Enabling a transformation to a bioeconomy in New Zealand

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Abstract

The 2009 OECD call for a global transition towards a bioeconomy has resulted in a number of nations adopting national or regional strategies to develop their bioeconomy. New Zealand's large biological resource base and a well-established cultural heritage in farm production, including a comparative advantage in livestock production, should make it well-positioned for bioeconomy-based wealth creation. However, ecological and societal limits require the current economic farming model to be re-evaluated. Using a transformation lens, in conjunction with a bioeconomy framework, this paper discusses what is required for New Zealand to transform into a fully functioning bioeconomy. The paper identifies several critical elements of a bioeconomy that are either not fully developed in New Zealand, or are clearly lacking, most notably finance and governance, and the need for public engagement in policy. It concludes that to enable New Zealand to realise the potential opportunity the bioeconomy offers, a more integrated and cohesive primary sector model is required that goes beyond tweaking the existing (livestock and primary production based) regime towards supporting and developing new niche production sectors, based on a clear vision jointly conceived with wider society.

1. Introduction

The use of the term bioeconomy, also referred to as the 'bio-based economy', 'bio-based society' and 'knowledge-based bioeconomy' (Mukhtarov et al. 2016; Scarlat et al. 2015) has escalated since 2005 (Bugge et al. 2016; Glössl, 2015). The bioeconomy is promoted variously as a means to create wealth; address a multitude of environmental pressures through the reduction and re-integration of waste streams (circular economy); generate new value from waste; and create myriad economic opportunities through the science, design and development of production and processing facilities and entirely new integrated and resilient industries. Broadly the term bioeconomy can be defined as comprising "those parts of the economy that use renewable biological resources from land and sea – such as crops, forests, fish, animals and micro-organisms – to produce food, materials and energy" (EU Commission, n.d). As a related concept to the green economy or the circular economy, a key feature is of byproducts re-entering the value chain to be incorporated in the production of higher value goods and services. Until 2005 the term was primarily used in relation to scientific and research activities focused on biotechnology (van Leeuwen et al. 2013), and many references to the bioeconomy maintain a strong biotechnology focus, but it would be misleading to suggest the bioeconomy is solely related to biotechnology.

A more detailed examination of the use and definition of the term bioeconomy reveals different interpretations across regions, countries and sectors (Staffas et al. 2013). However three harmonising elements can be identified, namely the sustainable use of natural (biomass) resource and a reduction in waste and pollutants; coupled with a transitioning away from dependence on fossil fuel resources; to achieve economic and social growth, and employment.

Beyond the conceptual development, what a functioning bioeconomy might look like in practice and the implications and opportunities for existing primary sector industries and wider society, is less clear. While the vision of a bioeconomy appears to enable solutions to some of the more intractable environmental global challenges, alongside generating new and lucrative ways to earn money from the primary sector, a transition to a bioeconomy would need to proceed cautiously to ensure wider societal goals and values are also being met. For example, biotechnology forms a component of many bioeconomy strategies and public concern regarding its safety, ethics and equity can be considerable. The ill-conceived promotion of the first generation of biofuels highlights the importance of critical evaluation to avoid unintended consequences of the widespread adoption of new policies, targets or technologies (Mohr and Raman 2013). While subsequent biofuel development has addressed many of the inefficiencies, conflicts between resources for food and fuel are likely to continue (e.g. Brigezu et al. 2012). In addition, concerns have been expressed around the implications of a bioeconomy for indigenous knowledge, ownership of resources, equity, and the extension of market forces to biological resources. The latter has been described variously as the '*extension of capitalism to life itself*', *'the neo-liberalisation of nature'* and '*biocapitalism*' (Birch 2010, Levidow 2015). Therefore, transparency regarding the foreseeable implications of a bioeconomy is desirable (Priefer et al. 2017).

We examine the case of New Zealand (NZ), a country with an historically strong economic base in primary production, to explore some of the changes required in order to transform to an innovative, integrated bioeconomy. New Zealand arguably already has a 'bioeconomy' in the literal sense of the term, as much of the economy is based on the primary sector (just over half of export earnings (New Zealand Treasury 2016)). An emerging literature distinguishes between the 'old bioeconomy' and the bioeconomy, differentiating between the traditional primary sector production and the more innovative and non-fossil fuel dependant bioeconomy (Kniuksta, 2009). We use the lens of a country at an early stage of its bioeconomy development, to draw on the experiences of other countries further down the path of transformation, and to synthesise the emerging academic literature around the bieconomy. Thus the article is of much wider relevance than to NZ alone, although our goal is also to catalyse thinking and conversation within the country. Our analysis includes an assessment of the current gaps in key areas of the bioeconomy; the choices that need to be made and the trade-offs associated with these choices.

In the NZ context there are two main drivers behind the transformation from the old economy to the bioeconomy: the economic driver of developing the value chain beyond commodity production; and the environmental and social drivers of improved sustainability and integration across society. While a growth model based heavily on the primary sector has served NZ well for many decades, it is beginning to show its environmental limits (OECD 2017), and society appears increasingly concerned with the environmental impacts from a continued reliance on the primary sector in its current form

(Jay, 2007; Blackett and Le Heron, 2008; Parliamentary Commissioner for the Environment 2015). Despite these constraints, the NZ Government has a goal of doubling primary sector exports from 2012 to 2025[1], but how this could be reached without significant environmental costs in the current system, is unclear. Therefore, at first glance, NZ appears to be well-placed to contribute to and gain from this new paradigm.

In the following section the methodological approach adopted is described, followed by a discussion on the major drivers and international approaches to developing a bioeconomy. We apply a framework from the literature to identify the areas of strengths and weaknesses in NZ's bioeconomy development to date, and discuss areas that could be strengthened and ways forward in order to fulfil NZ's potential as a leader in a global bioeconomy.

2. Methodological approach

The analysis in this paper is a mixed methods approach, based primarily on a review of relevant literature, complemented by a small survey and consultation with experts within the field of bioeconomic research in NZ.

Articles reflecting the current bioeconomy discourse and literature on innovation and transformation were sought using research databases (e.g. Scopus, WorldCat etc.) with an emphasis towards selecting bioeconomy and transition review articles, or those articles where national bioeconomy and biotechnology strategies were discussed. In addition to this scientific literature, international and regional policy strategies were reviewed, including relevant NZ policy documents.

To supplement the desk research, and to assess the perceptions of those involved in the primary sector in NZ, a short survey was conducted at a national symposium of a funding body - "Our Land and Water National Science Challenge." This involved distribution of paper surveys to roughly 100 participants prior to a presentation by one of the authors on the topic of the bioeconomy. Respondents were simply questioned on their familiarity with and expectations around the concept of the bioeconomy in a NZ context. Forty-seven completed, useable surveys were returned. In addition, two experts in the existing bioeconomy in NZ were consulted: A semi-structured phone interview was conducted with one, with questions asked regarding the development of the bioeconomy in NZ to date, and constraints and challenges in developing it further, while the other was asked to provide feedback on an early draft of this paper.

