academia and joined the New Zealand Deer Industry heading their newly established national programme against Johne's disease. This disease was the focus of my PhD and branching into an primary industry role I felt would be good experience to apply to further energy related work at some later date.

In 2014 I travelled on an AGMARDT Leadership Award to visit US energy experts in Biophysical Economics and Energy Return On Investment. In 2015 I completed the Kellogg Rural Leadership Programme. Both were excellent for my personal and professional growth. My Nuffield Scholarship will continue this adventure in leadership.

Perugia, Italy, September 2018

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Ausquest, Stuart Barden's place, Kenya.

Introduction

In 2018 a Nuffield International Farming Scholarship provided me with an incredible opportunity to undertake a period of professional development involving both international travel and time to focus on a topic of interest I have fostered since 2005.

The Contemporary Scholars Conference in Holland illuminated the fabulous tapestry of our world's food systems, bringing out the issues and opportunities that face us all heading into the future. My Global Focus Programme began immediately afterward, enabling my group to see these things first hand and talk with the people striving to push the boundaries in their own particular areas. Over the six weeks of often intense and frenetic travel our group explored the main themes we were seeing in more depth as we established a strong bond of friendship, one of the hallmarks of the Nuffield experience.

We travelled from the Netherlands to Oregon, Washington DC, the Czech Republic, Ukraine, Kenya, Johannesburg, Capetown, and then finally home. Then, four months later and soon after the arrival of our daughter Olive, my wife and I spent several weeks in Italy with the baby before and I continued through the United Kingdom and Ireland, culminating in a week at the United Nations Committee on Food Security in Rome as a delegate of the Private Sector Mechanism.

In addition to the travel, I discovered and joined the International Society for Biophysical Economics and within New Zealand the Wise Response group. I presented my preliminary findings remotely at the Biophysical Economics conference in New York and to the Otago Energy Research Centre Symposium on Energy and Climate Change. Attending the Asia Pacific Energy Leaders Summit in Wellington was another highlight of the scholarship. There I arrived at complete certainty that a biophysical perspective and Energy Return On Investment are simultaneously far beyond mainstream thinking and absolutely critical to planning sustainable systems for our future.

Fortuitously, release of the proposed Zero Carbon Act to guide New Zealand's transition to a low carbon economy was released around the same time. The framework, underlying data, and main objectives provided perfect grist to my mill.

The following report outlines development of an energy perspective on the world's food systems after the Nuffield Contemporary Scholars Conference and Global Focus Programme. It then introduces the field of biophysical economics and within this, Energy Return On Investment for a means of quantifying the energy flows through a system, for example a food production system. Energy supply and use within New Zealand are summarized then focus shifts to energy use within our primary production chains. A change then follows where the proposed Zero Carbon Bill is described and analysed using Energy Return On Investment and related energy metrics. The report concludes by drawing together the energy perspective of our primary production chains and the energy perspective of the Zero Carbon Bill to identify risks and opportunities for our wider rural sector in the proposed transition to a low emissions economy. Finally it offers recommendations on how a smooth transition to lower emissions systems may be achieved in this critical sector of New Zealand's economy and how the process of creating that transition could be used as a template to aid similar transitions across a diverse spectrum of food systems around the world.

The reader will no doubt notice my very physical and practical approach to this topic and my studious aversion to its political and economic elements. In my defense, what fascinates me is optimizing a transition to low emissions systems. If it is physically possible, then having the right people in the key political and economic positions should make it possible from these perspectives too.

Dry reservoir near Cape Town, South Africa.

Agriculture and food: a global perspective

Global food production has increased in recent decades in step with our human population and in response to a variety of factors (. Great leaps on the stepping stones of information technology, genetic improvement, chemical engineering, growing systems, fertilisers, machinery, as well as storage and distribution systems have seen our total food production spiral exponentially upward.

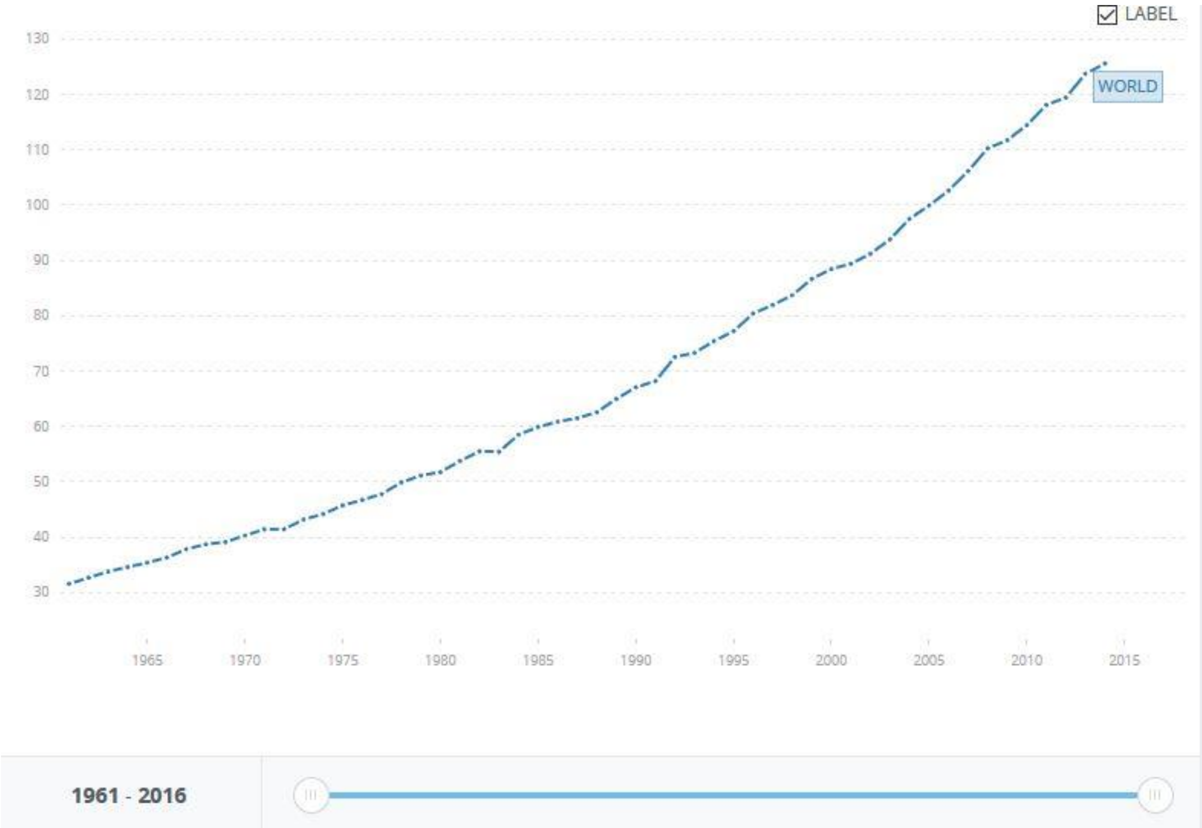


Figure 1. Exponential increase in world food production from 1965 to 2015 relative to the index value of 100 in 2004-06 (source: https://data.worldbank.org/indicator)

For those in the 'developed' world this trend has been enjoyed for the living memory of virtually everyone alive today. Yet all these stepping stones have been supported to a greater or lesser extent by an exponentially increasing amount of cheap energy from fossil fuels.

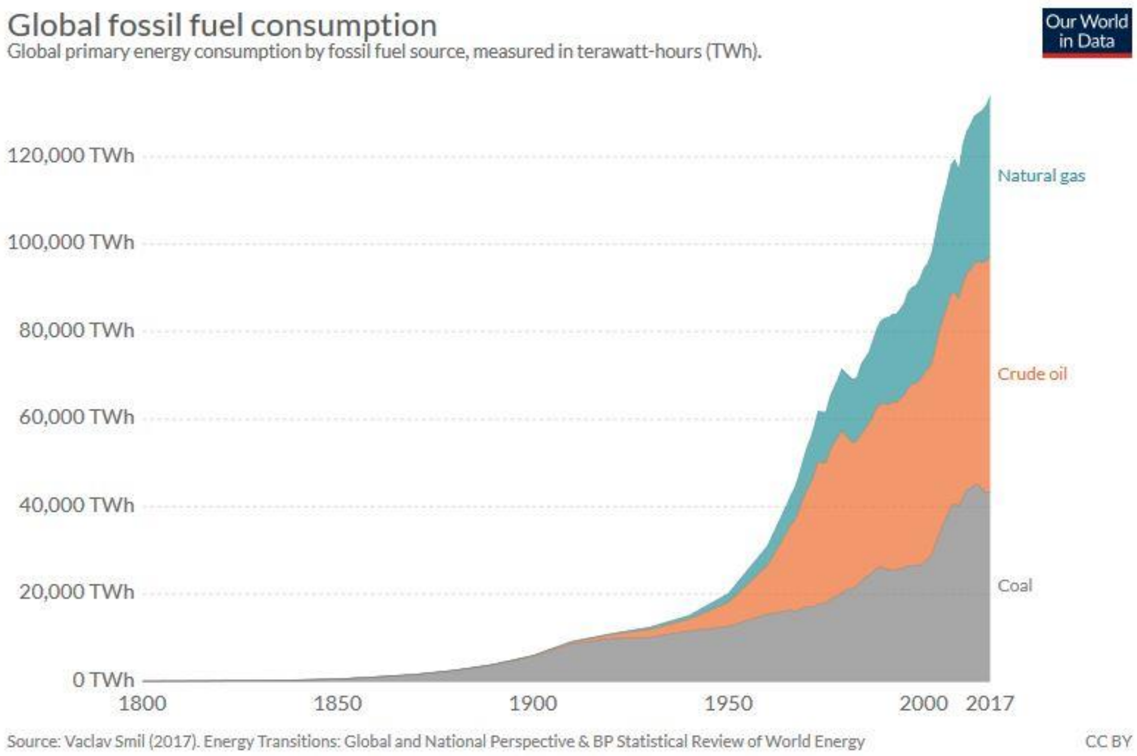


Figure 2. Global fossil fuel consumption showing the exponential increase since the 1950s, similar to the exponential increase in food production (source: https://ourworldindata.org/fossil-fuels).

Growing food is a natural thing and like all natural things has boundaries within the finite system that is our planet. Of course with something so diverse and enormous as our global food system, those boundaries manifest in different ways in different places.

This report focuses on the use of energy in food production, in particular how to use the perspective of energy as a way to optimize our food systems heading toward 2050. It attempts to comment both at the national scale for New Zealand and globally.

Between now and then the burgeoning human population is expected to top 9 billion people but in the face of intensifying constraints associated with increasingly changeable climatic conditions driven primarily by green house gas emissions primarily from our use of energy contained in fossil fuels.

To put the sheer scale of human endeavor in context a recent paper comparing the biomass of humans and their animals with the mass of other living things is a great help. The biomass of humans alone (around 0.06 Gigatonnes of carbon) is **an order of magnitude higher** than for **all** wild mammals (0.007 Gt carbon) and our livestock represent an additional 0.01 gigatonnes of carbon, again some 30% more than the biomass of wild mammals. They say humans and livestock outweigh all vertebrates combined excluding fish (Bar-on *et al.* 2018).

Insecurity associated with our global food supply has increased in recent years after a decade long trend of decline according to the latest report by the Food and Agriculture Organisation of the United Nations (FAO 2018). The latest evidence shows a rise in world hunger with shifts evident in South America, Africa, and Asia. Twenty two percent of children under five are afflicted by stunting. 50 million suffer wasting while 38 million more are overweight. Obesity is worsening, now affecting one in 8 adults. Hunger and excess often coexist in close proximity, compounded by poor access to healthy food. Increasing climate extremes exacerbate every single aspect of food security with conflict compounding things further.

Proposed solutions by The United Nations Committee on Food Security require increased partnership, multi-year large scale funded reduction of disaster risk reduction and climate change adaptation. In short, the solution is intensification of what we're already trying to do. We will need even more energy and resources than we do today. Solutions also hinge on numerous other goals described in the Sustainable Development Agenda (2030) such as reducing poverty and inequality while improving health, education, peace, justice and other elements of the good life. Similarly, achieving these goals requires intensification.

As these trends continue the ethical conflict for New Zealand in seeking to feed the most prosperous will intensify.

The role of energy

Life, from its simplest to most complex forms, requires energy. From respiration, chewing and digesting our breakfast, to the car we drive, and the industries that sustain our lifestyle. The very most fundamental concept of survival is to obtain enough energy to exist, grow, and reproduce (Hall 2017). Really, the only thing that changes is the scale (Figure 1).

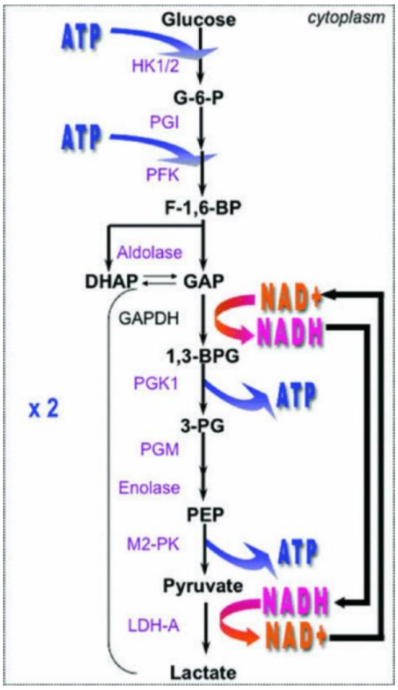


Figure 3.Energy supply systems – the glycolytic pathway occurring in the cells of your body that provides your 7.5MJ to keep you living and breathing each day, and BP's Thunderhorse oil platform with an oil production capacity of 1.5PJ/day – two hundred million times your daily requirement.

The source of energy on earth is ultimately the sun. Photosynthesis, fossil fuels, wind, flowing water, none would occur without energy from the sun.

Fundamentally, energy can be neither created nor destroyed, it can only change forms and tends to degrade from high to low quality (aka density / concentration). This stems directly from the laws of thermodynamics. A good example is that the energy (in chemical bonds) in diesel is converted to heat (thermal) and movement (kinetic) when propelling your truck.

Reversing back the way you came will not refill your diesel tank. That heat and movement are converted into progressively smaller energetic amounts as you brake and come to a stop, and the truck cools down. The energy in the diesel has been degraded and dissipated into much lower forms. This a rural example of the first law of thermodynamics. It's important.

Overwhelmingly in the developed world today energy is sourced from the combustion of hydrocarbons contained in fossil fuels. Bloomberg reported in October 2018 that global oil consumption in the last quarter measured had risen to an all-time high of just over 100 million barrels per day according to the International Energy Agency.

It is uncommon to consider the role of energy in our lives especially while it is plentiful and cheap. However It doesn't take long for an empty stomach or a low fuel gauge to make the owner think about getting some more. Similarly, if an energy source is making us sick (or we see it may in the future – climate change), we may cast about for healthier alternatives.

It is also uncommon to consider the global food supply network from the perspective of energy. I visited the School of Earth and Environment at Leeds University as part of my Nuffield travels, one of the three world leading groups (the others are in Venice and Barcelona, I am not multilingual) researching energy use in a post-growth society. The notion of energy use in the world's food systems came largely as a novelty to them. Incidentally, soon after I accepted a supervisory role for one of their new students who would begin investigating exactly this topic. Energy required to produce agricultural inputs like fertilisers, chemicals, and animal health remedies. Energy for the machinery, irrigation and other systems that enable the production of our crops, healthy animals and animal products. Energy also to create, maintain and fuel the systems that transport our products, process them, preserve them and distribute them around the world. While money is the medium we trade in, energy is the fuel that creates the trade.

Old olive grove, Lago Trasimino, Italy.

The challenge

The challenge I sought to address in my Nuffield scholarship was finding a solution to two seemingly irreconcilable facts.

Firstly, the exponential growing global consumption of fossil fuels cannot continue for the length of my career. The primary reasons being the associated emission of greenhouse gasses impacting our climate and the simple fact that these fuels are a finite resource.

Secondly, food production from increasingly energy intensive systems needs to increase substantially by 2050 to accommodate a projected human population of 9 billion people. Projections of the exact amount are pointless as they ignore the complexity of the global road to 2050 but everyone seems confident it will be a lot.

How could we plot a path to 2050 along which these points were brought together harmoniously.

We would need a method, or kind of energy compass, that could direct efforts within New Zealand and ultimately globally to best match our food production aspirations and our energy resources.

Importantly, I directed my attention to exploring this path based on the physical and practical aspects of energy and food production. I have studiously avoided related political, social, and economic elements on the premise that if the path is physically or practically impossible then they offer no solution. Similarly if it is indeed physically and practically attainable, our experts in these other elements can lead us to success provided they can see that path.

Also importantly I chose to largely ignore emissions from livestock, instead focusing on emissions from energy use. Considering the two individually at the high level of this report detracts from the core issue of reducing fossil fuel use. My approach is consistent with the latest publication by the Parliamentary Commissioner for the Environment, 'Farms, forests, and fossil fuels: the next great landscape transformation' released days before my report was submitted. It recommends separate targets for fossil based and biological emissions, where the latter only can be offset by forestry. This essentially enables a tighter focus on reducing fossil emissions but also makes progress reducing biological emissions more transparent (Parliamentary Commissioner for the Environment 2019).

