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Towards a bioeconomic vision for New Zealand – Unlocking barriers to enable new pathways and trajectories

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ABSTRACT

There has been significant national interest and movement towards bioeconomic policy over the past decade. Through an examination of the current bioeconomic pathways in New Zealand, this paper outlines key barriers that transition pathways will need to overcome and factors needing development within the country's bioeconomic environment. New Zealand's strength in primary production, coupled with a market-led economy and recent green growth with low carbon policies, provide an excellent platform for bioeconomic development. However, the strength in established biological industries and lack of clearly defined vision or cohesive support for bioeconomic development provide sufficient inertia to realising the full potential. For a bioeconomy in New Zealand to flourish, a primary sector model that is cohesive and more integrated is needed to develop new niche industries and attract finance, while providing an overarching governance system to the primary industries.

Introduction

New Zealand has long had an economy based on the primary industries – farming, forestry and food production. These have commonly been based on primary products as commodities, with New Zealand seen as a key commodity exporting economy in Asia-Pacific [1]. While many New Zealand energy and growth strategies hint at production via a bioeconomy [2,3], it has only been during the COVID-19 pandemic that a bioeconomy roadmap or strategy has emerged, primarily to accelerate recovery [4].

This new national strategy formalises New Zealand's potential to capitalise on its strength in natural resources, and existing strong research and development in the primary sector focussed on innovation for national wealth gain. However, it does appear to remain agri-dominant, constraining opportunities for inter-sectoral innovation and a wider application of biotechnology investment. By 2030, the new national strategy seeks to add $US30b in export earnings, reduce biogenic methane 10 % below 2017 levels, and grow employment in the primary sector by 10 % [4].

New Zealand economic policy since the mid-1980s has been market-led, with limited government intervention in the primary sector markets [5]. A heavily siloed agricultural economy has resulted with each primary sector operating in an insular manner and a duplication of efforts within research and development (R&D), trade policy and export marketing across the sectors [6]. As the population expands, meeting the Government's growth targets [7] in a sustainable manner will require a shift in thinking that allows for adding value to natural resources while also reducing environmental degradation and maintaining social licence to operate.

It may appear that New Zealand has a pre-existing dominance in biological industries, particularly in food and fibre, a well-established export economy, and therefore little capacity or need to increase and improve on building a flourishing bioeconomy. Such thinking ignores the fact that the current New Zealand primary-sector economy has several major limitations impeding the emergence of a bioeconomy, including its pre-existing dominance. This paper explores these limitations to the present 'old' bioeconomic production model currently operating in New Zealand, and discusses potential for transformation within the New Zealand primary production system. First, the paper provides a review of the visions and drivers of international bioeconomies and the current status of the bioeconomy in New Zealand. Following this the pathway and trajectories being taken to support a 'new' bioeconomy in New Zealand are examined, before identifying the main barriers to a more widespread adoption of this integrated

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bioeconomic approach. Strategies for overcoming these barriers to enable a flourishing bioeconomy are then discussed.

Bioeconomy drivers

Biotechnology has been a critical driver in the ability to transform biological resources for enhanced economic wealth and societal benefit [8]. The biotech 'revolution' reached a scale by which a new term, bioeconomy, was coined to encompass the wealth contribution being created from biotechnology — in 2012 biotechnology contributed $US324b to the US economy [9,10]. The OECD heavily reference biotechnology in the development and growth of a bioeconomic future [10]. In particular, biotechnological processes (including bioenergy, chemical and industrial biotech processes) have enabled higher value extraction from a range of biomass inputs across the primary sector, allowing conversion to critical components of the bioeconomy – biofuels, bioproducts and advanced food and fibre production [8].