3. Drivers and international approaches to bioeconomy developments

3.1 International approaches to the bioeconomy

The OECD (2009) emphasised the importance of coordinated policy action in bioeconomy development, to address the drivers of increased population, energy demand and an imperative to reduce greenhouse gas emissions. Since then at least 34 national bioeconomy strategies have

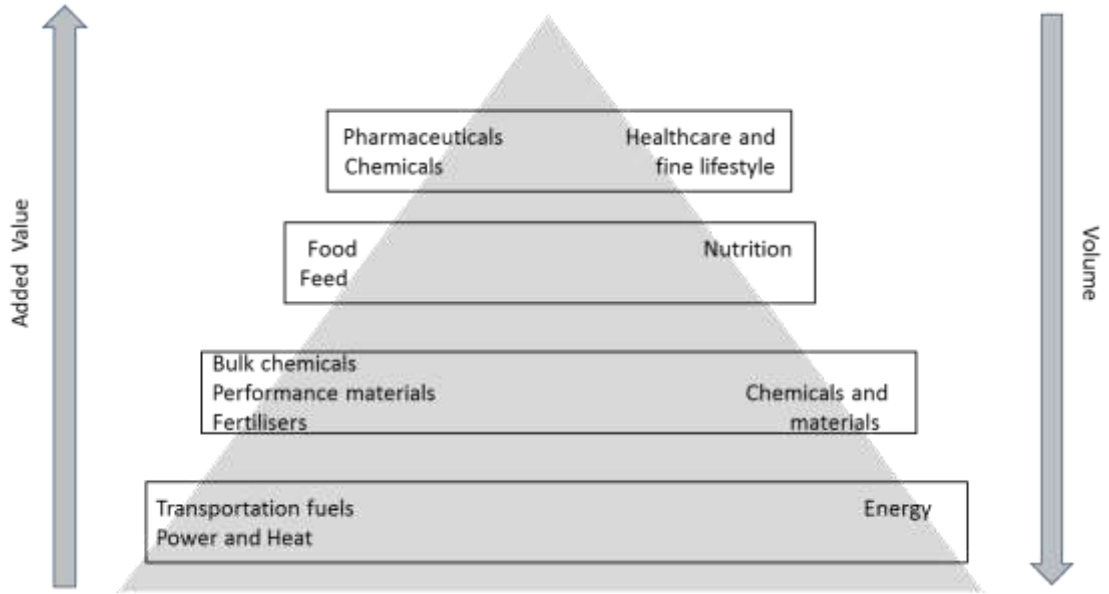
[1] https://www.mpi.govt.nz/exporting/overview/growing-exports/

emerged (Glössl, 2015), with a range of priorities, aspirations and varying levels of detail. Bugge et al. (2016) identify three visions for a bioeconomy: the 'bio-technology vision', the 'bio-resource vision' and the 'bio-ecology vision', where the first two are significantly influenced by an engineering and natural sciences perspective, and may be complementary to some extent, compared to the more ecological outlook of the third. These differing visions and their underlying aims, objectives, and priorities are apparent in the country strategies, often together with the aspiration of becoming the 'global leader' in the bioeconomy, although both the emergence of global leadership and the economic benefits are still to be realised.

Several studies and policy documents attempt to characterise through a framework the role and position of the bioeconomy in relation to the rest of the economy (e.g. Maciejczak 2015; Bosman & Rotmans, 2016). A related concept is the green economy or the circular economy that promotes the reduction of wastes by providing a whole-supply-chain viewpoint of resource inputs and outputs. While the frameworks differ according to the type of bioeconomy envisaged, a number of commonalities exist between many of the frameworks: at least some degree of circularity, with waste streams from one element forming inputs into other elements, although the extent of circularity varies between frameworks. The UK bioeconomy strategy (HM Government, 2015), for example, has a particular focus on waste minimisation and its framework is fully circular.

Others refer to or incorporate aspects of the bio-cascading principle (c.f. Bosman & Rotmans 2016), such as that depicted in the biomass value pyramid in Figure 1, where a highly developed [bioeconomy] "*uses green resources first in the production of food and feed and only afterwards (or simultaneously in the case of waste products) for chemicals, materials and energy*" (Burrill Media, 2014 pg 11). Generally, the premise states that the bioeconomy should aim for the top elements (pharmaceuticals and healthcare products), utilising the wastes from these processes for food, chemicals feed and energy. In reality however, countries that are already strong in biological economies such as farming and forestry tend to take the opposite approach, looking at ways to move their resources up the pyramid into higher value production.

Figure 1 Bio-cascading principle. (Bosman and Rotmans, 2016)



Some frameworks recognise the role that social structures, particularly governance, finance and societal expectations play in the functioning of an effective and innovative bioeconomy (e.g. van Leeuwen et al. 2013, Maciejczak 2015).

From our review of international strategies, we identified seven major drivers of bioeconomies, with some overlap found between them:

1. Increasing value: As countries look to build economic growth, they are increasingly driven by the potential to increase the value obtained from bio-products. Asian economies have typically approached this driver through an 'industrial biotech' pathway (D'hont, 2015). Biomass is reduced to its constituent chemical and molecular components and reassembled into more useful products, e.g. genetic markers, pharmaceuticals and nutraceuticals.

2. Addressing resource pressures: Human population growth and global economics are driving movement towards resource efficiency in terms of environmental footprints, and job creation in changing markets. For example, the Netherlands will exhaust its natural gas supply within the next two decades, and is looking to biowaste from the food processing industry as a secure alternative energy source (Bosman & Rotmans, 2016).

3. Energy security: An emerging focus on low-carbon biofuels and bioenergy as a means to gain energy security and reduce fossil-based energy has led the EU, Malaysia, India and Korea, for example, to develop bioenergy-based bioeconomy strategies. Malaysian R&D on biodiesel from palm oil began as early as 1982, in part driven by energy security concerns, and rural economic development goals (D'Hont 2015). India imports 80% of its crude oil needs, and has turned to bio-based energy to reduce its dependence on imported oil (Government of India 2012; D'hont 2015). With an expected five-fold increase in India's demand for electricity over the next 25 years, bioenergy is imperative to meet this need and growth targets of 7-9% of GDP (Burrill Media, 2014). Similarly, Korea imports 97% of its energy, all from fossil fuel resources and aims to become more energy independent through replacing 30% of its fossil fuels with biofuel (D'Hont 2015).

4. Job creation and economic growth: As conventional bio-based industries become an increasingly smaller share of countries' GDP, there is an incentive to turn to a bioeconomy to boost GDP. For example in India, where the proportion of GDP from agriculture has fallen from 30% to 14.5% over the past 25 years, there is the goal of growing the biotech industry from its current $4.3 billion value to more than $100 billion by 2025 (Burrill Media 2014). In Canada and Finland, the downturn in long-standing pulp and paper markets has seen the forest sector under pressure to turn to new markets for economic growth (Agriculture and Agri-Food Canada 2015; Ebadian 2017, Bosman & Rotmans 2016; Davies et al. 2016). Malaysia expects to grow its bioeconomy from the current 2 to 3 per cent of GDP to 8 to 10 per cent of GDP by 2020, creating 170 000 jobs from a $16 billion investment (D'hont 2015). In the UK, there are some instances of creating local employment through small-scale production of new materials (Bauen et al. 2016; Biovale 2015). In the USA, the bioeconomy has been promoted as a mass job creator. Similarly, in 2011, the United States introduced a 'Biopreferred Program', to facilitate the development, transformation and expansion of markets for bio-based products and creating jobs in rural America (McWolf 2014; Golden et al. 2015 pg 8).