Nuffield and seeing the world's food systems

On the Global Focus Programme we looked at a diverse range of food systems. From the very highest level of technical horticultural operations in the Netherlands to massive broad acre systems in Ukraine and subsistence production at the individual family level. The scope of what we saw is best conveyed in a series of images.

Low tech

Hi-mega tech

Hi tech

Future tech sim farming

Or future tech?

How can the relative ability of such diverse food systems be compared on an even footing? And how can we compare the wider system from seed to plate that these farms operate within?

Clearly there is a spectrum of complexity and intensity. How can they be quantified in a way that enables us to see the most effective ways to produce food?

A striking point from the Nuffield conference was that two billion small holders occupy 60% of the world's arable land. In light of efforts to increase food production between now and 2050 the importance of this point cannot be overstated. Partly because the vast majority of these small holders will use a tiny fraction of the technology and much lower input intensity than their large scale counterparts. Partly because they are the majority. And so, because there is far more scope to increase their food production for a comparatively small shift up the scale of intensification. It was evident first hand during our visits in Kenya where our hosts spoke with tremendous enthusiasm about using a little herbicide instead of hand weeding, or drought tolerant crop seeds, or another cow or two. They were perfectly aware of the power and potential lying in their smartphones and well into the process of making it work on the issues they face. A great example was the smartphone based finance Mpesa. Furthermore such a shift would do far more for improving the population and communities on that 60% of the world's arable land than increasing the productivity of the big farms and mega-companies, or of devising some mega-industry that can produce the world's food from factories rather than farms.

But there is a problem. Hand in hand with this earlier stage of development is less access to research and technology transfer that focusses specifically on their needs. These things need to come from elsewhere and they need to reflect the global need for food systems optimized for emissions and consequently energy too.

To get so deeply down to where the diversity of systems that we saw could be fundamentally weighed up I found myself heading towards the basics of physics. Surprisingly, it was not as onerous as I anticipated and not surprisingly when I started looking around I found that people were already well advanced in the process. I looked to see if other Nuffield scholars had explored the area of food and energy to see where their thinking was up to.

Previous Nuffield reports

A review of Nuffield reports investigating elements of sustainability shows just how remote the notion of energy use in farming and food is. It also shows the diverse interpretations of the term sustainability.

The challenges ahead for global food production from the perspective of the farmer have been explored recently by other Nuffield scholars (Inwood 2011) and from the perspective of energy, particularly in relation to on-farm biogas (Shanks 2010). Certainly Shanks would have been interested to combine the EROI methodology explored in this report with his research project, but the methodology at that time and now is relatively unknown.

An Australian report in 2012 looked at managing farm energy use to capitalize on carbon in tough Australian farming conditions. Exhaust emissions, satellite imagery, improved livestock, better fertilizer use and soil health were the main areas the scholar felt could be improved. He also noted the appeal of very intensive but small scale food production systems – 'micro farms' located close to market, compared to the Australian 'outback' (Smart 2012).

A UK report on the true cost of cheap food concluded that major changes to the global food system were imminent and unavoidable. Combined impacts of climate change, water limits, and human population growth would drive them. Compounded by the desire of people in developing nations to achieve the 'modern' lifestyle and the fundamental counterpoint of fossil fuel depletion, the tension this scholar anticipates was very clear (Craig 2013). His views on how these changes would influence the cost of cheap food would have been interesting.

Craig's report really resonated with me. I finished it even more fascinated by the idea of devising a system that could tease out these issues and plot a path through them, at least the energy side of them.

Enter biophysical economics.

A lens to look through: Biophysical economics

Biophysical economics (also known as thermoeconomics) is a school of heterodox economics focused on setting popular economic theory within the natural boundaries such as the laws of thermodynamics and biology. In essence, it is a link between what we understand to be economically possible and what we understand to be actually possible. A comparatively new school of thinking, most literature within it has emerged post 1990.

Biophysical economics as a concept is growing in importance as we approach the global peak in the supply of cheap energy and as we increasingly exceed the natural boundaries of our planet and resource base.

The vast majority of time since the end of the second world war has been characterized in the Western world by unprecedented rebuilding, development, expansion of global trade, mechanization, technological innovation and general economic boom times. To a character of this type biophysical considerations were simply too far beyond the edge of the horizon to contemplate. People were conscious during this time that these natural limits existed somewhere out there, but were operating so far within them that no pressure from them was felt.

That is not the case today. Today we are feeling the pressure of these limits and looking for ways to adapt.

The human desire to enjoy the modern lifestyle is unsurprising. Also unsurprising is our avoidance of the fact that such a lifestyle for all far exceeds the biophysical limits of our planet. A useful way of conceptualizing this was presented by O'Neill and his colleagues in their paper 'A good life within planetary boundaries' (Figure 4). For 150 countries they weighed up twelve social indicators (eg life expectancy, nutrition, education, etc) against seven biophysical boundaries (eg carbon dioxide emissions, nitrogen use, and water use). They found to achieve reasonable levels of these social indicators globally would require between two and six times the sustainable level of use of these resources. They also show that the countries held up by the world as the pinnacle of development are the exact same ones most overstepping their biophysical limits (O'Neill *et al.* 2018).

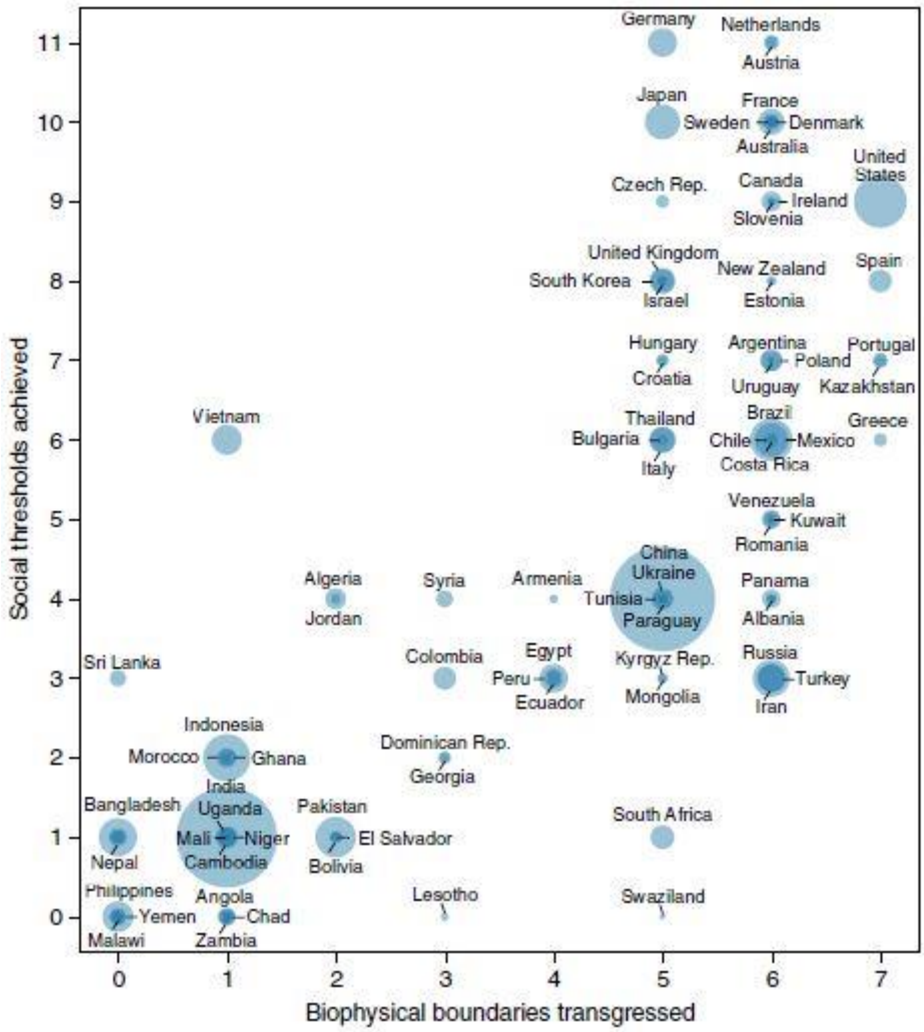


Figure 4. Number of social thresholds achieved versus number of biophysical boundaries transgressed, with circles scaled by population representing 109 countries (O'Neill et al. 2018)

Are their food systems overstepping natural boundaries too? And if so how might we find a way to bring them back within sustainable levels? A methodology known as Energy Return On Investment could be an exceptionally useful tool.

Energy Return On (Energy) Investment (EROI)

Energy Return on Investment (also known as Energy Return on Energy Invested) is a methodology within Biophysical Economics that represents energy entering and leaving a system as a ratio (Hall 2017). It is relatively new but its appeal is growing quickly, driven in substantial part by the tireless efforts of Professor Charlie Hall.

Professor Hall and myself at his home in Montana in 2014.

It is a powerfully basic, practical and immensely versatile means of quantifying energy flows. Obviously it provides valuable insights when applied to common energy sources like oil. For example a ratio of 40:1 indicates that the driller gets 40 barrels of oil back for every one they invest in drilling. So an oil well with EROI of 60:1 is a far more lucrative beast than one with EROI of 20:1.

Application of the methodology is broadening beyond energy sources with informative results.

The interesting thing is that for the inputs to any system EROI makes the important distinction between primary energy (also known as direct energy) and embodied energy. This is easiest to visualize in an example, a tractor given the agricultural tone focus of this report.

Over its lifetime our tractor consumes diesel. This is its direct energy.

But energy has also been invested into it forging the metals, producing the plastics, rubbers, manufacturing the electronics, refining the oils and so on that go into its construction. This is the embodied energy.

Now let's think a step further. Imagine the technology incorporated in a modern tractor. Computers, sensors, global positioning systems, rubber compounds, alloys, batteries, and the list goes on but we haven't even begun to consider what's involved in the implement that trails behind it. All of those technologies come from their own respective industries each of which consumes energy.

Think also about the maintenance systems that will keep out tractor running throughout its lifetime. Maybe also the recycling systems that will break our tractor down once its life is done.

The absolutely fabulous thing about Energy Return On Investment is that with practice thinking in this way, ones view of the world ceases to appear as a whole bunch of things and instead becomes a bogglingly dynamic swirl of energy flows running through every part of our lives, societies, industries and of course our tractor.

We can quantify these inputs in the very concrete form of joules.

We can also quantify the outputs from our system in joules, or sometimes it is easier as dollars. How much revenue did that tractor generate for the farmer? $100 per megajoule of energy consumed it its life cycle? $500/MJ.

If the farmer had purchased a smaller tractor or a different machine altogether, what would the return on its energy use be?

For a second example we will consider a typical sheep and beef farm. Quantify all the inputs from fertiliser to machinery, fuels, materials, buildings etc in joules per year. Quantify the outputs of beef, lamb, wool, maybe crops and surplus supplementary food in joules per year (perhaps metabolisable energy, perhaps not). The result is a ratio of the energy outputs and inputs for that system. Alternatively the ratio could be financial revenue to energy inputs which gives a measure of energy intensity (dollars made per joule used). Any food system, anywhere and under any conditions can be analysed in this way and compared with any other.

Now consider the possibility of comparing a broad acre cropping system in Ukraine with smallholder production in Kenya. Why not?

Or investigating what energy components of a system could be reduced to reduce emissions with minimal impact on the energy output of that system.

The scope for application is enormous because the ratio of the outputs to inputs is a measure of energy efficiency of that system.

But we need to be careful describing where we set the boundaries around our system so it is clear where we start and stop amidst that dynamic swirl that is the world. Particularly if we want to make it comparable with another system on a level footing.

We also need to be careful when only looking at the revenue per joule because this exposes our results to the blizzard of financial, social, and political instruments that contort the flow of money around the world. Sticking to joules produced per joule used elegantly sidesteps this issue completely.

Previous research in New Zealand has the recognized the value of EROI, stating that standard economic approaches to energy modelling cannot capture the full implications of declining EROI values unless they incorporate analysis of net energy yield (Peet and Baines 1986).

EROI values for energy sources

Energy Return On Investment has had widest application in quantifying the net energy obtained from common energy sources such as oil, natural gas, coal, wind turbines, photovoltaic panels and somewhat controversially, biofuels. EROI is an excellent method of identifying society's stage in processing energy from finite reserves, but there is vastly more utility to be explored in it yet.

Commonly EROI values range as high as around 100:1 for some hydroelectric schemes (Atlason and Unnthorsson 2014) and historic easily accessible, high quality reserves of oil, now long since consumed. That is 99 joules of energy delivered to society for a single joule invested obtaining it. At the other end of the spectrum is biodiesel made from corn with a reputed ratio of around 2:1, meaning two joules delivered to society for every joule in obtaining it by this method.

There are a couple of very important things to realise about EROI.

Important point one: each energy source has an EROI

Recognize the enormous difference in the rate of energy yield from the two examples above. Each of the other common sources has a variety of estimates of their yield too available in the literature which have been thoroughly summarized for thermal fuels (Figure 6) and for electricity generation (Figure 6) in (Murphy and Hall 2011) and (Hall *et al.* 2014).

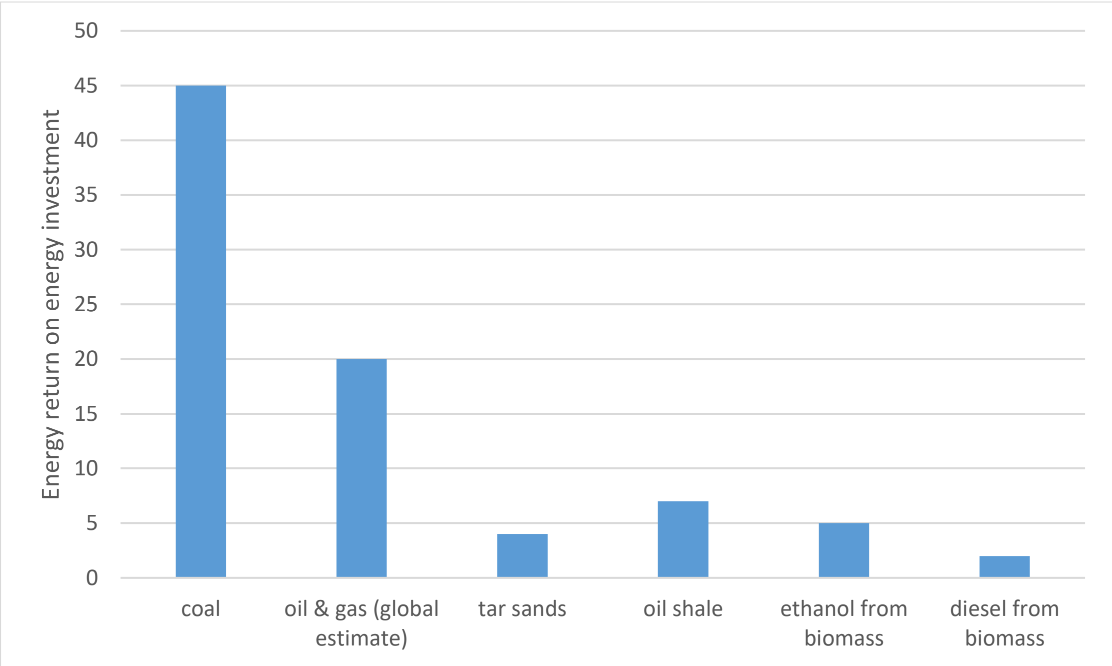


Figure 5. Average EROI values for thermal fuels from known published values (Hall et al. 2014)

Figure 5 shows that, from essentially a global perspective, coal is by far the most lucrative source of thermal energy (ie to generate heat, as distinct from being used to generate electricity). By a factor of two relative to conventional oil and gas and vastly more lucrative than other oil sources.