Some proponents of a bioeconomy cite this ability to capitalise on biotech advancements using biological systems (e.g. [9,11,12]), but the bioeconomy has come to mean much more than biotechnology. Today, 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, enable a low carbon economy, design and develop production and processing facilities and entirely new integrated and resilient industries and create myriad economic opportunities through biological science [6]. In a global strategy review, seven key drivers have been identified [6]:

1 Building the economic value through biobased industry.
2 Biological substitution to address resource pressures.
3 Energy security.
4 Boosting rural enterprise through job creation.
5 Waste reduction and circularity.
6 Health improvements to reduce poverty levels, improve life expectancy and reduce infant mortality.
7 Addressing climate change by reduction in greenhouse gas (GHG) emissions

Bioeconomy visions

Perspectives on the bioeconomy have shifted over time, beginning with an initial focus on biotechnology and green growth, before moving into a bio-resource focus and inclusion of environmental objectives, in particular resource substitution surrounding 'peak oil' in the first decade of this century. Over the past decade a 'biotech innovation' phase saw the rise of life sciences for commercial and industrial growth and is now being driven by a dichotomous evolution towards both circular bioeconomies that include cascading and the interlinkage of different biomass value chains, with an 'agroecological' emphasis on sufficiency and socio-political transition to achieve the same [13,14]. Three main 'visions' which various global strategies appear to be following have been outlined [15]. First, the bioeconomy as a means to create jobs and economic wealth through the application of biotechnology and commercialisation of biobased R&D. This 'biotechnology' vision led to science clusters and was mainly taken up by mainstream science fields. The second 'bioresource' vision expands on economic growth, but through a sustainability lens, and is usually achieved through the conversion and improvement in processing of bioresources. The bioeconomy is usually promoted in order to optimise land use, particularly in the establishment of marginal lands in biofuels production, and in increasing the volumes of bioresources and including bioresources to reduce waste flows. A consideration in this vision is the ability to enhance the rural sectors through sustainable regional development in agriculture. These first two visions have an engineering and natural sciences perspective and may be complementary to some extent [15]. In comparison, the 'bio-ecology' vision is more concerned with environmental conservation and maintenance, particularly sustained ecological viability and avoidance of degraded ecosystems, such as soils and water systems. This third vision takes a more integrated production and value-added approach, ensuring not only circularity, but ecological and social sustainability within production. In this vision the focus is moving towards impacts of bioeconomic policy and vision on society, and will require socio-political trajectories and socio-technical development to enable appropriate transition paths [13,14].

Bioeconomy pathway elements

The main boundaries of the bioeconomy were outlined in [16]. They include activities leading to:

- lowered GHG emissions;
- and/or reducing waste or incorporating renewable or recyclable materials;
- and/or processes which look to cascade value throughout the chain and extract higher value downstream from wastes;
- and/or new products that utilise the functional benefits that biological resources alone provide and that are not linked to waste reduction or fossil fuel substitution.

Broadly, a bioeconomy has three elements which most strategies adopt [6], namely:

1 Sustainable natural (biomass) resource use and a reduction in waste and pollutants; coupled with
2 a transition away from fossil fuel resource dependence; to achieve
3 economic and social growth and employment.

Four main bioeconomic pathway paradigms were outlined [14] that emerge from the intersection of visions (on an industrial biotechnology – agroecology continuum) with drivers (capitalist growth – low-production sufficiency continuum) (Fig. 1).

New Zealand context

New Zealand has 263,000 km^2 land mass and a small population base. This equates to 2.4 ha of land resource per capita, relatively generous at global scale. It has significantly higher pasturelands than the OECD average (40 % versus 23 %) and a higher forest cover (39 % versus 31 %), but lower arable cropping than OECD average (just 2 % compared to 12 %). New Zealand productive land use is dominated by pastoral farming, particularly dairy farming (45 % of agricultural operating income), followed by sheep and beef farming. Along with direct export earnings, the primary sectors are also fundamental to employment, particularly in the regions, and in the science sector [17]. New Zealand has been reducing reliance on coal and natural gas but relies heavily on imports of fossil fuel for transportation energy. 60 % of the 891 P J (PetaJoules) total primary energy supply consumed annually is in fossil fuels [18]. In contrast, New Zealand generates 366 P J of renewable energy, with the majority (55 %) from geothermal sources and 26 % from hydropower, 17 % bioenergy and 2 % wind. Fifty-eight of the 62 P J of bioenergy is in the form of biomass, usually combustion of sawmilling and pulp and paper residues [19].