5. Addressing climate change: Despite the academic rhetoric regarding the possible benefits in reducing GHG emissions through a bioeconomy (HM Government 2015), beyond the EU bioeconomy strategy and action plan, no other approaches to the bioeconomy appear to be driven by the need to address climate change directly. Although, there appears to be an implicit assumption that by replacing fossil fuels, climate change will be addressed.

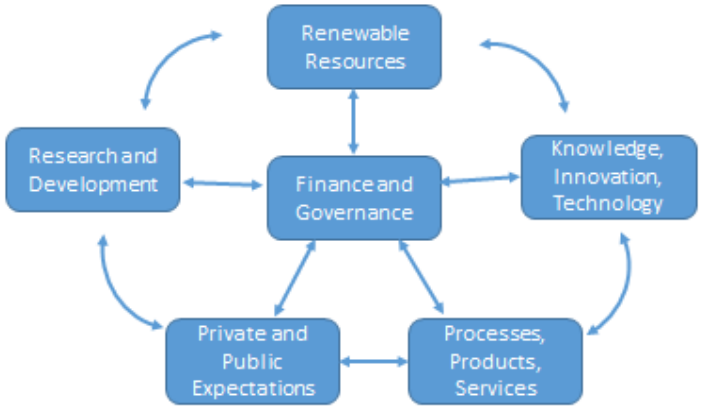
6.Waste reduction: Breaking down waste streams into useful elements in order to manufacture new biomaterials or biofuels is another driver of the bioeconomy, addressing both efficiency concerns as well as plastic pollution and landfill space (State of Green 2015). The UK in particular has a focus on harvest residues, process residues and byproducts and biogenic compounds from consumer and industrial waste (HM Government 2015; EPRS 2014).

7. Improving health: A further enabler for the bioeconomy is the need to improve people's health. India, for example, has a focus on improving life expectancy and reducing infant mortality (Government of India 2014) through biotechnology advances. Already producing 60% of the world's vaccines (Burrill Media 2014), India is well placed to achieve this. Australia also have a vision to be a biotechnology mogul through a strong reputation in the Western world for its biopharmaceuticals and biochemical sectors (Australian Government 2017).

4. Conceptual framework

While some frameworks contain many elements in a relatively complex structure, Maciejczak (2015) provides a simple but effective representation of a fully integrated bioeconomy, with six interconnected elements, represented in Figure 2.

Figure 2: Conceptual framework for bioeconomy analysis (based on Maciejczak 2015).



According to Maciejczak's framework, finance and governance sit in the centre of the framework with the five 'elements' of a bioeconomy encircling it. The elements consist of: renewable resources; knowledge, innovations, technologies; processes, products, services; private and public expectations, effects and results and; research and development.

More specifically:

- *Finance and Governance* refers to national level policies, strategies, direction, financing and funding available for R&D and implementation and adoption of bioeconomy technologies, systems etc.
- *Renewable resources* refers to primary sector raw materials, including land, water, solar and wind, and the existing primary sector commodity outputs (timber, fibre, agriculture, horticulture, aquaculture).

- *Knowledge, innovations, technologies* refer to industrial innovation and technologies developed primarily in the private sector that inform other elements.
- *Processes, products, services* captures the processes (e.g. biorefining, novel processing) that transform the renewable resources into products and services for the bioeconomy, including food, feed, chemicals, bioenergy, materials.
- *Research and development* represents research in Universities and Research Institutes, i.e. fundamental research that underpins both the technological developments and drives innovation and thinking.
- *Private and public expectations, effects and results* refers to the role of society in a bioeconomy, its preferences and concerns, as well as private companies and their interests.

Maciejczak (2015) presented the five elements on the outside as forming a circular process with the arrows in a clockwise direction, however we suggest that the interactions are in fact bi-directional, and have therefore adapted this concept for our analysis.

We use the framework in Figure 2 as a basis for assessing the state of NZ's bioeconomy in the following section. Each of the six elements (renewable resources; products and processes, knowledge and innovation; research and development; public and private expectations and governance) are discussed and the extent to which they are developed in the NZ context assessed. Finally, a 'traffic-light' rating of green, amber and red according to their level of development is provided, where green represents a good, comprehensive, strategic development in that area, amber reflects work occurring in the space but lacks a strategy or direction, and red indicates a lack of activity in this area.

5. Current state of the bioeconomy in New Zealand

5.1 Renewable Resources

On a per capita basis New Zealand has significantly more land resources (2.4 ha per person) than many countries (Coriolis, 2016). Table 1 shows that in terms of land cover it has a higher percentage of forest (39 per cent) than the OECD average (31 per cent). New Zealand also has access to significant marine resources due to its extensive coastline. In addition it has significant freshwater resources and associated high levels of water availability per capita (Coriolis, 2016) and low water stress overall, although with significant regional differences in resource availability and quality. Competition between land for food or fuel is not a pressing concern in NZ – although social and cultural barriers to moving from one type of production to the other may be significant (Wreford et al. 2017).

Table 1 Selected Resources of New Zealand compared to OECD average (OECD 2017)

Indicator	NZ	OECD
Land Area (000 km^2)	263	34,341
● Percentage Forest Area	39	31
● Percentage Permanent Pastures and Meadows	40	23
● Percentage Arable and Permanent Crops	2	12
● Percentage Other Land (built up and other)	19	33
Water Stress (abstraction as % of available resources)	1	10

Renewables as percentage of total energy	40.5	9.6

The abundance of natural resources is reflected in New Zealand's energy balance. Almost 80% of electricity generation is from renewable sources, including hydro, geothermal, wind and biomass. Renewables comprise 40 per cent of the overall energy balance (when energy for transport etc. is taken into account) compared to an OECD average of only just over 9 per cent.

New Zealand also has the advantage of a natural environment that is highly conducive to year-round pastoral agriculture, an absence of major agricultural diseases, and the potential for year-round production (New Zealand Treasury, 2016), however, pressures on these resources are increasing. According to the OECD (2017), the country is experiencing unprecedented levels of water scarcity and quality issues, very high per capita greenhouse gas (GHG) emissions, threats to biodiversity, significant erosion, as well as pressure on housing, and waste and water infrastructure.

Nonetheless, the area of land suitable for pastoral agriculture, and the social and cultural capital that exists in this sector, is striking. Interestingly, the international literature only mentions the use of animals in the bioeconomy peripherally, primarily in regard to the negative ecological effects of meat-dominated nutrition or the exploration of possible alternatives to animal protein (Priefer et al., 2017). However, a different livestock production niche model may enable an easier transition to a bioeconomy that leverages the current resource base and level of expertise. We discuss the role that synthetic animal protein may play later in this article, however the strength of NZ in livestock production may provide an opportunity for novel contributions to the bioeconomy from this area.

5.2 Processes, products, services

Directly building on the available resources, the agricultural, horticultural, forestry, mining and fishing industries play an important role in New Zealand's economy, particularly in the export sector. Overall, the primary sector directly accounts for around six per cent of real GDP with agriculture directly accounting for four per cent and forestry a further one per cent. The primary sector also contributes just over half of New Zealand's total export earnings (New Zealand Treasury 2016). Pastoral farming dominates the agricultural landscape in New Zealand with dairy farming the predominant agricultural activity (accounting for around 45 per cent of operating income in agriculture), followed by beef and sheep farming.