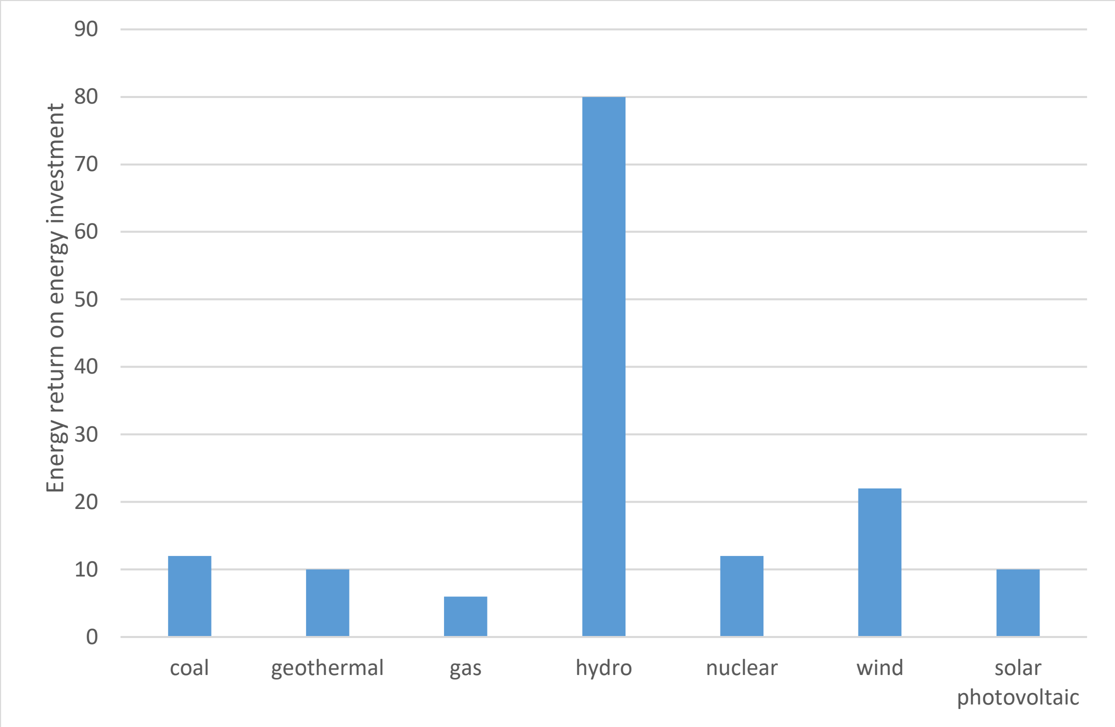


Figure 6. Average EROI values for sources of electricity as summarised in Hall et. al, 2014

Figure 6Figure 6 shows that when an energy source is used to produce electricity, again from an essentially global perspective, hydroelectric generation is far more lucrative than other common 'alternative' sources, but also better than coal and gas too.

An alternative approach to summarizing a variety of estimates is to compare a range of sources using a standard process (Weissbach *et al.* 2013). This suggests that the EROI for electricity generated by nuclear, hydro, coal, and natural gas power systems are an order of magnitude more effective than solar photovoltaics and wind (Figure 7). Differences in boundary decisions and methodology can substantially influence the results, a situation which urgently requires a remedy.

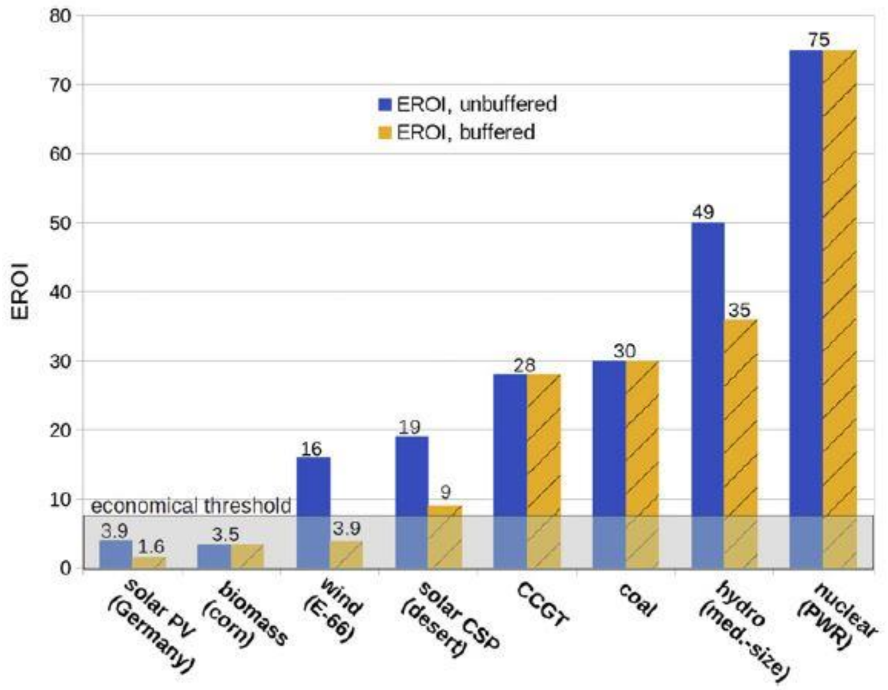


Figure 7. EROI values calculated by Weissbach et. al, 2013.

Important point two: Overall, EROI for fossil fuels is higher than alternatives

An absolutely critical point about any transition from fossil to renewable energy sources is this. A transition to renewables with low EROI values is tied rock solid to a reduction in energy use per capita. Globally, energy use per capita has increased at around 0.5% per annum in recent decades, with this fact reflected in a general trend of increasing prosperity. A recent publication in the Nature Energy journal estimated the reduction would be around 24-31% by 2050 (King and van den Burgh 2018). They tentatively suggested this may impact on the modern lifestyle. I was too frugal to spend fifty dollars buying the paper to read how big they thought the impact might be but I did a thought experiment instead.

Much of my professional life I have enjoyed an increasing in salary. Raises probably average out around 0.5% per annum. Definitely more than 0.05% and definitely less than 5%. If by association I am to experience a 24-31% decrease in income by 2050, my way of life would indeed be substantially different.

Another absolutely critical point about any transition from fossil to renewable energy sources is this. The longer a major transformation effort is postponed, the more difficult it becomes. This simple but purely true fact comes from the continual decline of gas and oil EROIs together with a shift away from coal more to reduce emissions.

Important point three: EROI of finite energy resources naturally declines

EROI values of exploitable resources like oil and coal tend to decrease over time (Figure 8). This is because the highest quality and most easily accessible resources tend to be exploited first, a natural conclusion for maximum profitability. Once they are gone a process begins of accessing lower quality, more distant and more challenging locations (think deep sea, arctic or unstable nations with high levels of violence) until it finally become uneconomic to extract energy from this source any longer.

One recent paper claims global EROI values for oil and gas peaked around the 1940s in the vicinity of 50:1 and 150:1 and have been declining since – see above Hall's estimates for oil which are less than half that peak , while for coal a peak is suggested between 2025 and 2045 at 100:1 (Court and Fizaine 2017).

Estimates for the EROI of global traded oil and gas reportedly dropped by almost half in the 20 years to 2010 according to (Gagnon *et al.* 2009) and continue to decline.

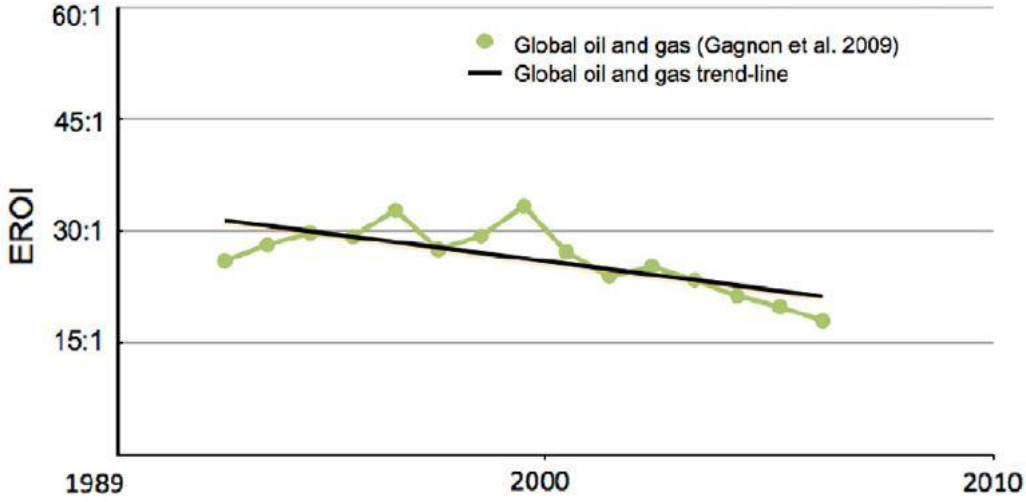


Figure 8. EROI for global traded oil and gas from 1989 to 2010 (Gagnon et al. 2009)

Gains in the efficiency with which the energy source is exploited are a means of reversing this decline in EROI. In some cases these may be quite effective and new technology contributes also, but one would assume that at some point the efficiency of exploitation is optimized at which point the overall decline in EROI resumes. It's a bit relentless.

Lean management is another catch-phrase for contending with a declining EROI. It is simply a systematic method for waste minimization without sacrificing productivity. By identifying what adds value and minimizing everything else, the system is optimized with Just In Time manufacturing, originally known as the Toyota Production System (Holweg 2007).

Important point four: what is the minimum EROI for society?

Arguably the most interesting but contentious concept associated with EROI is what is the minimum value required to maintain a given system. Somewhat selfishly the system of greatest interest is usually the modern lifestyle. A range of 20-30 is suggested by (Lambert *et al.* 2013) and 12-14 is mentioned by (Smil 2015), the difference highlighting the relatively newness of the methodology, scarcity of research on the topic and perhaps some inconsistency in system boundaries which need standardising.

While these estimates differ, what they do collectively suggest is that the modern lifestyle could not be maintained as it is today on energy sources with an EROI lower than 10. Keep this in mind when you read about later in this report about the projected EROI for New Zealand in 2050. The impact of this is hard to envisage. Hall et. al, (2009) concluded that if the overall EROI were to halve at no change in energy cost in the United States, approximately one third of discretionary spending would need to be reallocated to energy supply (Hall *et al.* 2009). They found that 9% of GDP in the US was spent on energy and 25% of GDP was discretionary spending. It would be interesting to calculate the same metrics for New Zealand.

Weissbach et al followed this idea in 2011 looking at the US and Germany, suggesting the threshold EROI for final energy consumption was 7 and EMROI (Energy Money Return On Investment) was 16 (Weissbach *et al.* 2013).

Fizaine and Court (2016) estimated energy expenditure for the US and world economies from 1850 to 2012. Over the 50 years of annual data to 2010 they estimated that to enjoy positive growth the US economy could not afford to spend more than 11% of its GDP on energy. Given the energy intensity of the US economy this translates to a minimum EROI of approximately 11:1 (Fizaine and Court 2016). These papers and the work by King et al and by Brand-Correa (2017) are the most intuitively interesting written on the idea that there might be some exact EROI below which a developed economy fails to grow. Another paper on the topic is referenced by Brand-Correa and despite my most valiant efforts I could make absolutely no sense of it at all (Herendeen 2015).

Research by Dale *et. al* in New Zealand has incorporated the concept of EROI in their biophysical energy-economy model 'GEMBA' which represents energy flows between the energy sector and the rest of the economy (Dale *et al.* 2010;2012a;b). Notably, model output shows that current levels of global energy consumption cannot be maintained using only renewable energy sources. They present a selection papers providing strong evidence that energy production is more capital intensive from renewable compared to non-renewable sources. The work proved ahead of its time in not capturing more attention, a position it unfortunately maintains today.

On would be inclined to think that the available volume of an energy resource is inversely proportional to its EROI. In practical terms, this means there are vast volumes of many types of resources that offer a low EROI to society. But if their value is lower than the minimum threshold we need to maintain society, we must either accept a decline in the energy supply to it, or find a richer resource elsewhere. Create a mental image of running your hometown on a mix of high EROI resources like oil, nuclear, and coal, or alternatively low EROI resources like firewood, ethanol from corn and photovoltaics. What do you see?

Important point five: the scientific field of EROI is growing but remains small

Publications mentioning or focusing on EROI have increased from a handful each year in the early 2000s to over 100 in 2018 (Figure 9). Increasing popularity and discussion will help establish some rules and resolve issues that inevitably challenge any emerging school of thought.

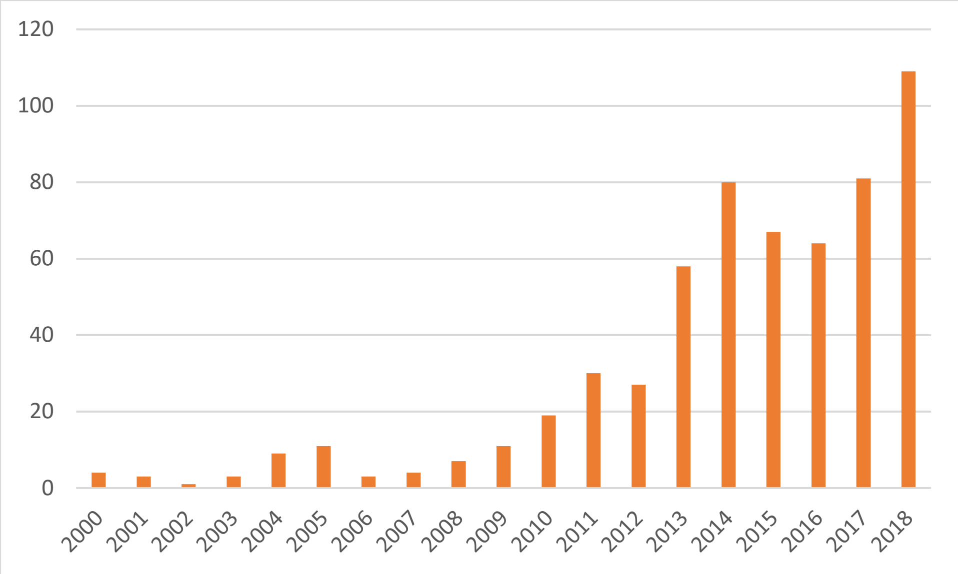


Figure 9. An annual count of scientific publications using the search term 'Energy Return On Investment' in Science Direct

The field is expanding from what was originally a rather myopic fixation on fossil fuels into the likes of prioritising the types and sources of energy imports, the wind potential available for projects to transition to wind from fossil fuels and linking EROI with greenhouse gas emissions and electricity generation options.

But awareness of it beyond the sphere of research is virtually nil. Throughout the entirety of my Nuffield travels not one scholar, host, or person that I met was aware of it. Except one, Kees the Dutch farmer from Mankivka in Ukraine, he naturally seemed to think along those lines which was remarkable. I was very surprised how little the role of energy in food production was discussed during our Contemporary Scholars Conference.

Later I attended the Asia Pacific Energy Leaders Summit in Wellington where the energy in business in the coming decades, particularly in New Zealand was discussed. Again there was not a single mention of EROI and only one single short presentation from the rural sector (Synlait) over two days of presentations. Instead there was an overwhelming focus on mass transport within cities (Uber, electric bicycles etc) a renewed interest on hydrogen (which is actually an energy storage device rather than an energy source), aviation, decentralised electricity systems integrating electricity generated at the household scale into the national grid, capped of with the Cora personal electric light aircraft currently under development in California and New Zealand. Food didn't figure, except at lunch.

EROI summary

To summarise the EROI section, the methodology is immensely useful being both versatile and informative for assessing energy and food systems from an energy perspective. The EROI values for alternative energy sources like wind and photovoltaics tend to be lower than for fossil fuels which means a low emissions transition with substantially more alternative energy will require the diversion of energy from maintaining society to maintaining society's energy supply. The EROI for our main fossil based energy sources declines over time so the sooner a transition to alternatives is made the easier it will be.

This methodology at present is virtually unheard of in industrial and commercial spheres, but its application is growing exponentially in the research sector.

Good food, Siena, Italy

Energy use in New Zealand

National primary energy supply (907 PJ in 2016) was mainly from fossil fuels (60%) but with substantial (40%) renewables in the form of geothermal (22%) and hydro (10%) for electricity generation (Figure 10). Wind, biogas and solar represent less than 5% of supply (Ministry of Business Innovation and Employment 2017).

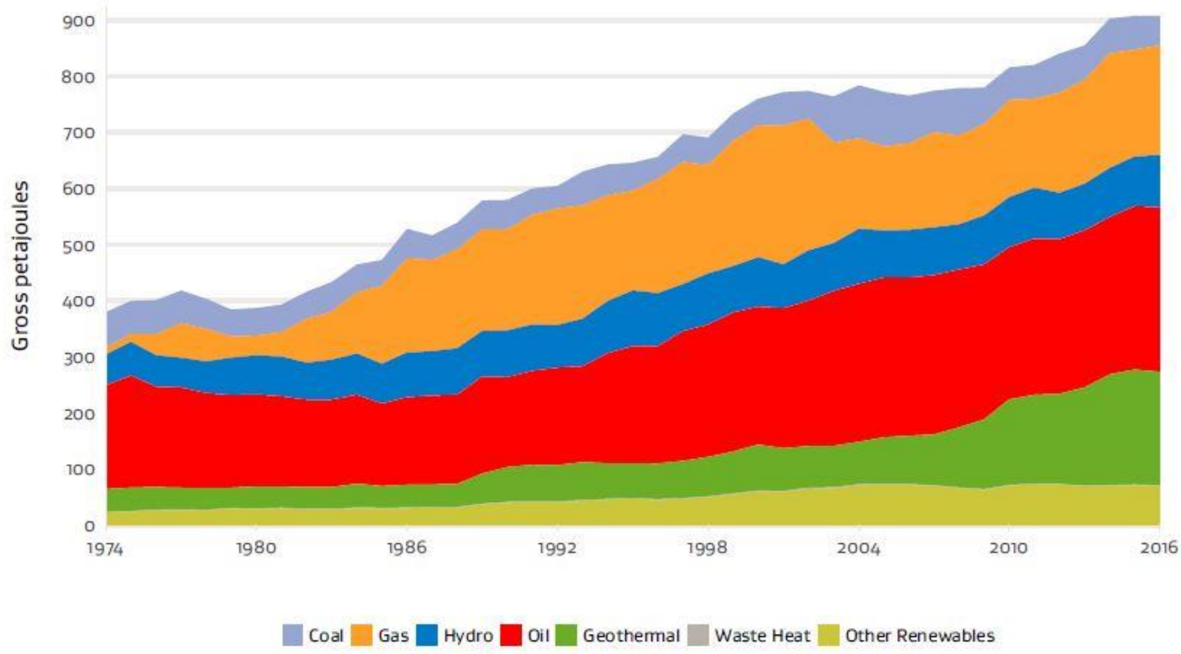


Figure 10. Primary energy consumed in New Zealand

We have an estimated 15 billion tonnes of coal reserves, of which 80% is lignite in the South Island (Ministry of Economic Development 2012). Our current rate of use is around 3.4 million tonnes per year of which a little under half is exported. At the current rate of use life expectancy of this resource is some 4,000 years, at ten times the current rate, still 400 years. There's no doubting it is a tremendous national resource hobbled by emissions. It would be fascinating to know the EROI for it.