Biotechnology contributes to the national economy, mainly through advances in industrial processing and genetics. The last national biotechnology survey was conducted in 2011 [20] where bioscience then contributed $US453 m to gross domestic product (GDP). BioTechNz, a member-funded association created by the New Zealand Technology Industry Association Incorporated to support the national biotechnology community, is currently surveying New Zealand biotechnology firms to establish their contribution to the economy as well as identifying opportunities to contribute to further economic

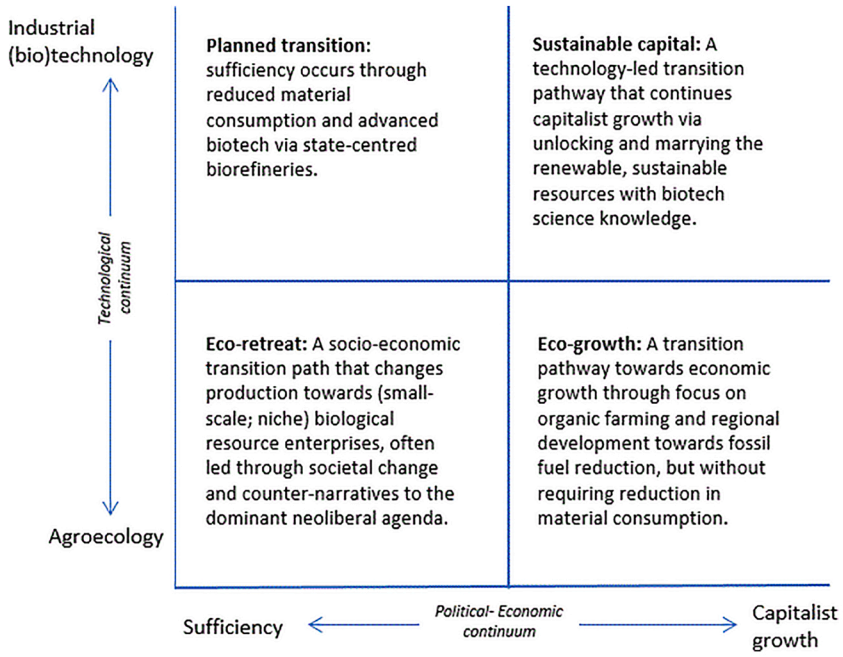

Fig. 1. Four transitional pathways concerning the bioeconomy narrative, as outlined by Hausknost et al. [14].

growth [21]. New Zealand's GDP contribution from the current bioeconomy is estimated at 23 %, or $US47b, with 38 % from food, 8 % from forestry, 26 % from construction (mostly housing), 15 % from support services, and 13 % from wastewater treatment [22]. Based on the available resources, New Zealand's primary sectors will still be predominant players in any transition to a 'new' bioeconomy, and have an important influence globally through exports, as nearly half our $US38.2billion export revenues are from the primary industries [17]. However, outside of agritech, biotechnology will likely have an increasing role to play in the growth of our bioeconomy in a post-COVID-19 environment for advancing healthcare and chemical processing technologies using molecular biology [21].

Methods

The analysis in this paper is a mixed methods approach, based primarily on a review of relevant literature, complemented by a survey of participants at a National Symposium in April 2017. 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 New Zealand policy documents. International literature concerning bioeconomic strategies, divergent visions of the bioeconomy, and current concepts concerning bioeconomic pathways and policy development (both international and within New Zealand) was examined. International approaches were concurrently assessed against the current New Zealand approach to bioeconomic development, primarily from grey literature, which complemented the data gathered through the survey.

The survey involved distribution of paper surveys to approximately 100 participants prior to a presentation by one of the authors on the topic of the bioeconomy. Questions were developed based on literature, particularly [23]. Respondents were questioned on their familiarity with and expectations around the concept of the bioeconomy in a NZ context. Forty-seven completed, useable surveys were returned. A descriptive analysis of the results was undertaken and is summarised in the next section. The data from the survey and grey literature was assessed against current drivers and visions as espoused by Bugge et al.[15] and Birner [13], and against the pathway quadrants developed by [14], to provide some insight into the current New Zealand approach to a bioeconomy. Finally, the strengths and weaknesses in New Zealand's bioeconomy, as outlined by [6], were cross-examined against the current trajectories using SWOT analysis and a causal framework investigating drivers, barriers and enablers.