In addition to the development of the long-standing New Zealand agricultural commodities, many farm diversifications from the 1980s to the present times have allowed the development of an expanded small-grower network of niche products and markets (Bowie 2016; Griffiths 2015; The Agri-Business Group 2015). A number of these (for example kiwifruit, manuka honey and merino wool) have become mainstream and have also developed their own subset of high-value bioproducts.

The manufacturing of products from the biobased primary industries forms a major component of total manufacturing activity in New Zealand, particularly dairy and meat products and wood and paper

(New Zealand Treasury 2016). In addition to the direct contribution of the primary sector, the processing of food, beverage and tobacco products for both domestic and export markets accounts for a further four per cent of GDP. Downstream activities, including transportation, rural financing and retailing related to primary production, also make important contributions to GDP.

A notable feature of the New Zealand economy is the significant contribution of the biobased industries to exports. For example, meat and dairy products, the most important agricultural exports, together accounted for around 38% of total merchandise export values in the year ended 30 September 2015 (New Zealand Treasury, 2016). Forestry and logging are also the basis of an important export industry with around 70 per cent of wood from the planted production forests exported in a variety of forms, including logs, wood chips, sawn timber, panel products, pulp and paper and further manufactured wooden products (New Zealand Treasury 2016), representing around 10 per cent of New Zealand's total merchandise exports. Fishing is also an important merchandise export earner, with 90 percent of New Zealand's commercial seafood production being exported. With fishing quotas fully allocated, forecast future growth in wild capture seafood exports is modest. Stronger growth is expected in aquaculture exports as salmon farm capacity expands. Overall New Zealand's Food and Beverage exports grew from $10 to $24 billion between 2004 and 2014 (Coriolis 2015).

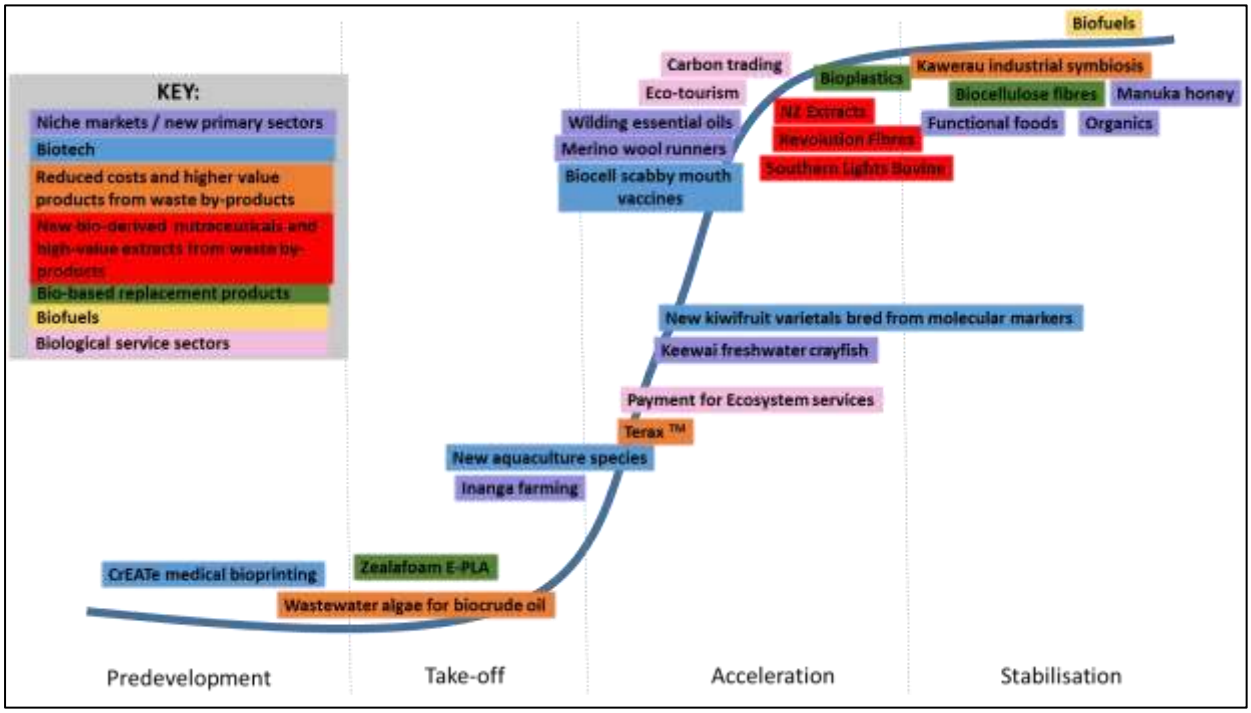
Beyond the traditional primary production, the development of the NZ bioeconomy has built on its strong primary production base and grown through areas such as genetic markers and livestock breeding programmes; and in new biomaterials, derived firstly from plant-based materials and waste fibres and effluent from wood processing industries, and latterly expanding to utilise other primary based sectoral waste, as well as municipal bio-waste streams.

Scanning across the 'old' bioeconomy and the emerging bioeconomy landscape of the primary sector, we see a mosaic of pathways at different stages of development and potentially different lifespans. These consist of:

a. A large production base from conventional biological sectors, often with commodity products as the major revenue component.
b. A growing number of smaller high-value derivatives sitting within the existing biological sectors. These have focussed on either niche product markets or credence attributes and labelling. (e.g. Lewis Road Creamery and sheep dairy; Organics)
c. Newer primary sectors that have become relatively well established - e.g. Deer; King salmon; Kiwifruit; Wine; honey; and merino clothing
d. New (aquacultural) livestock sectors that are emerging - Keewai; Scampi; Geoduck.
e. Biomaterials, particularly wood plastic composite and bioplastics developments (some emergent industries and offshore licensing)
f. A number of biotech companies have been created to develop and commercialise nutraceuticals and biosciences such as Zylem, Keraplast and the BioPolymer Network Ltd.
g. Pilot plant developments to turn industrial waste into high-grade extractives eg terex

New Zealand has developed all seven of these key bioeconomic pathways, to commercial production and launch, with a science and technology basis to support continued development, particularly in biowaste conversion (algae and sludge); biomaterials; and functional foods or plant varietals from gene markers. These pathways are mapped onto Figure 3 according to their position on a multi-phase transition curve (Rotmans et al. 2001).

Figure 3: Examples of New Zealand bioeconomy mapped against their multi-phase position



This demonstrates a number of transitions that are either accelerating or stabilizing. The spread of activities across multiple phases indicates a good depth for a New Zealand portfolio adaptation towards a bioeconomy transition, as well as a range of developing depth in bio-derived pharmaceuticals and the emergence of new primary sectors.

5.3 Research and development

In addition to universities and independent research organisations, Crown [Government] Research Institutes (CRIs) were established in their current form in 1992 and each of the seven CRIs is aligned with a productive sector of the economy or a grouping of natural resources. The intention is that CRIs

support their sectors to innovate and grow, although in recent years there has been a recognition of the need for interdisciplinarity and collaboration.