The long term trend for primary energy consumption by New Zealand is an increase of around 6PJ per year, 1.5% of consumption in 1990. Primary energy consumption by the agriculture, forestry and fisheries sector of the economy at around 50PJ is a small fraction (~5%) of New Zealand's total (Figure 11). It shows the same gradual increase over the last 26 years (Ministry of Business Innovation and Employment 2017)

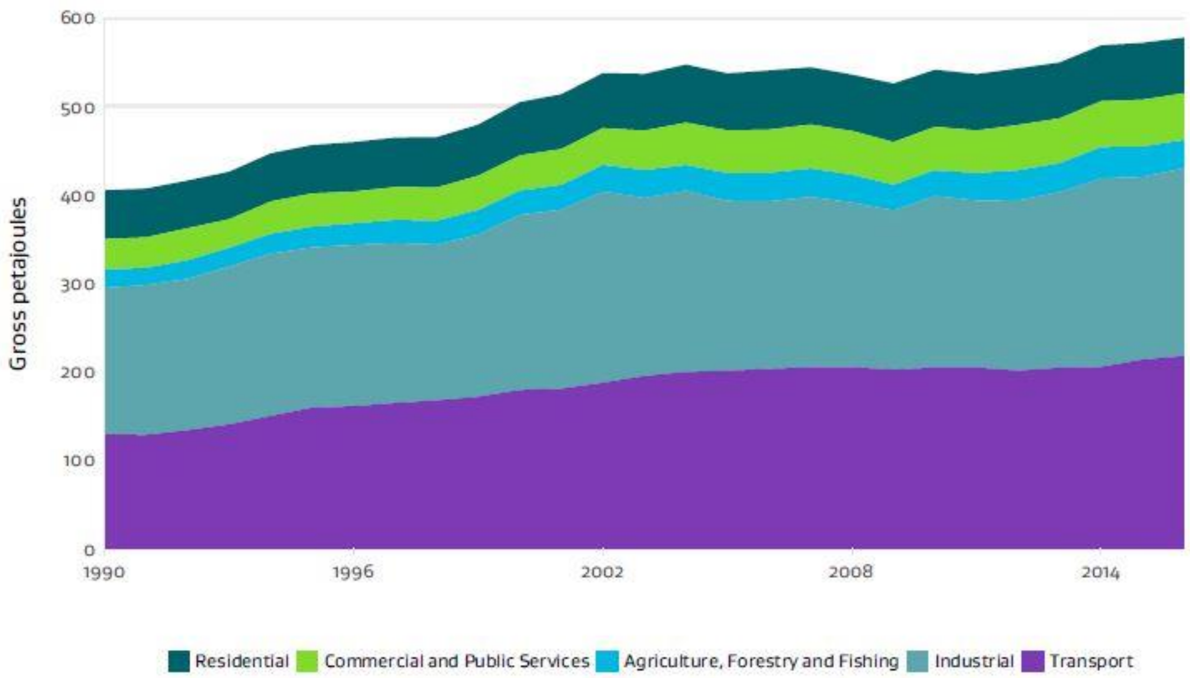


Figure 11. Consumer energy demand by sector (Ministry of Business Innovation and Employment 2017)

Overall, New Zealand has a 20% higher energy intensity than the OECD average (Ministry of Business Innovation and Employment 2017).

Summary of consumer energy use in New Zealand

Primary energy consumption in New Zealand is increasing exponentially at a rate of around 1.5% and currently around 900 PJ per annum. Most (60%) energy consumed comes from fossil fuels but with significant contributions from the renewable sources of geothermal (22%) and hydro (10%).

The perception that agriculture, forestry and fishing consume only a small percentage (~5%) of our primary energy is true but also misleading because significant energy use in the industry and transport sectors are also required to make them function. This is an important point.

A field of view: Energy use in New Zealand's primary production chains

For the purposes of this report the primary production chains are defined as all types of farming and horticulture. This also includes the process of growing the plants or animals, transporting them to a processing facility, processing, and delivery to consumers.

We are interested in these chains from the perspective of energy invested into their different links, the type of that energy, and what parts of the chain would be most enhanced or placed at risk by a transition towards the low emissions goals outlined in the proposed Zero Carbon Act .

A supply chain perspective is essential. It provides an opportunity to explore what the energetic impact would be of changes in the volumes of our commonly produced goods. Subsequently, it is a chance to anticipate what changes are necessary to achieve desired growth, both on-farm and in processing. There is little point in making big changes on-farm to produce a particular product if subsequent processing of that product is prohibitively energy intensive.

What do we know of energy consumption throughout these chains?

Energy use in New Zealand's primary production chains

Farming is a huge part of New Zealand's productivity and culture. The sector produces around 6% of GDP and 40% of our exports using close to 40% of our land.

Surprisingly there is only a small jumble of unrelated studies and statistics on energy use within New Zealand's primary production chains over the last couple of decades. Their boundaries vary and studies encompassing a full chain of production (dairy for example) were very rare.

Key statistics are summarized below from a high level down to information at the individual farm level.

Sector level

Primary energy consumption behind the farm gate is a small percentage (about 5%) of our national total. This is despite an increase of 52% in the 20 years from 1990 to 2010, with a peak in 2007 associated with widespread drought (Ministry of Business Innovation and Employment 2017).

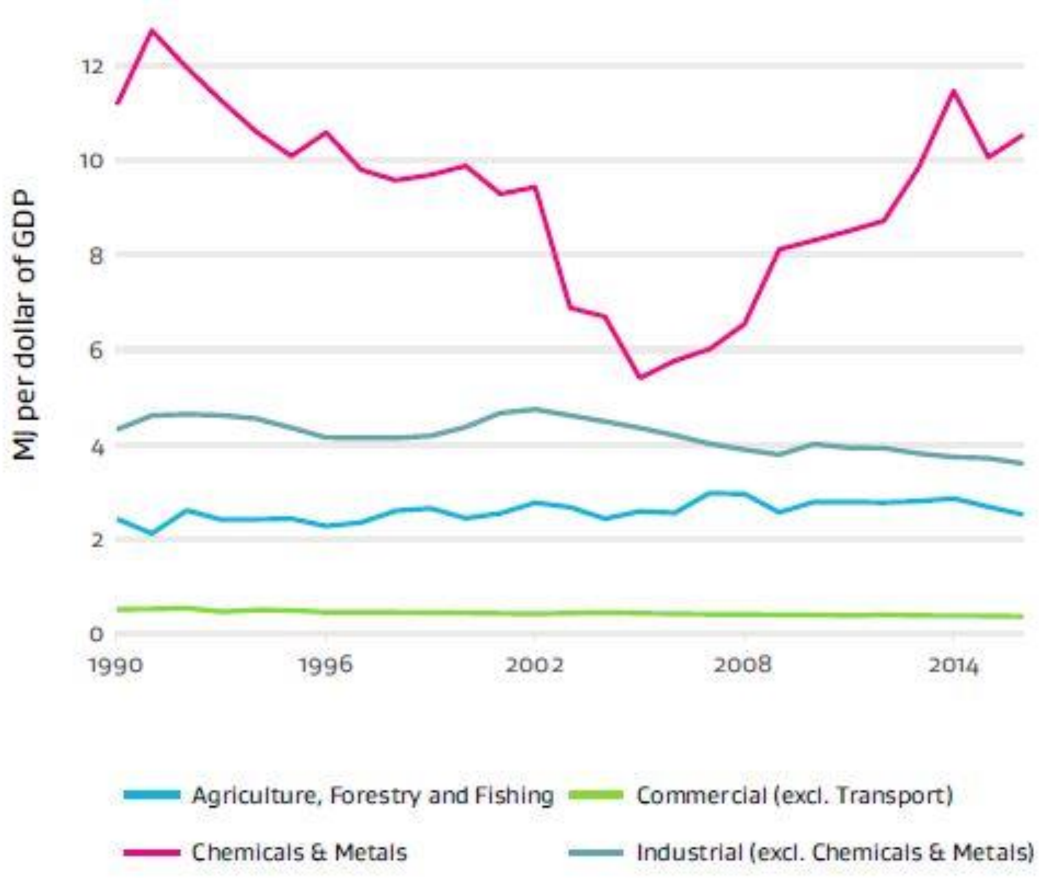


Figure 12.Primary energy consumption per dollar of GDP produced by sector (Ministry of Business Innovation and Employment 2017)

Figure 12 shows energy intensity per dollar of GDP produced. Agriculture, forestry and fishing have fairly steadily converted 2-3 MJ of energy into a dollar of GDP in the last couple of decades. However subsequent processing by the meat and dairy industries had around a 5 fold higher intensity at 12MJ per dollar of GDP (reported in 2011) which highlights the importance of looking at the whole chain of primary food production. Across all sectors, energy consumption was approximately 4MJ per dollar of GDP returned (Ministry of Economic Development 2012).

Total energy use in the New Zealand food system was split between production (28%), processing (32%), distribution (18%) and preparation (22%) in the report by the Centre for Advanced Engineering in 1996 (Centre for Advanced Engineering 1996). These figures now over 20 years old may have changed, particularly with respect to the increased use of irrigation. But interestingly they show a sharp contrast with the GDP data above. Energy use in processing they report as only 14% greater than production, but in the GDP data it is around five times greater. This highlights the need for a consistent approach to these methods of measurement. Firstly so different food systems can be compared on a standardized basis and secondly so when changes are made to them, the impact over time can also be seen on standardized basis.

Processing

In the processing of primary produce the biggest change over the last couple of decades has been in the dairy sector, whose energy use has more than doubled in the period from 1986 to 2014. Energy used in meat processing has actually declined slightly (Figure 13).

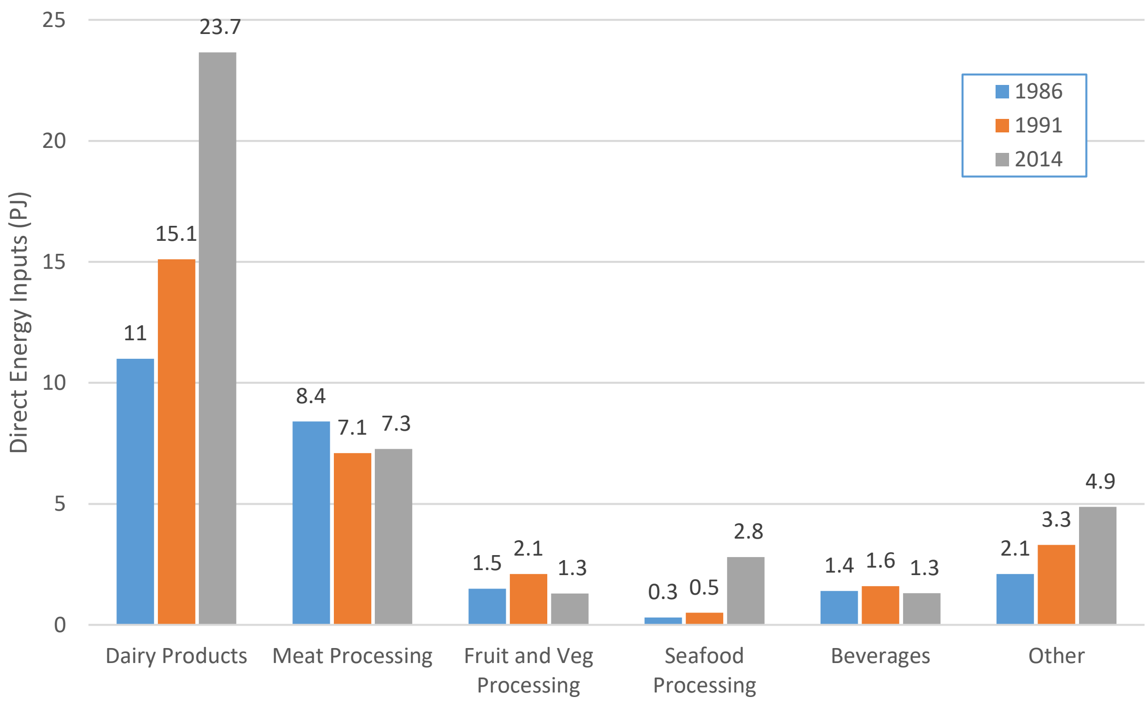


Figure 13. Direct energy use in the food processing sector (Centre for Advanced Engineering 1996)

Fonterra has demonstrated its forward thinking by publishing information on its energy consumption in its sustainability report (Fonterra 2017a;b). Raw milk collected and processed in New Zealand and Australia represent over 95% of Fonterra's reported energy use by global Fonterra manufacturing sites in 2016 at 29.4PJ, an energy intensity per tonne of finished goods of 7.55GJ/t or 0.53 $tCO_{2\ equiv}$. In another demonstration of great foresight they have included the contribution of different energy sources to their consumption (Figure 14).

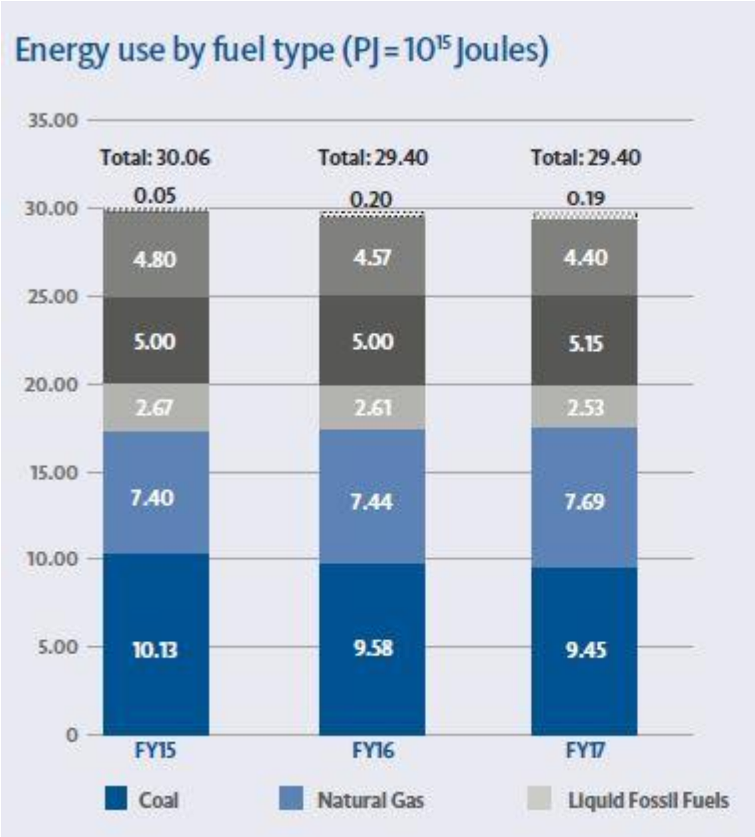


Figure 14. Fonterra energy use per year by fuel type

These figures incorporate direct and indirect energy used by manufacturing sites, the main research centre, large corporate sites, and their own milk collection transport fleet in New Zealand and Australia.

What we really need is comparable data for the red meat sector and all the other major contributors to New Zealand agriculture. Only then can we start to see the relative energy use in relation to output and to profit. This is a very different approach to using only economic data to assess what a transition to lower emissions primary industries would look like.

On farm

The analyses of farming systems from an energy perspective has been patchy and the methods used inconsistent. Still, for dairy farms there have been several good studies quantifying energy use and in some cases their emissions (Wells 1998;2001; Ledgard *et al.* 2007; Norton *et al.* 2011; Podolski 2016). But importantly, all except Ledgard consider up to the farm gate but not beyond. The methodology developed by Wells for his dairy analysis was applied by Norton *et. al* (2011) to a total of 96 sheep and beef farms, dairy farms and kiwifruit orchards as part of the wider Agricultural Research Group On Sustainability (ARGOS). This work also compared the inputs (Figure 15) and outputs (Figure 16) of these production systems under organic and conventional management (Norton *et al.* 2011).