A New Zealand approach to bioeconomy

In New Zealand, the current definition of a bioeconomy is "*The set of economic activities relating to the invention, development, production and use of biological products and processes*" p.18 [24]. This definition is fairly broad in nature, though it is missing many of the more social and environmental elements that are required for a fully functioning bioeconomy. This relates strongly to the more linear biotechnology or bio-resource vision than the interactive or circular bioecology visions outlined by Bugge et al. [15]. In [6], the area highlighted is that "*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*" p185 (just over half of export earnings [17]). Fig. 2, adapted from Wreford et al. [6], indicates the different outputs and impacts between the existing 'old' bioeconomy within New Zealand, and the emerging 'new' bioeconomy.

Two main drivers are behind New Zealand's bioeconomic transformation: developing higher value bio-based products or biological inputs to create economic value and improving sustainability through mitigating environmental issues (waste, pollution, energy use and GHG emissions).

What do New Zealanders "in the know" think?

Surveyed stakeholder respondents were most familiar with the term 'bioeconomy' in the context of bioenergy (57 %), and food production (51 %). Fewer than half were familiar with the bioeconomy in the

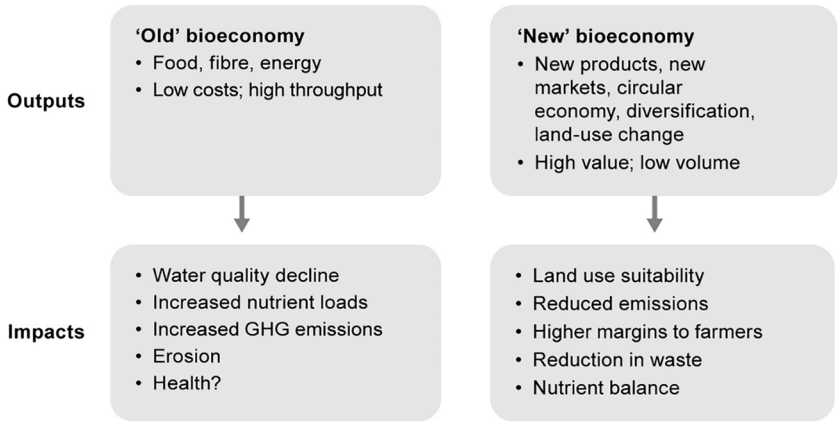

Fig. 2. The 'old' bioeconomy in New Zealand, characterised by low cost commodity-based export production of food, fibre and energy is contrasted against the nation's emerging 'new' bioeconomic model from Wreford et al. [6], along with current outputs, and potential mitigating impacts from the current dominant primary sector production.

context of biotechnology (38 %), 34 % were familiar in the context of innovative products from primary production, and 15 % were not familiar with the term at all. Using categories derived from BioVale [23], respondents ranked these categories (Fig. 3) with 1 = most important and 6 = least important. The highest ranked potential benefit was a shift from fossil fuels and associated 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). It is worth noting the high-ranking that a shift from fossil fuels received, as the current developments in the bioeconomy in New Zealand do not place particular emphasis on this benefit. Higher value products followed closely behind in the survey, which is where most of the focus is currently in New Zealand.

New Zealand's pathway to a 'new' bioeconomy

Although historically bio-resource centred in outlook, recent interest in creating a circular bioeconomy has emerged that addresses primary sector waste, and commitments to reduced GHG emissions (the low carbon economy), while maintaining economic growth [25–27]. These include a recognition of the opportunities available through high-value forest-based residues [28,29] and lowering of carbon emissions [30].

Overall (as stated in [6]), the scan of current activity within New Zealand's emerging bioeconomy shows the following bioeconomic pathways [6]:

1 A large production base from conventional biological sectors, often with commodity products as the major revenue component. *(COMMODITY BIOPRODUCTION)*
2 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. *(HIGH-VALUE DERIVATIVES)*
3 Newer primary sectors that are now fairly well established - e.g. deer, king salmon, kiwifruit, wine, honey, and merino wool clothing. *(EMERGENT PRIMARY SECTORS)*
4 New (aquacultural) livestock sectors that are emerging - Keewai™, scampi, geoduck. *(AQUACULTURAL LIVESTOCK)*
5 Biomaterials, particularly wood plastic composite and bioplastics developments (some emergent industries and offshore licensing). *(BIOMATERIALS)*
6 Several biotechnology companies have been created to develop and commercialise nutraceuticals *(NUTRACEUTICALS)*
7 Pilot plant developments to turn industrial waste into high-grade extractives. *(HIGH-GRADE EXTRACTIVES)*