The R&D aspect of the bioeconomy in New Zealand revolves around a collaboration called the Biopolymer Network Ltd, a joint venture between three CRIs focused on science and innovation in the bioeconomy. In the absence of a national bioeconomy strategy or vision universities and CRIs are approaching it from different directions and sector specific focus.

With the main sectors contributing to the bioeconomy being primary industries, the environment and health and manufacturing, each receives funding from a range of sources. The majority of Government R&D expenditure goes to the primary sector, followed by the environment and then health and manufacturing. Industry provides considerable funding to the manufacturing sector, while health receives the most funding from the higher education budget.

Whilst there is significant activity within R&D in the bioscience area, those operating in the sector identified a range of barriers to their development. Access to capital was seen as a barrier by nearly 60 per cent of organisations surveyed (StatsNZ 2012), suggesting that finance for research and development could be a key barrier to New Zealand realising significant growth in this area. Other significant barriers appear to be linked to availability of suitably skilled staff.

5.4 Knowledge, innovation, technology

New Zealand's bio-based economy has developed and innovated through adaptation to changing global market signals since the liberalisation in the 1980s. The bio-based sectors have been largely free from government policy constraints that have dictated the direction of travel in many other countries of the world. For example, within the EU, the Common Agricultural Policy has played a significant role in determining what and how primary agricultural products have been produced. However, this freedom means that New Zealand does not have a publicly funded knowledge transfer system and relies on sectoral based institutions (such as DairyNZ and Beef+Lamb) as well as private sector providers.

If we consider commercialization of the sector as an element of innovation, the bioscience survey also highlighted the challenges faced by bioscience entities in commercializing their products (StatsNZ 2012). As with research and development, access to capital was seen as a significant barrier to commercialisation by nearly 50 per cent of organisations. Regulation was also frequently cited as a barrier. Interestingly, marketing factors were also important including the distance from market (cited by 24 per cent of organisations in 2011) and lack of distribution channels (cited by 22 per cent of organisations).

5.5 Public/private expectations

This element incorporates the public and private expectations of a bioeconomy, including the social acceptability of different elements. In New Zealand, an increasing rural-urban divide has developed

over the past decade (c.f. Bennett 2017), with a perception that the dairy industry intensification (e.g. Grant 2017), though contributing much to the economy, has negative environmental impact. Some argue that water quality and quantity have reached crisis point, with unprecedented numbers of rivers unfit for swimming and localised outbreaks of *campylobactor* in municipal drinking water (c.f. Sutherland 2016). This emerging reality is in stark contrast to the image NZ has historically traded on 'clean and green' and '100% Pure' and continues to leverage (Miller et al. 2014). Despite the 'dirty dairy' image, both rural and urban lifestyle and industry is responsible for the pollution, with little curtailment on irrigation and water-use restrictions. In parallel with its strong primary sector base, particularly from livestock production, NZ has a very high proportion of greenhouse gases originating from this sector. The difficulty of reducing livestock emissions without affecting production is well-documented (FAO 2006) and although NZ has made great strides in reducing the emissions intensity of its production (e.g. Beukes et al. 2010), as a signatory to the Paris Climate Change Agreement, absolute emissions must also be reduced considerably. The current system shows few indications of options to reduce absolute emissions in any meaningful way. This disconnect between public expectations and other elements of the current 'bioeconomy' represents a shortcoming in the status quo system, and if the negative perception spreads internationally could threaten NZ's export markets.

Until 2016 there had been no discussion of biotechnology and social acceptability when the Prime Minister's Chief Science Advisor released a speech on the topic (Gluckman 2016). The most recent comprehensive work on social acceptance of biotechnology (where biotechnology has been defined as a "multidisciplinary set of scientific techniques which can be used to modify living organisms, make products or address health issues (Cook & Fairweather 2005) took place in the early 2000s. Cook et al. (2004) found that biotechnology is a public concern, however, there are differing levels of concern: high concern about biotech and GM in agriculture, but medical uses are more acceptable. In a similar study, Cook and Fairweather (2005) found high (68%) levels of acceptance for biotech in growing fuel crops, but only 26% acceptance in farm animals. They further note that future attitudes towards biotech may become more positive, but slowly, as these attitudes are resilient and resistant to change. The MPI (2017) Primary Sector Science Roadmap, highlights throughout that there is a pressing need to examine public acceptance (or social licence) of biotechnology before its introduction. Understanding and aligning with societal preferences will be critical to ensuring a lasting and constructive bioeconomy.

In the survey conducted for this study, most respondents were familiar with the bioeconomy in the context of bioenergy (57%), and food production (51%). Less than half were familiar with the bioeconomy in the context of biotechnology (38%), 34% were familiar in the context of innovative products from primary production, and 15%[2] were not familiar with the term.

Respondents were also asked to rank a number of potential benefits from a bioeconomy. The results of this ranking are illustrated in Figure 4, with 1 being equal to most important and 6 to least important. The highest ranked potential benefit was a shift from fossil fuels and associated

[2] Total is greater than 100 as respondents were not limited to selecting only one option

environmental effects (2.82), followed closely by higher value products (2.98) and a resource-efficient society (3.05). Ranking slightly lower in terms of priorities was less waste to landfill (4.02) and improved health and nutrition (4.28). Further down in priority was energy security (5.23) and lowest ranked of all was job creation (5.51). Respondents were able to add their own suggestions for further potential benefits, which included 'global leadership', 'boosting NZ's sense of identity', 'harnessing Iwi (Maori) knowledge', 'reciprocity/care for all of life', 'connection between urban and rural communities' and 'holistic role in the primary sector', which seem to touch on a more social/cultural dimension that is not captured in the categories provided.

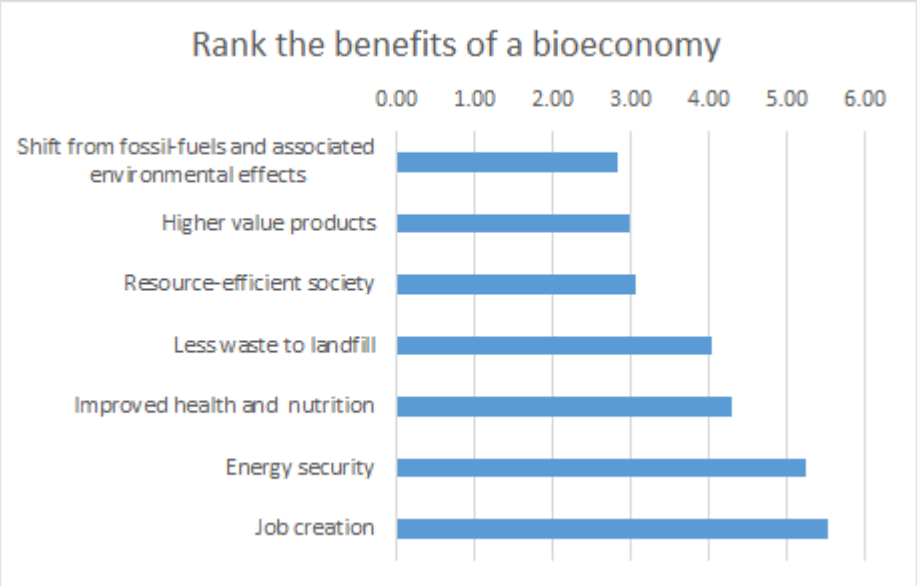


Figure 4: Participants' ranking of the potential benefits from a bioeconomy

It is worth noting the high-ranking that a shift from fossil fuels received, as the current developments in the bioeconomy in NZ do not place particular emphasis on this benefit. Although, higher value products were ranked second (and only marginally below fossil fuels), and this better reflects where most of the focus is currently in NZ.