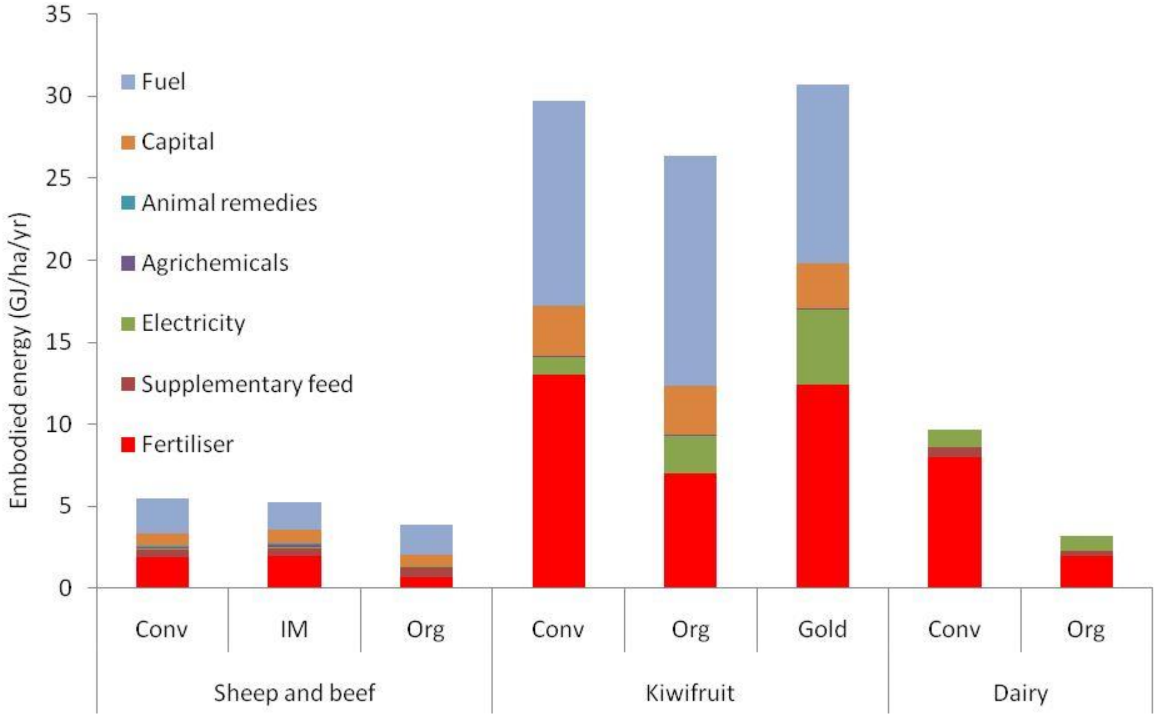


Figure 15. Energy embodied in inputs used by common New Zealand farm systems under conventional (conv) or organic (org) management

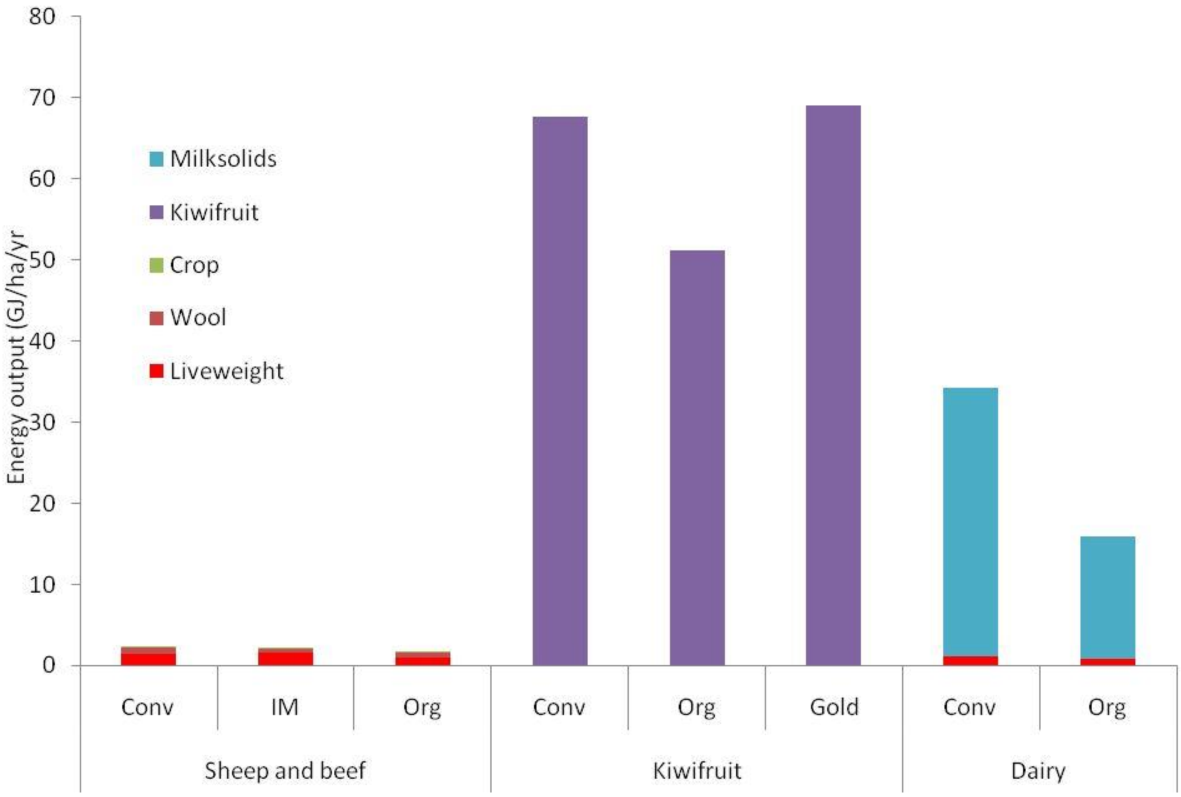


Figure 16. Energy embodied in outputs used by common New Zealand farm systems under conventional (conv) or organic (org) management

This work generated some fascinating findings.

In terms of output per hectare per year, dairy farms and kiwifruit orchards were 17 and 33 times greater than for sheep and beef farms.

Organic management of these three food systems was less intensive than conventional. That means it used less inputs but got less outputs too. But interestingly the ratio with which inputs were converted to outputs was virtually the same under organic and conventional management for a given system type. If we explore this idea further, a mass shift of our farm systems toward the organic end of the intensity spectrum would definitely reduce our stocking rates, input use, and emissions, but joule for joule it will reduce our total output proportionally.

This study also supported the abundant evidence that food energy can be produced far more efficiently from growing plants than from growing animals. Kiwifruit orchards were around five times better at converting input energy to output energy than sheep and beef farms. But the crop production on those farms (forage crops but also crops for human consumption) had double the efficiency of the kiwifruit system.

The EROI for sheep and beef farms was around 0.36 (interquartile range 0.3 – 0.5). For dairy farms it was 3.5 for the conventional group and 3.1 for the organic group suggesting that increased intensity was associated with increased efficiency too. The EROI range for these 24 herds was around 2.5 – 5. For kiwifruit orchards the EROI was around 1.8 with an interquartile range of 1.3-2.6. So the dairy system appears more efficient at converting input energy to output energy than kiwifruit orchards, just unfortunately the return per kilo on those outputs differs substantially.

While this work creates a standardised platform on which to compare these food production systems, it stopped at the farm gate. Consequently we have no idea whether the relative merits or drawbacks of these systems might be completely overshadowed by the downstream energy requirements for transporting, processing, and shipping their product. A good example of this our very scant knowledge of the rural transport sector.

Rural transport

An interesting point is that the rural transport network that delivers much of the farm inputs and carts stock is completely contained within the transport sector. As a critical component of the primary food production chain, the energy invested in this network should be understood at a rudimentary level at the very least.

In 2016 Fonterra and Z Energy announced the conversion of five of Fonterra's sites to Z Energy's biodiesel blend fuel (Evans 2016). Diesel consumption at around 46 million litres Fonterra equates to around 1.65PJ run through the trucks. At an EROI of 20:1 for diesel, this is 1.73PJ for the energy required to make and deliver the diesel, then run it through the trucks.

Fonterra anticipates tallow providing 5% of this energy in diesel. The EROI for tallow is around 1.5:1 (Barber *et al.* 2007) meaning the primary energy required to get that 1.65PJ of diesel rises from 1.73 to 1.78 (3%) for what is, at end of the day, only 5% renewable fuel. Extrapolate to 40% tallow or a similar EROI alternative, that's a 25% increase in the amount of primary energy required for those trucks. Can't work. The increased cost has to be built in. If it's 25% more? What happens when there's a 25% jump in the price of fuel at the pump? Electric trucks anyone? Ask Elon Musk.

Fonterra burns the same amount of energy in diesel (Evans 2016) as New Zealand exports as tallow (anonymous 2015). Tallow will not save our transport sector, even together with old fish and chip oil. Decarbonising heavy transport Is more challenging than for light vehicles which are better suited to electrification.

The current New Zealand Unit price for emissions on fuel is $20 equates to 5c/l for petrol and 5.5c/l for diesel. A rise to $100/tCO2equiv would roughly mean a 10% increase in petrol price (New Zealand Productivity Commission 2018a).

Export of primary produce

From an energy perspective New Zealand is best to produce high value per unit weight goods. Being a long way from key markets for our primary produce rising shipping expenses due to emissions related taxes may significantly impact the viability of these goods in future. Cherries are good a good example, to minimize the energy cost of production relative to returns. Looking at our main export products below it is clear this is not usually the case.

In 2015 export of dairy products by tonnage (around 2.6 million tonnes) amounted to around half of our total primary exports, ignoring logs and wood pulp which dwarf the others at almost 20 million tonnes (Table 1). On this basis, a look at the impact of a low emissions transition on Fonterra is warranted.

Table 1. Tonnes of primary export from New Zealand in 2015 (Statistics New Zealand 2016)

Product	Exported (tonnes)
Milk powder	1,813,000
Butter	477,000
Cheese	303,000
Beef and veal	420,000
Lamb and mutton	378,000
All meat and offals	897,000
Fish	200,000
Fish, crustaceans, and molluscs	270,000
Kiwifruit	408,000
Apples	308,000
Logs	18,443,000
Wood pulp	1,185,000
Wine (liters)	209,000,000
Iron, steel and articles	665,000

Summary of energy information for New Zealand's primary production chains

While there are instances of data and studies available on energy use in our primary production chains they lack consistency and cohesion. Consequently we do not have an overarching view of how and where energy goes within it which is a risk given our imminent efforts to reduce emissions and consequently energy use. We also lack a standardised approach to compare different chains like dairy, red meat, and pork for example.

At the sector level, agriculture, forestry and fisheries but also the industrial sector too have not improved their GDP generated per unit of energy used in the last 30 or so years. This is an important point if we anticipate a doubling of GDP in 2050 Zero Carbon modelling.

The Agricultural Research Group On Sustainability produced the most comprehensive analysis of primary food production systems from and EROI perspective in New Zealand and quite possibly the world, to date. It showed how this kind of standardised analytical approach can be used to compare the merits and efficiencies of growing systems as diverse as meat, dairy, kiwifruit, and crops. It would be an important starting point for further EROI work in primary production.

In both the production and processing part of the chain energy consumption has been increasing in recent decades.

Energy use in the rural transport system remains a total unknown and potentially significant risk to the overall chain in the face of a tax on carbon emissions.

The merit in high value, low energy intensity primary products is clear but the practicalities of their production of course takes precedence.

Broadening our perspective: Energy use in New Zealand and the Zero Carbon Bill

Climate change is accelerating and the urgency for change intensifying (Intergovernmental Panel on Climate Change 2015).

New Zealand has set a target under the Paris Agreement to reduce its emissions by 30% below 2005 levels by 2030 and to adopt increasingly more ambitious targets in the future.

But we, like the rest of the world are finding this increasingly challenging, despite being able to pick a few low hanging fruit. Globally, our drive to decarbonize is materializing as a head-on collision with our innate human drive to grow. This dichotomy is most acute at than the cutting edge of the developed world. It was perfectly captured in the February edition of the Economist magazine, published just days before the report you are reading was completed. Exxonmobil, a leading global oil major, plans to pump 25% more oil and gas in 2025 than it did in 2017, anticipating growth in global demand of 13%. But according to the IPCC it must fall by 20% by 2030 and 55% by 2050 (Economist 2019).

Dispel any notion of a mighty struggle between these ideologies. Global investment in the future of renewable energy sources, at around $300 billion is the archetypal David, three orders of magnitude below the multi-trillion Goliath of the oil industry (Economist 2019).

Dispel too any notion that scheming by great oil barons is at the bottom of this disparity. The oil industry is simply responding to incentives set by society and returns profits to many of the world's biggest investment funds, the same funds that underpin some of the developed world's biggest and most stabilising systems, insurance, retirement funds and health care to name but a few.

The reader is urged to reflect on what this means for the drive to decarbonize. The author for one arrived at the same conclusion as the Economist in that substantial political pressure will be essential, sufficient to drive a change that many will perceive as negative. Herein lies the challenge.

New Zealand has begun exploring potential pathways to reducing emissions by three quarters or more by 2050 with efforts spearheaded by the proposed Zero Carbon Bill.

It is not alone in this, with similar actions evident in many countries spurred by the IPCC. For example Ireland where 97% of the Members of the Citizen's Assembly recommended that to ensure climate change is at the centre of policy-making in Ireland and that as a matter of urgency a new or existing independent body should be enabled to effect change there.

The honorable James Shaw, Minister for Climate Change, heralded New Zealand's initiative on December 18, 2017 as 'the first important move to deliver on our commitments to be a leader in climate change" (https://www.beehive.govt.nz/release/first-important-step-towards-zero-carbon-act).

GLOBE-NZ, a parliamentary working group, commissioned Vivid Economics (London) to provide scenario modelling to inform their discussion. Vivid presented to the group on March 20, 2017 (Kazaglis and Ward 2017) and released a summary report (Vivid Economics 2017a) and technical report (Vivid Economics 2017b) shortly thereafter.

I met with Paul Sammon of Vivid Economics in London in September 2018 to better understand their perspective and the position from which the report came. It was clear that this perspective was deep seated within fundamental economics. There was little biophysical appreciation of the transition process.

The New Zealand Productivity Commission is an independent Crown entity whose role is to "provide advice to the government on improving productivity in a way that is directed to supporting the overall wellbeing of New Zealanders…". It released a draft report (New Zealand Productivity Commission 2018b) in April 2018 for public consultation. This report put Vivid's scenario modelling in context with New Zealand's role in climate change and mitigation, proposed pathways to low emissions, associated laws and institutions, plus an emissions trading scheme. The final report was released August 2018 (New Zealand Productivity Commission 2018a).

Three scenarios were explored to achieve the goal of net zero domestic emissions by 2100 (Vivid Economics 2017b);

Off track 2050 is a reduction in emissions between 2014 and 2050 of around 10-25% and insufficient to meet the goal.

Innovative 2050 assumes optimistic technological developments and rates of land use change whereby net emissions fall by 70-80% by 2050, putting us on track to meet the goal.

Resourceful 2050 is an intermediate option. It assumes significant afforestation, some increases in efficiency and modest reductions in animal numbers. Net emissions fall by 65-75% by 2050 which is likely to have us on track to meet our goal.

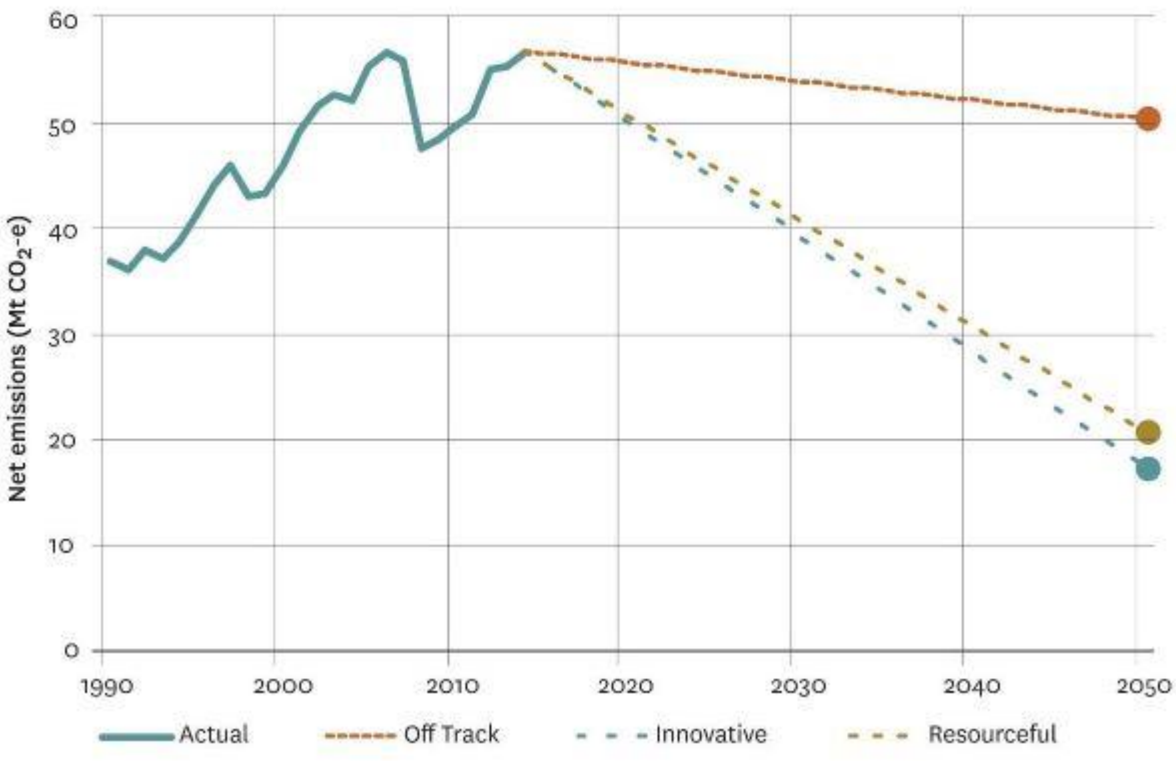


Figure 17. Emissions reductions scenarios (Vivid Economics 2017b)

Overall, Figure 17 above shows we hope to achieve a u-turn in the trend of our net emissions since 1990. The scale of that challenge cannot be overstated. Nevertheless, progress in these scenarios will certainly be achieved by three fundamental physical changes.