The bioeconomy pathways, when mapped against the framework in [14], show that the transition is still largely driven by capitalist growth rather than sufficiency trajectories, but is split between the development in new agro-ecological industries and a focus on industrial biotech (Fig. 4). New Zealand has yet to move fully into an 'Eco-retreat' driven pathway that addresses the current social concerns of agricultural expansion coming from the non-producer side of the debate. While these individual pathways show promise, they are unlikely to lead to the full realisation of the 'new' bioeconomic direction in the presence of several barriers, discussed below.

By assessing the New Zealand bioeconomy against a set of six structural elements (Renewable resources; Knowledge, innovation & technology; Finance and governance; Research & development; Private and public expectations; Processes, products & services) strengths and weaknesses present in enabling bioeconomic transformation have been highlighted [6]. An examination of New Zealand's current bioeconomic

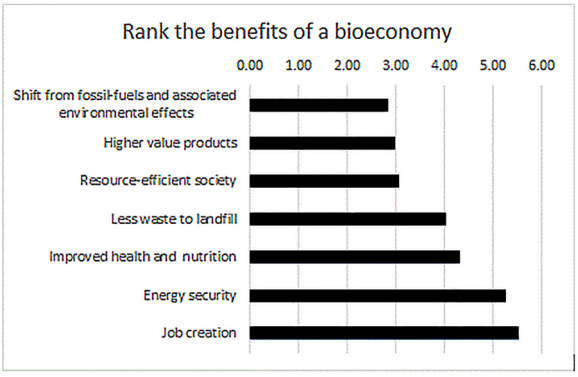

Fig. 3. New Zealand ranking of the potential benefits from a bioeconomy. Seven categories derived from BioVale [23] provide an indication of bioeconomic drivers. Stakeholders were asked: "Please rank the following potential benefits of a bioeconomy in the order of importance to New Zealand, in your opinion (number 1 = most important; 6 least important)".

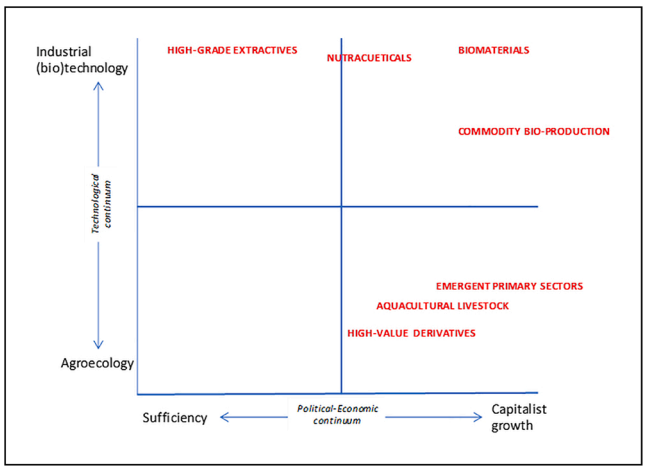

Fig. 4. Mapping New Zealand's bioeconomic pathways. The framework in [14] displays the seven pathways from Wreford et al. [6] against technological and political-economic axes. The resulting mapping demonstrates a current gap in any 'Eco-retreat' driven pathway.

system against the 'new' bioeconomy vision and pathways shows several barriers to transitional pathways present in the primary-sector system that might hamper bioeconomic development reaching its full potential, due to the following weaknesses. First, the returns from agricultural production are low compared to international profits [31,32]; secondly, the environmental cost of production is reaching a point by which it is clear that changes to the current intensification norm are needed [33]; thirdly, New Zealand's siloed primary sector economy and market dominance of large well-established corporates provides inertia to sectoral transformation; fourthly, some recent efforts to build and grow the bioeconomy have been met with social and market resistance; and finally, New Zealand is currently lacking governance and financial enablers to provide effective transition [6].