Thinking about the producers' perspectives and their likelihood to transform systems, a Survey of Rural Decision Makers (Brown 2015) aimed primarily at those involved in primary industries, shows that overall, rural decision-makers lean towards being willing to take risks with new ideas, however they are more evenly split between being the first to try something new and remaining with the status quo. The survey found that rural decision-makers have limited plans to change land-uses, but they do have plans to intensify sheep and/or beef, prime cattle/bull beef and hay/silage/baleage (Brown 2015). Those involved with deer, grazing and other stock are more willing to be early adopters with new ideas. Forestry (primarily farm foresters) was a notable exception towards being less willing to be the first to try something new (Brown 2015).

5.6 Governance/Finance

Before 2017, there appears to have been very little strategic development towards a bioeconomy in NZ, despite the international momentum and rhetoric around the bioeconomy, and the significant

potential for NZ to contribute. The Royal Society of NZ report 'Facing the future: towards a green economy for NZ' (Royal Societ 2014) contains some commonalities with a bioeconomy, but is limited in its vision. In 2009 NZBio, an industry organisation created to highlight New Zealand's achievements and capability in biotechnology, produced a report 'Driving Economic Growth through Bio-based Approaches' (NZBIO 2009), with an ambitious vision for NZ bio-economy, but seven years later there appears little progress in this regard. In contrast to international expansion of a bioeconomy based on a strong policy basis, often in response to environmental protocols, it appears most of the advancement in New Zealand towards a bioeconomy via R&D and niche production is driven by the private sector.

The Primary Sector Science Roadmap (MPI 2017) is the first government document specifically referring to the bioeconomy, with the sub-title "Strengthening New Zealand's bioeconomy for future generations". This Roadmap will provide direction to strategy and investment decision-making by funders, R&D providers, industry and government departments. Thus, the Science Roadmap is not a policy or governance instrument per se, but a guide for funding stakeholders in establishing strategies, policies and investment decisions with respect to the primary industries and bioeconomy. The Roadmap is a direct response to criticisms that there was no widely shared view or direction of the future of science and technology capability needs across the primary industries (p. 6). The MPI (2017) Roadmap acknowledges that beyond pure technological changes, the science produced through this strategy will be used to provide evidence for policy and decision-makers to strengthen and integrate the primary sectors towards a bioeconomy.

In 2009, NZBIO hosted a bioeconomy industry summit to discuss the 2009 OECD report and to discuss challenges, opportunities and future steps required to create an optimal bioeconomy in New Zealand. The 2009 summit noted that some regulatory and tax changes have been made in the early 2000s to encourage investment, such as relaxing overseas investment rules, removal of barriers to accessing offshore venture capital investment, and allowing CRIs to use more effective commercialisation routes for their IP (NZBIO 2009). Further recommendations were framed around improving the investment environment, however, there was no recommendation for coherent government policy or alignment of sector strategies.

There have been some regulatory changes focused on biotechnology specifically, including developing policy coherence in order to make it easier to undertake biotech research and development (NZBIO, 2008; 2009). In 2011 the New Zealand government convened a business-focused "Green Growth Advisory Group" to examine the much broader remit of greening New Zealand's growth, premised partially on a bio-based economy, but leveraging off of New Zealand's 'clean, green, 100% pure' image.

With respect to capital and finance, the NZBIO 2009 summit noted that 85% of biotechnology funds come from companies' own funds, whether sourced internally or externally. These funds are limited, and the summit noted that New Zealand capital markets are small and do not provide an exit for investors, and that there is a significant lack of incentive for capital contribution from the private sector domestically and internationally. Shifts within global industries after the 2008 financial crisis

have made it difficult for New Zealand bio-based industries to source investment capital (NZBIO, 2008).

From an enterprise perspective, very little capital has been raised through initial public offerings; significant amounts have been raised through secondary offerings. Interestingly, the report notes that investment in biotechnology from the private sector fell by two million dollars over the previous two years, however venture capital funding has been increasing slightly. These facts support the earlier finding that many bioscience organisations found access to capital to be a barrier to both development and commercialisation of new products and services.

5.7 The New Zealand bioeconomy

Having examined the six key aspects of a bioeconomy in NZ, we uncover three aspects that stand out: NZ has strength in Renewable Resources; but weaknesses in terms of Finance and Governance (governance particularly) and weaknesses in Public and Private Expectations. Strengths and progress exist across other elements but gaps remain.

Figure 5 illustrates our assessment of the current state of NZ's bioeconomy. As well as the individual components it is important to note that a further gap not illustrated in this figure are weaknesses in terms of the arrows (integration).

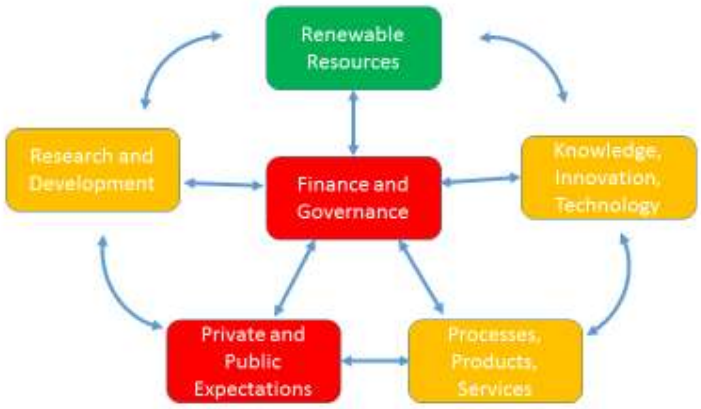


Figure 5: An assessment of the current state of NZ's bioeconomy where Green = strong; Amber = mixed, strengths in some areas but areas still to be developed; Red = weak.

5.8 What is NZ's position in relation to other countries?

Having outlined the current situation in New Zealand it is useful to reflect on how it relates to other countries. Much of the debate around the effectiveness and implications of transformation to a bioeconomy internationally (see Priefer et al. 2017) centres around the availability of land for

production beyond food. In this sense NZ is in a strong position domestically, but increasing global demand for food may prioritise food production ahead of other uses. Compared to other countries, it is clear that many of the strengths and weaknesses of New Zealand in the old economy can also be related to the bioeconomy. For example, its small domestic market and distance to other markets may mean that specific aspects of the bioeconomy that require close proximity to the end-user are unlikely to be feasible for NZ. That said, if higher value products can be derived from the bioeconomy this may help offset some of the 'costs' associated with remoteness. This could be of major advantage to NZ when compared to countries with access to large markets (either domestically or within close proximity). With the old economy it may be argued that the key success of New Zealand has come from being a low cost provider of commodities (meat, milk powder, logs, etc) to other countries. Similarly the question is whether NZ can successfully develop its own value added bioeconomy or whether it becomes a feedstock provider for other countries as they develop their bioeconomies. An advantage that New Zealand has is that it is less constrained by cumbersome policy than many developed economies (as dictated by the CAP in the EU and the Farm Bill in the US). In terms of creating the right environment for new and innovative businesses international comparisons place New Zealand high both in terms of innovation[3] and also in terms of ease of doing business[4].