- Conversion of marginal farmland to forestry.
- Changes to the structure and methods of agriculture.
- Shift from fossil fuels to electricity and low-emissions energy.

Each change has a significant bearing on our primary food production chain and warrants exploration, particularly putting it in context with historical trends and likely advances in technology.

Conversion of marginal farmland to forestry

The conversion of marginal farmland to forestry to offset and reduce emissions is in my view a very good idea and a very safe bet. It is also comparatively easy and quick to implement.

If only biological emissions from livestock were to be offset by forestry, as recommended in the latest PCE report (Parliamentary Commissioner for the Environment 2019), progress in that regard would be far more transparent and quicker than if fossil based emissions were also offset this way.

Wood as a product of much lower energy intensity than concrete must certainly replace it for many building uses in future. This also favors afforestation. From a biophysical perspective avoiding a monoculture of trees enhances biodiversity, environmental health and aesthetics. A modicum of management can further enhance biodiversity, as demonstrated in the 'rewilding' projects at Knepp and Ennerdale in the UK.

Figure 18. The Ennerdale rewilding project, Lakes District, UK.

A further possibility is to manage wild populations of food animals like deer, sheep or goats within these areas. Like some large game estate models used overseas, occasional and ethical harvest would provide an alternative income stream plus help manage the composition of vegetation. A little more income, a little less gorse, and a tiny bit more methane.

But Still, a reality check before we seek to capitalize on the excitement. Concerted stimulation will be necessary to erect a reforesting effort of 44,000-90,000ha/yr in light of the forestry trend over the last couple of decades. The area going into new plantings now all but completely flaccid after a peak of around 100,000ha/yr a little over 20 years ago. We would need another u-turn.

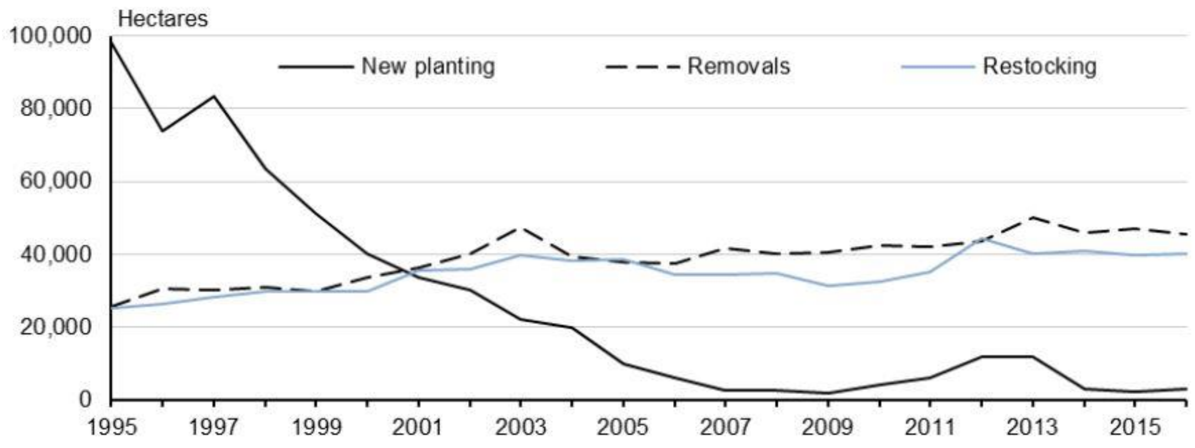


Figure 19. Key drivers of the change in forestry stocks from 1995-2016 (NZStats 2018)

Reinvigorating forestry was discussed in the February 2019 issue of the KPMG Field Notes (issue 447), specifically the challenge of finding labour to plant trees. The starting point was that wages of $400/day were attractive and that surely this would be sufficient. Jessica Berentson-Shaw's point (The Workshop think tank) was that people could not see sufficient long term improvement in their well-being to leave the unemployment benefit in favour of relocating to short term, seasonal, weather dependent work. Those wages alone were not enough, the conclusion being that 'good work that works for people' is needed to improve productivity and wellbeing in the long term. From every angle, this last sentence is at odds with the concept of improving energy return on investment and New Zealand's transition to a low carbon economy.

Changes to the structure and method of farm systems

This has a potentially massive impact on our rural landscape and like forestry, will take a major shift from the trends we have seen in the last couple of decades, especially growth in dairy.

A shift to lower emissions farm management systems would in principle be more toward plant based rather livestock production. Also toward lower intensity and probably with greater diversity.

But how to develop these new systems that farmers can clearly see are still practically sensible and will maintain farm financial viability?

The hypothesis that this development process could be easy has the inherent assumption that the present systems are inefficient uses of land type and production/processing systems. But efficiency of these chains has been refined over many decades in pursuit of optimized financial returns.

The alternative hypothesis, that the process will be at a cost means said cost is met either by the farmer or by the consumer (in some way). The already variable nature of primary production, increasing further with climate change dictates that for consistency, payment (eg offsetting of emissions) should be guaranteed by a more reliable source.

A standardized approach to quantify existing and potential systems in terms of energy use and emissions is essential as an adjunct to economic methods. The ARGOS study (see page 40-41) illustrates EROI's potential to do just this.

Perhaps we could explore species capable of manufacture into alternative protein, meat like products. We already have a global reputation for good meat. Why not trade on that to position to create a reputation for producing these rapidly growing materials with immense potential and ideal positioning with respect to sustainability.

Shifting from fossil fuels to electricity

Our primary production chains depend heavily on a transport system fueled exclusively by diesel and processing which is also mostly fossil fueled.

Replacing diesel with electricity depends on the physical limitations of batteries which are improving and a hotbed of research activity. Today, it seems the reality of electric heavy duty transport is much closer than many would envisage.

The success of electric long haul trucks in the EU was considered technically feasible in a recent analysis which also noted that MAN, Mercedes, Volvo and others have announced sales and series production there. Analysing the total cost of ownership considering wages, maintenance, insurance, fuel, electricity cost, and road charges showed sensitivity was greatest to the price of electricity which is contrary to the popular view that electric heavy duty trucks would not be technically or economically feasible (Earl *et al.* 2018).

A study of electrically powered heavy duty transport in Germany found that on average the battery requirement would constrict the vehicle to 80% of its payload when diesel powered (Mareev *et al.* 2018)

The impact of charging requirements on the grid remains an important consideration.

The impact of shifting something like the processing of milk from coal and gas to more sustainable sources is outlined below for Fonterra, showing it is not without challenge.

The Zero Carbon bill as a starting point

The Zero Carbon bill is an excellent starting point from which to establish a staged process of investment and divestment toward our desired end point. Uncertainty inherent in the overall process is large and we must be careful not to let that choke initial progress which we must accept may require periodic redirection.

It is endorsed in the subsequent related report Adapting to Climate Change. Those authors emphasize the importance of having a dynamic plan with monitoring and reporting, assessing the risks, and establishing stable governance for a long term job. They also note prevention rather than cure, do it once and do it right, work together, and prioritise the vulnerable (Climate Change Adaptation Technical Working Group 2018).

A fitting method to help create the political and economic instruments necessary for transition in the face of much uncertainty is described by Courtney and Lovallo in their paper 'Predicting the unpredictable - bringing rigor and reality to early stage R&D decisions (Courtney and Lovallo 2004). They emphasise a process of identifying what decision makers 'need to believe' in order to make the right investments. Where there are no cases or precedents to inform that belief within their area of expertise, similar examples elsewhere should be sourced. The authors describe this process as a way to increase the rigor of early stage research and development decisions in the face of great uncertainty (they call it true ambiguity). An approach of this kind is worthy of consideration by the climate advisory panel.

Sharpening our focus: EROI and our transition to lower emissions

Probably the most important point to come out of this report is that a biophysical analysis of the change scenarios illustrates a key impact of the Zero Carbon Bill not readily perceived, much less quantified, in the standard economic theory underpinning Vivid Economic's modelling. It is the game changer and here is why. The biophysical results show a substantial reduction in our ability to deliver energy to the New Zealand economy.

A brief description of EROI method

A valuable inclusion in the technical report by Vivid Economics (Vivid Economics 2017b) is table 2 (appendix 3) which details the amount and sources of energy meeting demand in 2014 and anticipated to meet demand in the low emissions scenarios of 2050.

By converting the units in this table from gigawatt hours to joules and using EROI values from the scientific literature (erring on the optimistic side wherever possible) it is possible to derive an EROI value for the scenarios and for 2014. Note that the electricity generation, industry, and transport sectors are described in their table which, while not the entire economy, nevertheless comprise around three quarters of our national energy consumption.

Creating an interactive spreadsheet model for these scenarios at a national scale (appendix 1), for Fonterra (appendix 2) of these scenarios allows experimentation with both the amounts of energy, their sources, and the EROI value of those sources. These three factors are key determinants of the energy landscape in 2050.

Similar estimates for other countries

Naturally these figures should be compared with similar estimates made for other countries. While disappointingly rare, contrasting them reveals interesting points.

Firstly, there are several other national estimates of EROI in the literature, but with varied methodologies which makes their direct comparison indicative rather than definitive yet still very informative. The most recent study by (Brand-Correa *et al.* 2017) combined data for the UK from the Eora Multi Regional Input Output (MRIO) database and International Energy Association (IEA) data using matrix algebra and reported a national annual EROI ranging from 5.6 to 13.8 in the period from 1997-2012. I met with the authors of this paper at the University of Leeds to discuss its implications and came away impressed by the methodology but recognized it was beyond the scope of a Nuffield scholarship.

More importantly, King et. al (2015) explored the relationship between biophysical and economic elements for 44 countries representing over 90% of global GDP from 1978 to 2010. They calculated monetary expenditure on primary energy and NEPR (net external power ratio; energy production/direct energy inputs within the energy industry) which is very much like EROI. Collectively they found that the global NEPR declined from 34 in 1980 to 17 in 1986 before ranging between 14 and 16 between 1991 and 2010 (King *et al.* 2015)). They also found that when expenditure/NEPR was less than 1, the world was in a low growth or recessionary state (King *et al.* 2015).

In the third and final of King *et. al*'s series of papers they say explicitly that "*the turn of the 21st century represents the period of cheapest energy in the history of human civilization (to date)…with important ramifications for strategies to solve future environmental problems* *such as reducing emissions. Rapidly decreasing emissions while internalizing their costs into the economy might increase energy expenditure to such a degree as to prevent economic growth during that transition*" (King 2015).

In an uncertainly remarkable turn of events my EROI value calculated using the energy projections by Vivid Economics (Table 2) for the less ambitious scenario (14.1) lies at the lower margin and for the more ambitious scenario (10), lies well below the margin of values reported by King et al.

Perhaps more importantly, my estimates suggest a decline in EROI of 30 – 50% by 2050 relative to 2014. This means we will need around 7-9% of our total energy to run our energy supply systems rather than the 4.6% we needed in 2014. Combine this with a drop in national energy consumption of between 7-15% depending on the scenario and we are looking at a significant drop in the energy delivered to New Zealand society. But with the expectation that we can double GDP in the same period.

A critical question is whether a tax on carbon dioxide emitted and the right political and economic instruments can generate sufficient money and direct it in a way that successfully neutralizes these impacts.

Table 2. Estimated EROI for key sectors of the New Zealand economy based on proposed low emissions scenarios to 2050 by Vivid Economics

Sector	*Measured in 2014*	*Off track 2050*	*Innovative 2050*	*Resourceful 2050*
Electricity	17.7	17.5	8.9	17.5
Transport	18	13.3	10.4	13.3
Heat and direct energy	21.7	14.3	9.9	14.3
Overall energy delivered	**20.3**	**14.1**	**10.0**	**14.1**

Intensity of GDP per GJ

In Figure 12 we see the energy density of our GDP for the agriculture/forestry/fishing and industry sectors has been virtually constant over the last 25 years at about 2 and about 4 respectively. Transport is not shown but I think we can safely conclude a similar trend exists there.

A key assumption underlying the low emissions scenarios is that this measure of productivity will slightly more than double by 2050 (Table 3).

It is profoundly difficult to fathom how such a spectacular transformation could occur, at least in the primary industries. The last decade in my industry level work across farming, meat processing and animal health strongly suggests our systems have made big strides toward optimization, for both profit and efficiency. They definitely do not still contain sufficient scope to double productivity. Interpreting Figure 12, one can best assume that improvements we have made in our farming and processing systems have been enough to overcome the increase in our costs but not enough to generate large amounts of additional wealth.

Energy and GDP per person

Vivid Economics state their predictions of economic and population growth under their scenarios are broadly consistent with MBIE's Electricity Demand and Generation Scenarios (EDGS) (MBIE 2016), and modelling by the Business New Zealand Energy Council (Business Energy Council New Zealand 2015). Their predictions are an increase in GDP from $211billion to $422billion by 2050 and in population from 4.5 to 6.1 million.

Under the new energy mix in 2050 the scenarios predict a reduction in energy delivered per person of 31-37% (Table 3). Granted this ignores the minor sectors, but overall the point is plain that we will be trying to do more with a lot less. Against the trend of energy consumed per person back to 1960 the scenario appears even more ambitious. Again, this could conceivably be remedied by receiving much higher prices for our products and investing those returns into increasing our energy supply. But importantly the countries consuming most of our produce will hopefully be engaged in their own transition to low emissions which is unlikely to make them amenable to big increases in their price of food.

Table 3. Energy intensity for GDP, GDP per person and energy per person under low emissions scenarios.

	2014	***Off track***	***Innovative***	***Resourceful***
GDP ($)	2.11E+11	4.22E+11	4.22E+11	4.22E+11
Energy (industry and transport, J)	5.94E+17	5.42E+17	5.05E+17	5.53E+17
Population	4.50E+06	6.10E+06	6.10E+06	6.10E+06
$GDP/MJ	$3.56	$7.79	$8.36	$7.64
$GDP/person	$46,956	$69,246	$69,246	$69,246
GJ/person	13.2	8.9	8.3	9.1
% Reduction in energy per person		33%	37%	31%

If we compare the historical trend in energy consumption per person per year (https://www.theglobaleconomy.com/New-Zealand/Energy_use_per_capita/) with Vivid Economics scenarios, which I have increased by 25% to account for the fact that industry and transport account for only about 75% of our total energy consumption we have **Error! eference source not found.**7. It indicates reversal of a trend that has been reasonably consistent until 2000, consistent with the work by King et al (2015), and that in 2050 New Zealanders will be using about the same energy per person as we did in the late 1970s. I scarcely remember life back then but do recall vastly less travel, fewer appliances and less technology and choice in general. Not nearly so glamourous or technologically beguiling as life today.

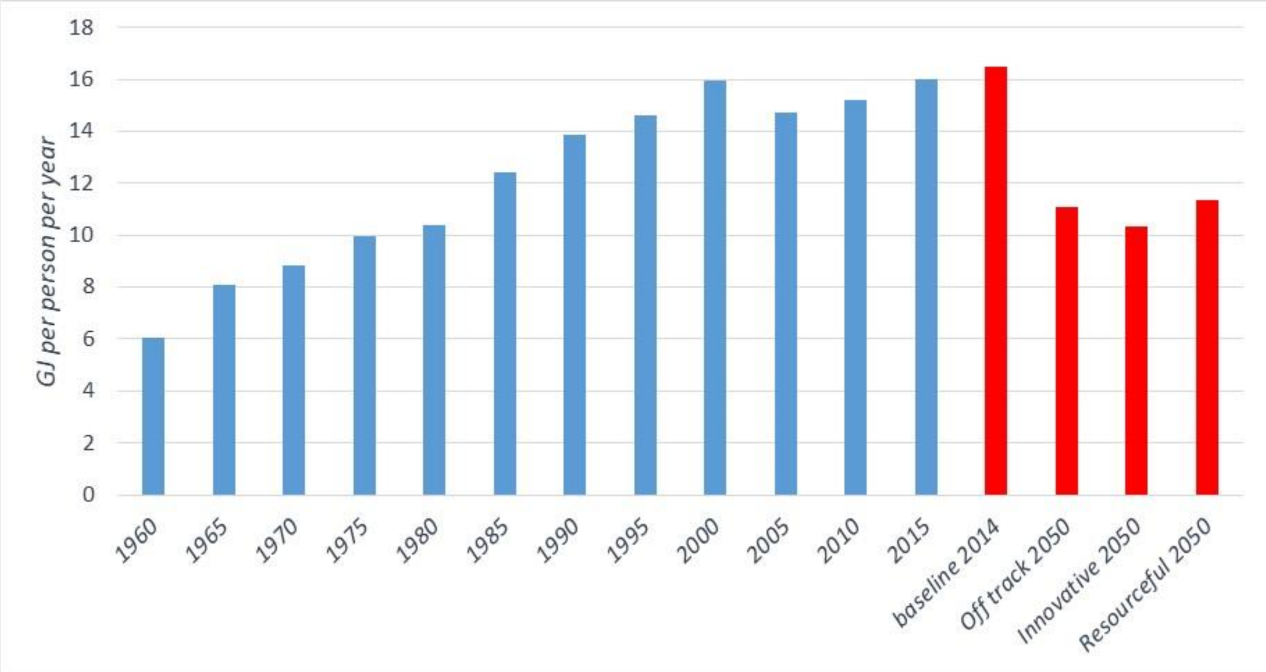


Figure 20. Comparison of the historical trend and scenario projections for 2050 for energy use per person per year

What impact will this have on our primary production systems?