Low returns to producers from export revenue and downstream margins

The real contribution of agriculture, forestry and fisheries to the national GDP has dropped from around 8–10 % in the 1970s to 4–6 % during 2015–2020 [34], though accounting for agricultural additionalities it has been estimated at closer to 12 % GDP contribution [35]. Returns from primary production are still much lower than their real market value, due to three core factors. First, the majority of New Zealand's primary production is in commodity goods, used as 'feedstocks' into other sectors, and into international markets for secondary processing. New Zealand has lower than optimal manufacturing and processing sectors in which to turn these goods into higher value products but lower labour costs relative to many other industrialised nations [36]. Secondly, market value is lost due to competition both within and between industries and sectors. Collaboration in terms of joint marketing for export access, joint transportation, port and warehouse storage, shipping and inventory assessment could benefit New Zealand producers from the same regions, or having similar supply chain partners. Thirdly, some commentators note that there is increased revenue to be made through capitalising further on the unique attributes that provenance and cultural heritage provide, even for commodity goods [37]. As a result, the primary sector goods sold in international markets for $US167b earn the New Zealand economy just $US25b, meaning the nation loses out on 85 % of the real value of our largest sectoral exports [31].

The environmental cost of intensified production

The "sustainable intensification" [38] route followed by New Zealand primary production is now in question, as the country experiences unprecedented levels of polluted waterways [39] and very little reduction in GHG emissions [40]. A radical reduction in New Zealand's dairy cattle numbers is required to reach climate change obligations [41], in conjunction with increased tree planting [42]. Recommendations from the OECD are for New Zealand to develop a long-term vision for a transition towards a low-carbon, greener economy. However, the New Zealand government currently promotes a 'green growth' strategy [7], aimed at substantially increasing export revenues, thus retaining a capitalist growth over sufficiency model. Attaining the higher export revenues without significant increases in environmental costs requires higher value production. Higher value production, or ensuring our lost export value moves back up the supply chain to producers' pockets, will need a cross-sectoral viewpoint, alongside new sector emergence from a multi-sector and multi-actor innovation system that supports and aids the bioeconomic transition path.

A siloed primary industry

New Zealand's primary sectors operate independently of one another, which is not conducive to the principle of circular economy and the sort of supply chain integration needed for biorefinery inputs, which often draw from multiple feedstock sources. Although at the national level the Ministry of Primary Industries provides overarching policy, both sectoral governance and producer bodies are structured to enable independent production and thinking. For example, multiple producer bodies exist for each major sector: horticulture (ZESPRI), agriculture (Beef + Lamb; DairyNZ), fisheries (SeafoodNZ) and forestry (WOODCO). This is also evident from the prevalence of sectoral-based activities, in terms of field days, seminars, pro-sector initiatives and member associations, from within R&D itself to industry organisations and farmers themselves. Bioeconomy initiatives also tend to be promoted as sectoral growth strategies, such as the wood processing strategy, and aquaculture strategy. These look to enhance economic returns to a single sector, rather than creating a cross-cutting bioeconomy allowing for multiple feedstocks and a range of high value outputs through a regional strategy for industrial biofinery. More recently, calls for a national strategy on sustainable food production have emerged, but again this lacks integration with other bioeconomic sectors such as biofuels and biofibre production [43].

Social and market resistance to change

One cannot assume that 'all things bio-based' will naturally result in improved Sustainable Development Goal (SDG) outcomes, as evidence shows that the bioeconomy cannot be considered as self-evidently sustainable [44]. If done well, it will provide goods and resources for an ever-increasing population, while reducing the amount of carbon emissions and enabling developing nations to participate in greater economic wealth generation. Poorly designed bioeconomic transition that requires an immense volume of biomass demand could result in harmful impacts such as biodiversity and soil loss, competition over land use, and escalation of hunger and resource conflict [45,46]. European bioeconomy strategies now acknowledge that a biobased economy can only be sustainable through a concurrent socio-ecological transformation [47,48].

In New Zealand, the aquaculture sector has shown significant potential, and an aquaculture strategy has been released aiming for a quadrupling in value of the industry by 2035 [49]. However, public resistance to aquaculture due to rapid growth has been an issue for over a decade [50]. More recently, public resistance to salmon farms in the Marlborough Sounds has resulted in legal challenges, with only four of nine farms being approved [51]. Resistance and public concerns surround the impact on local residents from a change in visual ocean vista, night lighting, the perceived fouling of waterways and introduced species [52,53].