6. Discussion

From the analysis in the previous section, it is apparent that NZ has considerable strengths in some areas of the bioeconomy framework, particularly in the bio-physical resource and related expertise. It is a bio-resource rich nation with an already well established 'bioeconomy', in contrast to many other countries where the availability of sustainably produced biomass presents a critical limit to their own bioeconomies (Priefer et al. 2017). In some ways biobased products could integrate easily across the historical primary industries. Whilst many countries aspire to being global leaders in the bioeconomy, New Zealand could be in an almost unique position to achieve such a leadership position within any bioeconomic transformation, given the level of available resources and the associated level of expertise in the primary sectors. Moving away from commodity-based old-economy products to more innovative bioeconomy production may also assist in meeting the country's international climate obligations. Strengths to leverage include the historical farming and plant-based land use practices, and the research capability built around these; the unique indigenous flora and faunal base alongside industries with quality pest and disease-free status; the breeding and genetic quality; and the innovation system - agile, collaborative and fast-adopting of modern biotech science (NZBio 2017).

There are however some important gaps observed in the existing NZ model to forming a coherent, sustainable bioeconomy. 'Finance and Governance' was assessed in the previous section as being in the red category, with a weak presence in the current bioeconomy development in NZ. The 'Public and Private Expectations' element was also found to be weak, and the other elements had aspects of strength but were not fully developed. Building on the evidence discussed in the previous section, here we identify a number of critical factors relating to these two weak elements and provide some reflections on where NZ could capitalise on its strengths.

[3] www.globalinnovationindex.org
[4] http://www.doingbusiness.org/rankings

6.1 Finance and Governance

We deduce that the largest barrier to the strategic development of a bioeconomy in NZ is the inertia caused by lack of a cross-sectoral government bioeconomy strategy, with clearly identified goals, indicators and incentives. Without this high-level direction, developments are likely to remain fragmented, sectorally based, and possibly also conflicting. Incremental, fragmented approaches are not likely to be sufficient to transform current systems and in a direction consistent with societal values. Incoherent sectoral approaches may undermine developments in other areas and lead to unintended consequences. Furthermore, the linkages between the elements in our framework are arguably as important as the elements themselves, and again require some facilitation to develop. We discuss possible mechanisms to develop and strengthen these linkages.

System and sectoral integration

A bioeconomy is based upon the principle of circularity and integration and a continued sectoral mentality will impede innovation in this area. Sector bodies exist to promote the development and continuation of their own sector, and in NZ research bodies (CRIs, mentioned previously) are formed to support the existing sectors. A strong bioeconomy would require cross-sectoral innovation platforms with a focus on longer term transformational change (Mukhtarov 2016; Dolata 2009). Without a national initiative to bridge the sectors and integrate across, change from these current 'silos' is unlikely. At the individual level, some forms of agriculture do practice a 'whole-systems' approach, typically biodynamic and organic ventures, often at a small scale, although increasingly sectors are adopting such practices (e.g. wine). While there are recognised behavioural barriers to changing systems or increasing diversity (e.g. Wreford et al. 2017), more mainstream adoption of these principles may be possible, but would require cost efficiency in production.

At the larger scale, industrial symbiosis engages separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products. Waste by-products from one industry are used by another in a co-dependent economic relationship for mutual benefit. In a NZ example, the principle has been adopted between local wood processors, geothermal energy production, government, R&D, indigenous and logistics and service agencies in the Kawerau region. Industrial symbiosis 'involves the exchange of materials, energy, water, by-products, services, knowledge, intellectual property, social capital and networks to reduce resource costs, increase revenues and create new business opportunities' (Industrial Symbiosis Kawerau, n.d.). Industrial symbiosis models between disparate and distant industries have proven effective within the UK, for example. This circular economic model may prove beneficial for other regional economies within New Zealand.

Support of emerging niches

Many of the potential contributions to a bioeconomy will begin as niche production, with the niches ultimately driving the system forward in a new direction (Schot and Geels 2008). The previous section described the development of a number of niche products in NZ already. For niche production to

succeed it requires a market-backed approach (Bowie 2016; McLeod, 2009). Those succeeding in the new global model have a deep understanding of the differentiating attributes of their products, innovations, customer relationships and brand story, and actively take on the role of marketing these to the world, rather than leaving it to third parties and producer bodies. The bioeconomy of the future will need to be focussed around a strong marketing strategy (such as demonstrated by Wine NZ for example).

Supportive infrastructure in NZ in terms of dedicated R&D programmes into emergent sector issues (such as the native freshwater crayfish, kiwifruit, aquaculture and honey production) has proven essential to enable quality production. In addition, government support and incentives for firms to penetrate emerging sectors (such as biotech grants, R&D consortia and even afforestation grants and support for new vineyard plantings) can allow the sectors to operate at scale, and support establishment and credibility. Support is required across sectors, especially from mainstream producers, for niche industries to enter the mainstream. Kilgour (2008) reflects that kiwifruit growers found it difficult to become established as other vine sectors did not take the opportunity seriously, leading to lack of support and lack of vine growing leverage.

The multi-level perspective of Schot and Geels (2008) has been criticised for having a bias towards incremental change within the incumbent actor clusters, and an inability for niches to break through to regime level if they are not within a sectoral-based niche. The ability to scale out sits with industry governance, compared with scaling up, which can occur at the individual firm level. Scale up requires capital investment, but scaling out can also occur through applications of a technology into a larger sector with similar need. There may also be significant resistance to change, and fear of loss of power and market dominance from within the regime, who may restrict the ability of a niche to break through. Experience from Finland (Bosman and Rotmans 2016) finds that the rhetoric around transition to the bioeconomy comes largely from existing actors, while the most radical innovation comes from niches. Often those technologies and innovations most able to elicit structural changes are those that sit across different sectors (returning to the role of sectoral integration). Dolata (2009 pg 1069) states that *'the more a new technology affects the existing patterns of economic activity in a given sectoral system and the less it is able to be implemented, used, and efficiently exploited within its existing institutional and organizational framework, the greater the pressure on the sector and its actors is to undergo significant change*'. Cross-cutting technologies such as digital agriculture and nanotechnology have the capacity to bring about significant changes across all primary sectors.

An effort to diversify the sectors away from sheep and beef; poultry; apple and kiwifruit and wine production into a number of new species, varietals and consumer-driven markets provides a wider platform for a selection to expand and grow the bioeconomic resource base. In forestry, the historical dependence on single species (radiata pine) and single market production (tangible forest products) is expanding into ecosystem service provision (recreational tourism and adventure parks, carbon trading and riparian and catchment level water quality payment for services), bio-polymer development, as well as diversified production from under-cropping.