We saw earlier (Figure 11) that agriculture, forestry and our fisheries account for a modest (~5%) of our energy consumption. But we need to consider the full primary food production chain including the energy used on-farm, embodied in farm inputs like fertiliser and in the transport, industrial processing and distribution of our produce to consumers to identify the key risks. There's little point having brilliant energy efficiency milking cows if the downstream processing energy requirements are so high as to make the production chain unfeasible. At a considered guess the primary food chain probably consumes 20-30%, perhaps slightly more, of our national energy consumption.

Transport and industrial processing are critical aspects of our primary food production. Fonterra at least are seriously considering their path to 2050 but no evidence suggested our rural transport system was doing likewise. Fonterra see their divestment from coal and Glencoal Energy Limited as a goal by 2025. They identify electricity and wood biomass as potential replacements for this energy source but note for wood potential issues around security of supply and availability of the necessary volumes. This is a brilliant example of a practical perspective on exactly the issue of EROI for their processing energy (Fonterra 2017a). The indicative values (Figure 5) in this report for coal and for wood as a thermal fuel are around 45 and 10. Similarly the excellent book by Smil (2015) reports a power density for coal (2,000-14,000 watts per meter squared) at least a thousand times that for plantation style wood (Smil 2015). It is no wonder that Fonterra are struggling with how to meet their needs if they abandon coal. Let's explore this a bit more.

Take Fonterra's energy consumption now and in 2050 following Vivid's scenarios with the following assumptions:

- They consume the same amount of energy in 2050 as 2016.

- They replace coal primarily with electricity and biomass – we assume they overcome the security of supply and volume issues.
- They halve (*Resourceful*) or completely shift (*Innovative*) away from gas.
- They halve (*Resourceful*) or completely shift (*Innovative*) away from liquid fossil fuels.
- The EROI value for electricity used in 2050 is that determined for all NZ under the *Resourceful* or *Innovative* scenarios.

Then, apply an EROI perspective:

	2016				
EROI	***Fonterra (petajoules)***	***Consumption***	***Primary***	***Invested***	***Returned***
45	Coal	9.5	9.7	0.21	9.5
20	Gas	7.7	8.1	0.39	7.7
20	Liquid fossil fuels	2.5	2.6	0.13	2.5
18	Electricity	5	5.3	0.28	5.0
15	Purchased steam	4.5	4.8	0.30	4.5
10	Biomass	0.2	0.2	0.02	0.2
total		**29.40**	**30.72**	**1.32**	**29.40**
				EROI	***22.3***

	Resourceful 2050 scenario				
EROI	***Fonterra (petajoules)***	***Consumption***	***Primary***	***Invested***	***Returned***
45	Coal	0	0.0	0.00	0.0
18	Gas	3.8	4.0	0.21	3.8
12	Liquid fossil fuels	1	1.1	0.08	1.0
14	Electricity	14.2	15.2	1.01	14.2
15	Purchased steam	4.5	4.8	0.30	4.5
10	Biomass	5.9	6.5	0.59	5.9
total		**29.40**	**31.60**	**2.20**	**29.40**
				EROI	***13.4***

	Innovative 2050 scenario				
EROI	***Fonterra (petajoules)***	***Consumption***	***Primary***	***Invested***	***Returned***
45	Coal	0	0.0	0.00	0.0
18	Gas	0	0.0	0.00	0.0
12	Liquid fossil fuels	0	0.0	0.00	0.0
9	Electricity	16	17.8	1.78	16.0
15	Purchased steam	4.5	4.8	0.30	4.5
10	Biomass	8.9	9.8	0.89	8.9
total		**29.40**	**32.37**	**2.97**	**29.40**
				EROI	***9.9***

Then graph this to visualize the additional primary energy required to meet their energy needs:

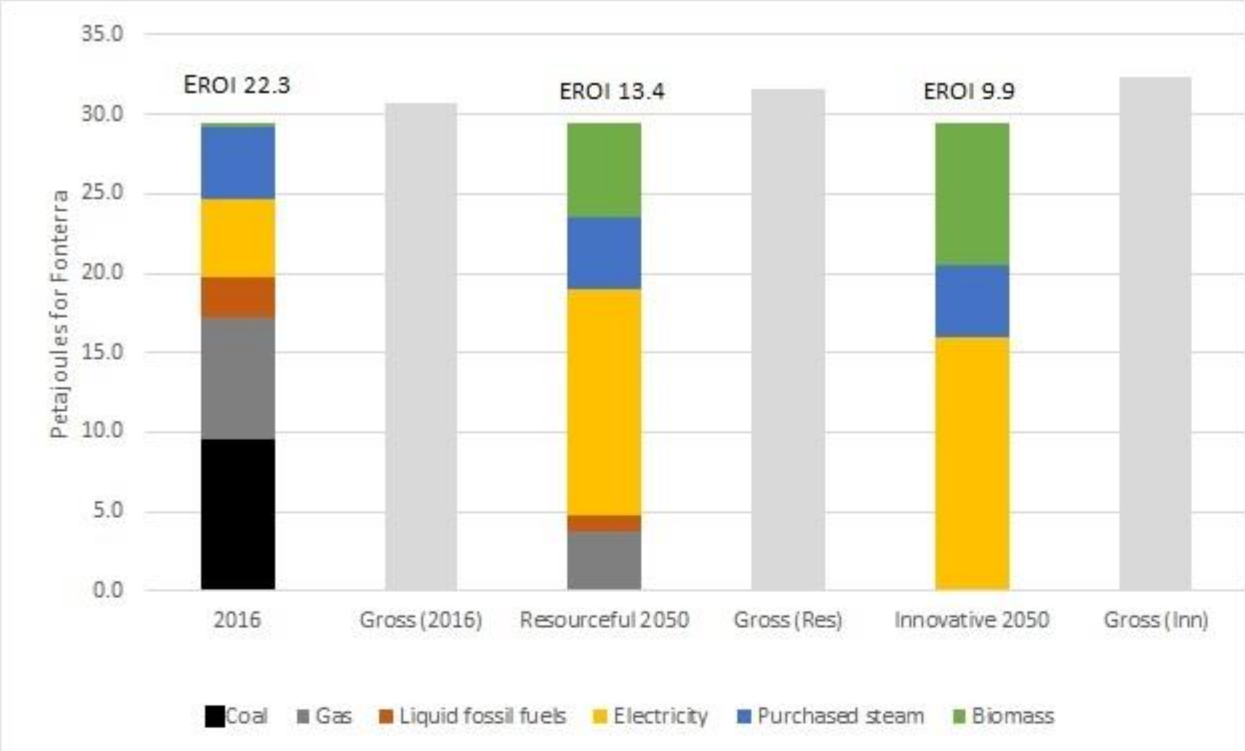


Figure 21. Examples of the impact on EROI from a transition to low emissions energy for Fonterra

The EROI for Fonterra's 29.4 petajoules used for processing in 2016 was 22 (appendix 2). Under the Resourceful and Innovative scenarios it drops to 13 and 10. With the present energy mix 1.3PJ is invested to return the 29.4 they use. With the mix under the Resourceful and Innovative scenarios in 2050, the investment is 2.2 and 3PJ, an increase of around 7% and 10%. While this may not sound like a staggering amount, bear in mind that a) ***EVERY*** industry in New Zealand that shifts away from fossil fuels will be in a similar position and b) I have for simplicity assumed ***NO GROWTH*** in energy consumption by Fonterra between now and 2050. For an indication of the actual growth rate see Figure 13 which shows it doubled in the dairy processing industry to 23.7PJ between 1986 and 2014.

The projections by Vivid have an increase in the amount of heat and direct energy used in 2050 of 14% (Resourceful) and 8% (Innovative) which would accommodate Fonterra under the former but not the latter scenario. But again, I've ignored growth in Fonterra's energy consumption between now and then. If it grew at but a fraction of what it has in the past decade, its demand will exceed Vivid's general expectations for heat and direct energy. We won't go into Vivid Economics' expectation of a drop in energy use in the transport sector of around half.

We need similar analyses for the red meat companies and other significant processing systems for primary produce.

There is not data readily available for the rural transport sector. This too is a critical knowledge gap in our understanding of our production chains.

Cost and investment associated with change

If the general belief, like mine, is that this transition is unavoidable, then equally unavoidable is bearing its cost one way or another. But we are struggling to picture how.

The cost will be substantial, for the primary industries and the rest of the country. The importance of its equitable distribution a focus of the 'just transition' section in the Productivity Commission's 'Low emissions economy final report'.

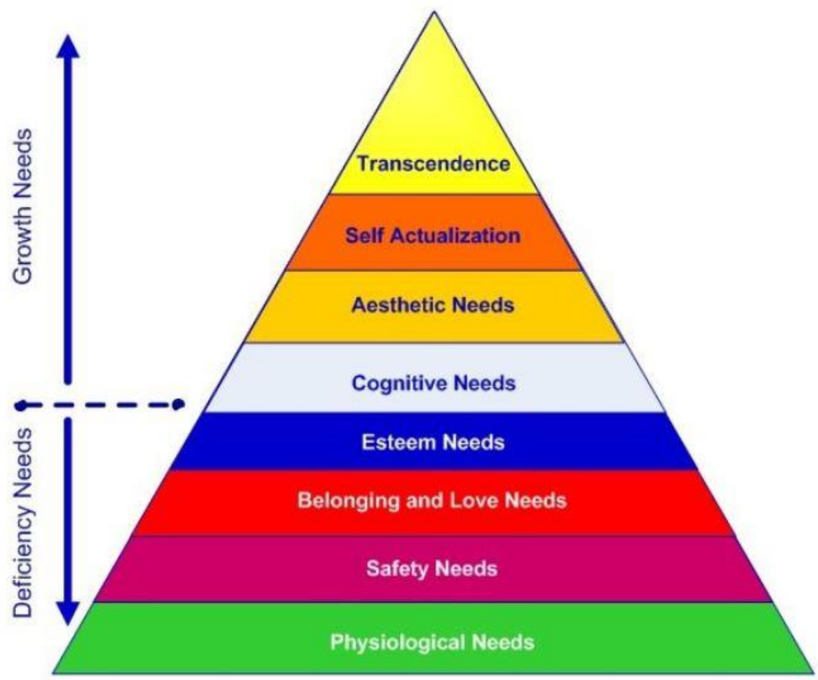
The associated political, economic and social mechanisms are beyond the scope of this report. Still, there are well known points worth mentioning.

To suggest a doubling of GDP along with this transition risks misleading and disenfranchising the public. This is to be carefully avoided to maintain their enduring support in bearing these costs.

A transition to lower emissions systems by our trading partners will place strain on them, like us. Hence their appetite for paying more for our produce, as a means of offsetting the costs of our transition, will be small.

The longer we wait to engage seriously in the transition process the harder and more costly it will become.

Fundamentally the places to look first for major energy savings are those that do not impact upon food, health, education and other core social structures. Things such as air travel, big cars, multiple vehicle ownership, efforts to colonise Mars and unfortunately tourism. The final backstop must be something like Maslow's hierarchy of needs (below).



Visionary work: The Zero Carbon Bill is a fantastic asset

The Zero Carbon Bill is a fantastic asset to New Zealand. It puts us on a very competitive footing amongst other countries racing to mitigate climate change. It initiates discussion on the key issues which is absolutely essential on the proviso that once concluded the necessary and agreed action is taken. It brings people, cultures, and groups together for a common cause. It represents a vehicle for developing our thinking and applying it in policy. Without it and the scenarios that underpin it there would be no context in which to show how important a biophysical perspective is on this process which has thus far been driven only by economics. Fizaine and Court (2016) state, after exploring a minimum EROI below which the US economy is driven into recession, that "*a coherent economic policy should be founded on improving net energy efficiency. This would yield a "double dividend": increased societal EROI (through decreased energy intensity of capital investment), and decreased sensitivity to energy price volatility*".

It is a starting point and a great one at that. Naturally it is a dynamic, iterative thing that will grow and take the shape we need over time.

Critically, it outlines the mechanisms, the laws and institutions (Figure 22) we will need to coordinate, inform and monitor the change we need. This is immensely constructive. The independent Climate Commission is the natural point at which a biophysical perspective can inform our national direction.

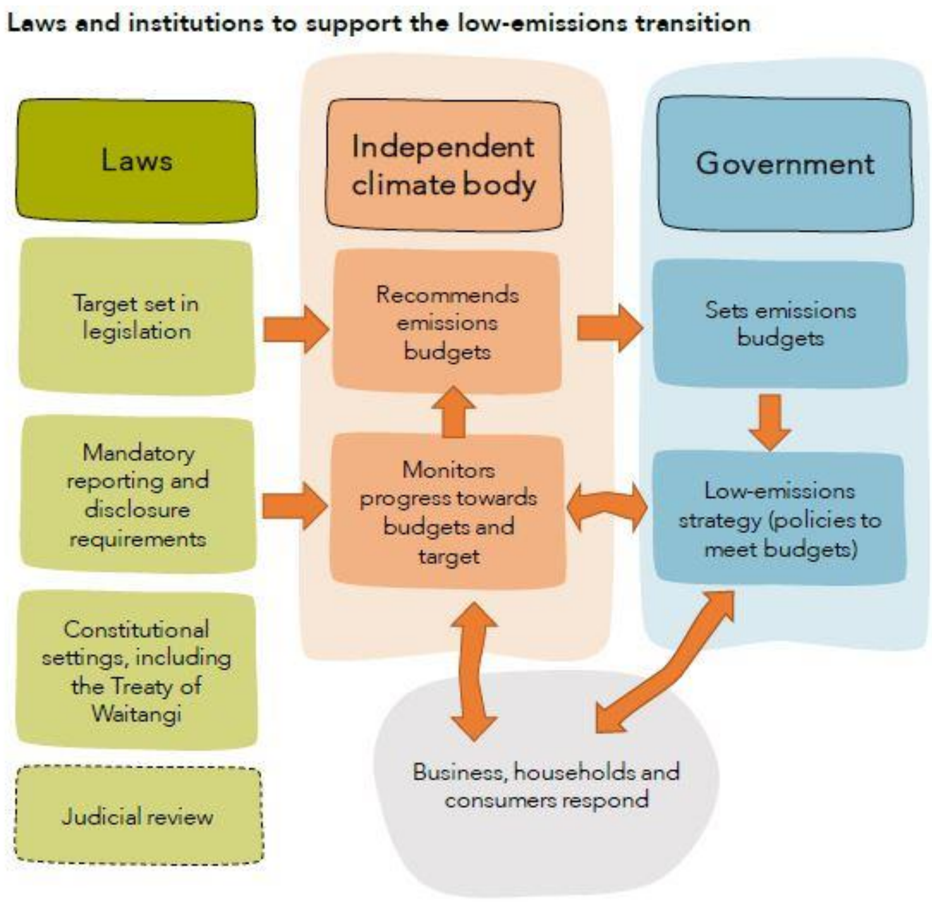


Figure 22. Laws and institutions to support the low-emissions transition

It brings the tough questions to the fore. The debate is already vigorous on the nature and pricing of an emissions trading scheme, the inclusion of farm based emissions in our national profile, and the treatment of short and long lived greenhouse gases.

It creates a place and coordination to bring the efforts of other countries for comparison, review, and maybe even adoption.

Future gazing: Where to now?

Communicate the importance of the EROI relationship to our food systems and those leading our Zero Carbon transition.

A far more coordinated understanding of the energy stocks and flows throughout the full primary production chain is essential in identifying the risks and opportunities in it achieving a low emissions transition.

A biophysical approach and use of Energy Return On Investment methodology in particular are invaluable tools for achieving this understanding.

A 'Transition Institute' should be established to to undertake this work, as recently suggested by Professor Susan Krumdiek, University of Canterbury. The institute should be recommended by the Interim Climate Change Committee as a key means of informing the work undertaken by the proposed Climate Change Commission. Expertise for the Transition Institute is available within New Zealand, and internationally if necessary. Part of my Nuffield journey has been establishing a network with individuals and groups who offer this expertise, for example the International Society for Biophysical Economics and leading research groups focusing on post-growth economics such as the School of Earth and Environment at Leeds, UK.