Presently, New Zealand takes a precautionary principle to use of new technology [54]. Acceptance of genetic modification (GM) could radically enhance a bioeconomy in New Zealand, but social support appears to differ depending on how GM is implemented [55,56], and the

economic benefits remain uncertain [57]. More recently, it was found that public acceptance of GM for controlling invasive species was still contentious and highly variable and depended on the context in which it might be introduced [58]. Public concern regarding the 'neo--liberalisation of nature' and 'biocapitalism' through extension of market forces to biological resources [59,60] as well as ownership, equity and capture of indigenous knowledge, requires deliberation when creating bioeconomic value.

Lack of governance and finance as enabler

In the early 2000s, there was much interest and growth within the New Zealand science environment towards biotechnology, and a national biotechnology strategy emerged in 2003 [61]. The formation of NZBIO as a networking and connecting private sector organisation to debate and enhance issues of biotechnology for New Zealand further advanced the nation's biotechnology sector. In 2010, the New Zealand Bioenergy Strategy was released [62], with strong support from the forestry and wood processing sectors of New Zealand. While incorporated in some international bioeconomic reviews (e.g. [63]) as a national bioeconomy strategy, this was developed independently outside of government by the Bioenergy Association of New Zealand (BANZ) and NZBIO.

The New Zealand Bioenergy Strategy sought to deliver substantial economic growth and employment, but also noted the need for collaborative industry vision, and strong government leadership in order to achieve the primary goals: supplying 25 % of the country's energy need and 30 % of the country's transport fuels by 2040, through leveraging the capacity and expertise in the forestry and wood processing sectors [19]. Globally, biofuels consumption between 2019–2028 is anticipated to increase in both bioethanol (by 21b litres) and biodiesel (by 7b litres) [64]. Following the heightened interest at the start of the century, the optimism and momentum around biotechnology for New Zealand has waned, though BioTechNZ retains a vision for New Zealand to "maximise NZ bioscience and technology capability to create a strong NZ bioeconomy" [65]. Today, New Zealand no longer has a national biotechnology strategy, though BioTechNZ states that this is "vital" [66]. The failure of some New Zealand biotechnology start-ups is also attributed to lack of investment, both private and public (e.g. Protemix, ICP), where the size of the investment market in New Zealand makes economies of scale to commercialise biotechnology more difficult [67, 68]. Biotechnology leaders advocate an environmental application for its growth in New Zealand over health and medical applications, leveraging strong biomass resources and agritech science [66].

The first indications of government policy since 2003 towards creating a bioeconomy only emerged in 2017 with the Primary Sector Science Roadmap [3] where the bioeconomy is specifically referred to, with the sub-title "Strengthening New Zealand's bioeconomy for future generations". More recently, the New Zealand Energy Efficiency and Conservation Strategy 2017–22 (NZEECS) [69] has sought to establish an energy productive, low emissions economy, mainly through enhancing production of renewables and reducing reliance on fossil fuels, particularly in transportation (through increased electric vehicle fleet) and electricity supply (a target of 90 % renewable electricity production by 2025) [19]. Most recently, (July 2020), the New Zealand Government released "Fit for a Better World" as a post-COVID-19 recovery strategy encompassing principles of Te Taio (respect for the natural world), zero carbon and quality food and fibre products [4]. This bioeconomy strategy sees the primary sector as the foundation of New Zealand's economic recovery, and envisions "Providing the world's most discerning consumers with outstanding, ethically-produced food, natural fibres, drinks, co-and bioproducts, all sourced from our land and oceans" p. 3 [4]

Both finance and governance were identified [6] as critical elements that are currently not fully present in the New Zealand bioeconomic system, and that hamper a high-value bioeconomy from being fully realised. Though the strategy and vision now promote a fully integrated bioeconomic pathway to be realised, the supporting governance and financial structures to implement and realise the national vision remain critical.

Developing a bioeconomic environment

Overcoming the barriers identified in the previous section is essential for New Zealand to achieve its potential in this area, while leveraging off the strength of our primary sectors. In returning to the strengths previously identified [6], and nascent developing pathways, four factors may facilitate a sustainable pathway to a genuine bioeconomy: 1. allowing room for a greater number of smaller-scale operators; 2. enabling markets for higher-value bio-based producers; 3. ensuring continuity for the established mainstream; and 4. increasing adaptability and flexibility within the various bio-based sectors to allow cross fertilisation to occur.