Infrastructural change

Over recent decades, NZ has consolidated its production, processing and manufacturing infrastructure in centralised hubs (E. McCrae pers. comment). In a decentralised bioeconomy, processing and manufacturing would be much more regionally distributed, in smaller and more agile clusters, with the employment and added-value remaining in the regions. This approach is advocated by some authors internationally (Bruins 2012) in response to proposed large scale biorefineries in regional hubs centred around existing trading ports, such as Hamburg or Rotterdam (Hennig et al. 2016). Given the long, thin geography of NZ's land mass, this decentralisation could provide efficiency gains as well as regional development opportunities. Such a move would represent a considerable shift from the current situation and is unlikely to occur without high-level support and direction.

In addition, a large challenge to overcome in order to transform the biological industries is the poor infrastructure and low degree of venture capitalism. New Zealand public-sector investment is mostly in land and buildings rather than company shares, so raising capital for projects can prove a challenge. New Zealand, though not small in area, is limited in population base and may lack the ability to finance and adequately scale at global levels. For a bioeconomy to develop the issue of how to be viable with smaller scale must be addressed.

6.2 Developing a shared vision of a bieconomy

Many of the examples of existing bioeconomy developments in NZ focus on technical developments and innovations (c.f 'practical' sphere put forward by O'Brien and Sygna 2013), a focus typical of work across sustainability and innovation arenas (O'Brien and Sygna 2013). The lack of engagement and direction from the political realm has been highlighted in previous sections of this article, and here we emphasise the importance also of the social aspects of individuals and communities. To date in NZ there has been no public engagement or debate regarding a bioeconomy, in part due to the lack of strategic direction. However the bottom-up developments have also not considered a wider societal needs, nor has the rhetoric considered the implications for different parts of society.

Mukhtarov (2016) notes that it is not enough to only look at 'how' a bioeconomy transition should occur within a sector, but also around the examination of intra- and inter-sectoral tradeoffs in any transition to a bioeconomy, and to what extent such a transition is viable and appropriate, requiring public debates and the engagement of multiple stakeholders in developing an appropriate transition pathway. Research funding and development are recognised as being important tools for stimulating the bioeconomy for example, but deciding on the research areas and types of knowledge to be funded is more controversial (Priefer et al. 2017). Unless stakeholders from across society are included in discussions, implementation pathways for the bioeconomy will be limited from the beginning (with a likely focus on socially contested technologies) (Birch et al. 2014). Without a national level vision and examination of all the implications, society will not be able to form an informed perspective and voice their opinion. Furthermore, without an open and transparent public discourse around the potential benefits, as well as possible negative implications, with the genuine involvement of all sectors of

society, the undirected individual developments risk alienating the wider public. The full benefits of a bioeconomy will not be realised without wider societal support.

A transformation of any kind can be threatening to existing industries. NZ's existing primary sectors are arguably generally conservative, and may regard aspects of the bioeconomy with scepticism. Given the level of financial, cultural and social capital invested, this is unsurprising, and responding to accommodate disruptive technologies poses some threat to well-established business models and thinking. Supporting the niche industries and individuals in a transition and working together may assist the system as a whole in achieving a greater degree of engagement and enthusiasm. For example, synthetic meat, grown in a laboratory rather than by farming animals, may form an important part of a bioeconomy, having the potential to transform the way society perceives and consumes meat, with considerably lower environmental and animal welfare implications (Tuomisto, 2011). The implications of a growth in this production of meat are significant for NZ, which specialises in animal husbandry and has a cultural history of farming. By engaging with the technology proactively, NZ may be able to leverage its livestock breeding programmes, so that the stem cells and tissue fibre used in the manufacture of clonal cell-grown meat comes from the healthiest and tastiest animals. The proliferation of cultured meat may also result in much higher values for farm-grown 'real' meat.

The implications for indigenous values must also be openly engaged with: New Zealand's cultural heritage as a nation, particularly for indigenous peoples, has been forged to a large extent on its natural resource base – cultivating the land and harvesting the waters feature within the indigenous (Maori) folklore. Many plants and fauna are considered 'taonga' (treasure) species due to both historical and cultural significance. In order to ensure an equitable sharing of resources, and the benefits derived from these, a number of countries internationally have engaged in bioeconomy ventures with indigenous partners (Te Momo, 2007), for example the South-African IK-based cooperatives (Indigenous knowledge). Local knowledge around plant cultivation, their nutritional and medicinal value and the varietals with highest protein component is seen as a vital link to the future of South Africa's food security (Tang, 2016) and indigenous knowledge is seen as a cross-cutting pillar within the South African Bioeconomy Strategy. How this knowledge is gathered and recognised must be handled very sensitively.

7. Conclusion

NZ clearly has a strong biobased resource together with the requisite knowledge and skills, to develop the technical elements of a bioeconomy. It has the potential to be a global leader and exemplar, though the strength of the current primary sector may also mean the effort required to redirect efforts towards growing a truly transformational bioeconomy may not be realised easily.

The current primary sector economic model for New Zealand, based predominantly on agricultural products from a livestock base and supplemented by forestry and horticulture, is under pressure from both environmental limits and increasing backlash from a concerned public. Despite large inroads by the primary sector towards sustainable resource management, alternative bioeconomic pathways will be required to both supplement and transform conventional production, in order to maintain the country's prized 'clean and green' image. Currently a range of promising niche developments have

emerged to enable a gradual transition, presenting an interesting picture of innovation and creativity. But for the full benefits of a bioeconomy to be realised, including a reduction in waste, GHG emissions, added value, and production efficiency, the scale and interconnection needs to be increased considerably.

The analysis in this paper identifies several critical elements of a bioeconomy that are either not fully developed in NZ, or are clearly lacking, most notably finance and governance. In conjunction with these missing elements, the three connections between the elements are limited. While the potential for a bioeconomy is very high in NZ, the journey towards it has barely begun. Indeed, with scant mention of the term across government documents, and little evidence of its use beyond research sectors, the socio-cultural element of transformation is plainly absent. Efforts to date to build a bioeconomy are ad hoc, largely growing out of existing sectors, and the system lacks a clear vision and direction other than some well-meaning insular strategies and a recent primary sector roadmap. Current activity is still little more than tweaks to the original paradigm, however the challenges facing NZ, as well as the potential opportunities, require much more than this. It would seem that the lack of intentional strategy around the biobased economy, despite being a global bio-based producer and leading export marketer of biobased products, puts NZ at risk of a diluted result.

This article provides glimpses of how this new bioeconomy may develop. However, a more detailed analysis outlining potential future directions is required to articulate the clear vision of what the NZ bioeconomy would look like, including the feasibility and implications for the whole of society. This approach would result in some strong recommendations for action in order to build a detailed policy plan. In the absence of a high-level governance directive, existing players within and between sectors would need to provide impetus and a means for niche actions to become mainstreamed and linked within the wider system.

Successful transformation to a strong bioeconomy, as suggested in this paper, requires strategically re-positioning and restructuring the bioeconomic direction for NZ, integrating existing efforts into a cohesive whole. The cohesive whole is likely to require thinking outside the mainstream players and require a quite different cross-sectoral and pan-government primary system, one that connects the strong existing regime sectors with new niche players. It also requires a proactive and agile sectoral system that can adapt to encompass new biobased activities and ideas, supported by infrastructural governance from the macro-level landscape, built from engagement of society as a whole.

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