Applying EROI to optimise farm systems is a great starting point for New Zealand before applying it to other productive sectors. Farmers have a deep and fundamental understanding of the balance and interlinking relationships of the inputs and outputs of the systems that generate their livelihoods. They are also famously adaptive with little more, the story goes, than a piece of number eight wire. This view and mentality are perfectly suited to understanding and implementing an EROI based review of their farm systems.

A critical area for analysis is farm viability in the face of increasing costs of inputs and rural services. With limited scope for individual farmers to pass such costs on to the consumer or wider society to reflect the true price of food a good alternative mechanism needs to be devised. Subsidies for farming have been an unpopular concept since their abolition in the mid-1980s but the reality is they may need a revisit if other options cannot be found.

In following on from this, society and New Zealand's primary food systems will need to determine some points at which decisive action would be taken given that envisaged new tech has not eventuated. There is a tough decision to make here, because the action will need to be more drastic than had the technology emerged.

A framework to quantify and optimise energy use throughout the primary food production chain is a powerful tool. It could be adapted to represent the diverse variety of food chains around the world, but transcending localised issues such as currency, stage of development, production intensity, and infrastructural and capital limitations. In essence, it could be used to energetically optimise any food system. It would equally be of value in less developed countries anticipating large population growth and technological progress as in highly developed nations with intensive production systems looking to simplify back to reduce emissions. It also has substantial utility in the energetic optimisation of systems unrelated to food.

New Zealand has a global reputation for innovation in agriculture that my Nuffield travels show is well deserved. Agriculture is woven into the fabric of our culture. It is beholden on us to be at the forefront of developing ways to make farming a vibrant and harmonious fit with national and international food requirements in the coming decades. We are lucky to benefit from a steady rule of law, low corruption, great resources – especially water, an effective rural service, good infrastructure plus importantly a moderate level of intensification. More so, our 'can do' attitude with a piece of number eight wire is something of immeasurable value in the face of growing uncertainty around the world about the best way to tackle the emissions issue. If there is anyone to pioneer the way to feed nine billion people on a fraction of our current resource base, it's us.

Hand milking, Yoani farm, the Stanley family, Kenya.

Conclusion

The Nuffield Scholarship provided an opportunity to future gaze with leaders in agriculture and see the practicalities of the world's food systems first hand.

It also afforded me an opportunity to investigate EROI methodology that would enable us, from a physical perspective at least, meet the challenge of adapting food systems around the world and within New Zealand to feed the world in 2050 in greater harmony with our environment.

I conclude that the challenge of effectively reducing our emissions to successfully adapt to and limit climate change is greater than we have realised. But still there are solutions.

The Zero Carbon Bill is one such solution, as wonderfully bold as it is forward thinking. But it must be grounded in physical reality as well as economics.

EROI can provide this grounding and a physical means of optimising our energy transition. The Bill itself sets out the means for its inclusion. The methodology is neither onerous nor complex.

Even its simplistic application in this report shows the economic projection of doubling our GDP, particularly by the primary industries, by 2050 is much too optimistic. Physically, the drop in energy use of 10-20% combined with population increase suggests per capita energy consumption similar to what we had in the late 1970s.

Far more insight could be gained with a more detailed analysis.

Our primary food production chains are the ideal place to begin. They are a key driver of our national prosperity and embedded in our culture. Their people have a famously practical and innovative nature along with an inherent understanding of balancing the physical inputs and outputs of their systems. By international standards they operate within stable political and legal environments, free of corruption, and with a moderate level of intensity.

There is a natural progression to use EROI beyond the primary industries in two directions. Firstly, to other parts of the New Zealand economy. Secondly, to the other major food systems, intense and otherwise, around the globe.

A simple model was developed to demonstrate this purely from an energy perspective. It is based on a small but rapidly growing body of scientific literature. It could readily be adapted to parts or all of our primary production systems to optimise a transition to lower emissions systems. Directing the extension and development of this methodology should be seen as an important role for New Zealand's independent Climate Commission. Potentially also to other food systems around the world to enable their comparison from an energy efficiency perspective, unbiased by a blizzard of other economic and political forces.

Recommendations

Overall

Employ Energy Return On (Energy) Investment (EROI) methodology to optimise New Zealand's primary food production chain's transition to lower emissions systems. In so doing create a process to aid similar transitions by a diverse array of food production systems around the world, cognizant of potentially needing to feed nine billion people by 2050.

Step 1: A Transition Institute

Establish a Transition Institute, linked to the Interim Climate Change Committee as a vehicle to undertake Energy Return On Investment modelling. The Institute links the Committee with representatives of primary industries and research entities. Its mission is to bring together expertise readily available within New Zealand, and where necessary internationally to undertake and communicate EROI work. It is funded as an emissions reduction tool, possibly initially by an Agricultural Emissions Fund.

Step 2: An EROI picture of NZ primary production chains

Create a picture (model) of energy flows throughout our dairy, red meat, and other major primary industry production chains. Identify and fill knowledge gaps for a comprehensive picture. Match these inputs against the industry's outputs in terms of emissions, financial returns, and energy (dietary). We now have an energy perspective with which to optimise our curret food systems and to assess potential alternatives.

Step 3: Identify strengths, weaknesses, opportunities

Use the model to explore the impacts of energy related changes on the components of the systems. For example less fossil fuels, less dairy and more forestry, or alternative processing fuels. Measuring the impact both financially and energetically and on emissions. Weaknesses and risks are identified and communicated. There follows dialogue on optimal configuration of these systems for balancing profitability, production, other elements of sustainability along with further measures determined important by stakeholders.

Step 4: Implementing change to lower emissions systems

The Transition Institute communicates findings to the Independent Climate Commission to inform the Commission's recommendations to the government on emissions budgets. The industry representatives from the Institute coordinate these changes to their respective sectors who in turn drive deployment and integration with other sustainability initiatives, for example water quality. The outcome is more energetically resilient and lower emissions food production chains, along with a powerful energy-food modelling resource.

Step 5: Exporting our expertise to the world

We then work with a party such as the Committee On World Food Security within the Food And Agriculture Organisation along with the International Society for Biophysical Economics to adapt our model to represent common food systems throughout the world, from small scale mixed farming to mega-food systems, and alternative protein systems.

We can then compare their ability to produce dietary energy and financial returns, plus quantify their relative potential to produce more food for minimal additional input, showing the path to globally optimised food production. Intuitively, one would think the greatest gains stand to be made in the least developed systems. But such systems are typically in less developed areas where priorities do not include this kind of modelling.

EROI when applied to world food production stands to make a critical, evidence based and exceptionally robust contribution to optimising food production both within New Zealand and internationally. This is a fundamentally critical step in our efforts to mitigate and adapt to the impact of climate change.

Hazelnut dust, George Packing Company, Oregon, United States of America

Appendix1: EROI spreadsheet for Zero Carbon scenarios

EROI	Petajoules	2014 Primary	2014 invested	2014 returned	Off track 2050 Primary	Off track 2050 invested	Off track 2050 returned	Innovative 2050 Primary	Innovative 2050 invested	Innovative 2050 returned	Resourceful 2050 Primary	Resourceful 2050 invested	Resourceful 2050 returned
	Energy delivered	623	29	594	580	38	542	556	51	505	592	39	553
	Heat and direct energy	*406.2*	*17.9*	*388.3*	*462.6*	*30.2*	*432.4*	*460.3*	*42.4*	*418.0*	*475.5*	*31.2*	*444.4*
* scenario value	Electricity	148.9	7.96	140.9	234.7	12.66	222.0	291.4	29.37	262.0	236.3	12.76	223.5
25 12	Direct fuels	257.3	9.90	247.4	227.9	17.53	210.4	168.9	13.00	155.9	239.3	18.40	220.8
	Transport	*216.7*	*11.4*	*205.3*	*117.8*	*8.2*	*109.5*	*95.4*	*8.4*	*87.1*	*116.7*	*8.2*	*108.6*
* scenario value	Electricity	0.2	0.01	0.2	36.3	1.96	34.3	42.6	4.29	38.3	35.2	1.90	33.3
18 12	Direct fuels	216.5	11.39	205.1	81.5	6.27	75.2	52.9	4.07	48.8	81.5	6.27	75.2
	Electricity generation	*160.5*	*8.6*	*151.9*	*290.5*	*15.7*	*274.8*	*339.5*	*34.2*	*305.3*	*292.2*	*15.8*	*276.4*
12	Coal	7.1	0.55	6.6	2.9	0.22	2.6	0.0	0.00	0.0	2.9	0.22	2.7
6	Gas	27.6	3.94	23.6	25.8	3.68	22.1	7.5	0.31	7.2	25.9	3.70	22.2
80	Hydro	87.8	1.08	86.7	106.0	1.31	104.7	106.0	1.21	104.8	106.0	1.31	104.7
10	Geothermal	27.2	2.47	24.7	67.7	6.15	61.5	71.1	2.76	68.3	68.1	6.19	61.9
10	Solar	0.1	0.01	0.1	7.9	0.72	7.2	14.2	13.40	0.8	7.9	0.72	7.2
22	Wind	8.2	0.36	7.9	76.1	3.31	72.8	137.2	15.43	121.8	77.2	3.36	73.9
14	Biofuels	2.3	0.15	2.1	3.9	0.26	3.6	3.5	1.12	2.3	3.9	0.26	3.6
10	Other	0.2	0.02	0.2	0.3	0.02	0.2	0.0	0.00	0.0	0.3	0.02	0.2
total			**8.58**	**151.89**		**15.67**	**274.8**		**34.22**	**305.3**		**15.79**	**276.4**
Avg EROI (electricity)				*17.7*			*17.5*			*8.9*			*17.5*
Avg EROI (transport energy)				*18.0*			*13.3*			*10.4*			*13.3*
Avg EROI (heat & direct energy)				*21.7*			*14.3*			*9.9*			*14.3*
Avg EROI (overall energy delivered)				*20.3*			*14.1*			*10.0*			*14.1*
Percent change in EROI relative to 2014							*30%*			*51%*			*31%*

Appendix 2: EROI spreadsheet for Fonterra energy use

	2016				
EROI	***Fonterra (petajoules)***	***Consumption***	***Primary***	***Invested***	***Returned***
45	Coal	9.5	9.7	0.21	9.5
20	Gas	7.7	8.1	0.39	7.7
20	Liquid fossil fuels	2.5	2.6	0.13	2.5
18	Electricity	5	5.3	0.28	5.0
15	Purchased steam	4.5	4.8	0.30	4.5
10	Biomass	0.2	0.2	0.02	0.2
total		**29.40**	**30.72**	**1.32**	**29.40**
				EROI	***22.3***

	Resourceful 2050 scenario				
EROI	***Fonterra (petajoules)***	***Consumption***	***Primary***	***Invested***	***Returned***
45	Coal	0	0.0	0.00	0.0
18	Gas	3.8	4.0	0.21	3.8
12	Liquid fossil fuels	1	1.1	0.08	1.0
14	Electricity	14.2	15.2	1.01	14.2
15	Purchased steam	4.5	4.8	0.30	4.5
10	Biomass	5.9	6.5	0.59	5.9
total		**29.40**	**31.60**	**2.20**	**29.40**
				EROI	***13.4***

	Innovative 2050 scenario				
EROI	***Fonterra (petajoules)***	***Consumption***	***Primary***	***Invested***	***Returned***
45	Coal	0	0.0	0.00	0.0
18	Gas	0	0.0	0.00	0.0
12	Liquid fossil fuels	0	0.0	0.00	0.0
9	Electricity	16	17.8	1.78	16.0
15	Purchased steam	4.5	4.8	0.30	4.5
10	Biomass	8.9	9.8	0.89	8.9
total		**29.40**	**32.37**	**2.97**	**29.40**
				EROI	***9.9***

Appendix 3: Vivid Economics Net Zero Technical Report, Table 2, page 8

	2014	Off track 2050	Innovative 2050	Resourceful 2050
Energy delivered (GWh)	164892	150259	140288	153592
Electricity (total)	39,206	70,926	83,414	71,347
Heat and direct energy	107866	120103	116106	123436
Electricity	39,148	61,668	72,784	62,089
Direct fuels	68718	58434	43318	61347
Transport	57,026	30,156	24,185	30,156
Electricity	58	9528	10630	9258
Direct fuels	56,968	20,898	13,555	20,898
Electricity generation (GWh)	42,193	76,330	89,769	76,782
Coal	1,831	736	0	741
Gas	6,567	6,132	1,795	6,168
Hydro	24,076	29,076	29,076	29,076
Geothermal	6,871	17,089	17,954	17,190
Solar	17	1,996	3,591	2,007
Wind	2,192	20,226	36,456	20,518
Biofuels	585	1,007	898	1,013
Other	54	68	0	69

And converted from gigawatt hours to joules:

Converted to PJ	2014	Off track 2050	Innovative 2050	Resourceful 2050
Energy delivered	593.6	540.9	505.0	552.9
Electricity (total)	141.1	255.3	300.3	256.8
Heat and direct energy	388.3	432.4	418.0	444.4
Electricity	140.9	222.0	262.0	223.5
Direct fuels	247.4	210.4	155.9	220.8
Transport	205.3	108.6	87.1	108.6
Electricity	0.2	34.3	38.3	33.3
Direct fuels	205.1	75.2	48.8	75.2
Electricity generation	151.9	274.8	323.2	276.4
Coal	6.6	2.6	0.0	2.7
Gas	23.6	22.1	6.5	22.2
Hydro	86.7	104.7	104.7	104.7
Geothermal	24.7	61.5	64.6	61.9
Solar	0.1	7.2	12.9	7.2
Wind	7.9	72.8	131.2	73.9

Biofuels	2.1	3.6	3.2	3.6
Other	0.2	0.2	0.0	0.2

Stuart Barden's son, Ausquest, Kenya

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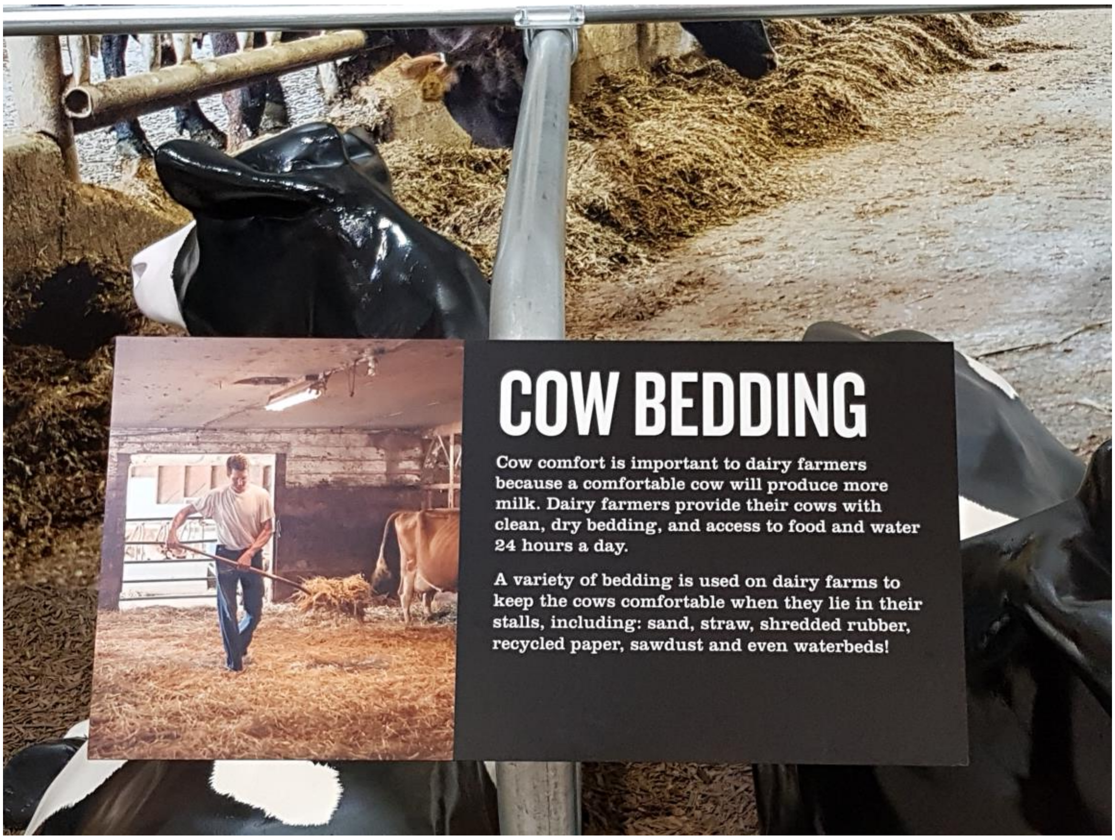
Kitchen table, Eburru, Kenya

David Stanley and Turi McFarlane discussing Temple Grandin inspired cattle yards

Old cattle yards

Chinese manufactured motorcycles, affordable at $800 transforming Kenyan transport

Nut processing factory, South Africa



Dairy promotion centre and ice creamery, Oregon

Dairy farming, Oregon, USA

Precision agriculture on Chernozem soil, Ukraine

Rural traffic, Ukraine

Storage shed, Ukraine

The old and the new, Ukraine