Allowing room for a greater number of smaller-scale operators

For a bioeconomy to develop, New Zealand needs to conquer the question of how to be viable with smaller scale. While consolidation provides efficiencies and economies of scale in commodity production, smaller scale enterprises will likely be in specialised production and niche markets. Remote rural communities require some form of enterprise and small scale, distributed production that supports a circular bioeconomy could achieve the drivers for greener economic growth, as well as job creation and regional development. Smaller scale producers will, however, need to leverage the capability built from within the mainstream players, particularly in terms of R&D capacity, integration into the larger sectoral supply chains, and infrastructural investment.

Enabling markets for higher-value bio-based producers

For smaller-scale operators to thrive, they will require entry into global markets. The global marketplace rewards producers that can connect with consumers on an individual and experiential level. Many smaller enterprises will require a range of global supply chain partnerships that can build and deliver higher-value production and provide differentiated marketing solutions to ensure wealth from consumers reaches the original producers. Quality niche production of goods that meet conditions sought after by international markets have been realised by a small number of producers, some of which (e.g. Comvita, WineNZ, MerinoNZ) have moved from niche production into mainstream agricultural export-revenue production.

Ensuring continuity for the established mainstream

Not all production will need to transition immediately to a 'new' bioeconomic business model, and in ensuring growth for the smaller-scale and higher value niche producers, any bioeconomy strategy must also provide stable continuity and transition time for the existing cash cow. There is large momentum in the existing New Zealand bioeconomic system, with many producers both wanting to transition to a more sustainable and higher-value production model, but fearing the transitional loss of power-base and authority that their sector, business model or enterprise currently has. High capital investment for niche production may only be available from within existing large corporate agricultural entities, who can aid transition. More established sectors have a role to play in niche industry support by linking with them, as well as enabling boundary expansion within their larger sectors to enable new thinking and potential development paths. Niches in turn can assist the established sectors to transition by providing opportunities for diversity and innovation.

Increasing adaptability and flexibility within the various bio-based sectors to allow cross fertilisation to occur

Breaking down the heavily siloed structural system within the primary sector is essential to enabling circularity and a production system that can handle multiple input feedstocks, cross-sectoral actors and a regional biorefinery approach to distribution and marketing of multiple

biological outputs – food, fuels (energy and power), as well as value-added biomaterials and biochemicals from biomass [70]. At the larger scale, separate entities could come together in an industrial collective involving physical exchange of materials, energy, water, and/or by-products. In a fully-functioning bioeconomy, regionally distributed processing and manufacturing through smaller and more agile clusters might displace the current centralised hubs that support regional but specialised production, processing and manufacturing infrastructure, but might fail without high-level vision and pathway support. Enacting cross-sectoral pathways and integration within stakeholder processes, as called upon by Leining and Kerr [71] is now urgently required. It is likely that radical changes in food production and fibre processing would be required to both better position New Zealand's primary industries, while also avoiding further environmental damage. In reorganising the bioeconomy to meet these challenges, building flexibility in future land and value chain options should be introduced to avoid new types of silos forming, while also improving natural resource base resilience to future shocks.

Conclusion

New Zealand has the required elements in a large and well developed biological resource-base, the necessary expertise and drivers, and the emerging impetus for system change. Ironically, the current primary sector strength may be the prime inertia in the system towards enabling a new bioeconomy from forming. To fully transition to a functioning bioeconomy, New Zealand will need to unlock and open the bounded edges that define its agricultural, forestry and marine sectors, to enable cross-fertilisation of ideas and technologies, as well as create less distinct sectoral boundaries that allow for penetration by new market players, particularly in the service and manufacturing industries. Unlocking bounded systems to incorporate increased biotech capability and applications to flourish could lead to novel solutions to environmental restoration and regional economic growth for New Zealand. Finding ways of linking and connecting the primary sectors with the service and manufacturing sectors through the application of bioscience to non-primary markets is also critical.

Without whole of government support and interventions, shifting towards and realising the full potential of the new bioeconomy seems unlikely. While the Ministry for Primary Industries has produced a defined strategy, it needs to lead rather than defer to the market-led economy, to support collaborative partnerships outside of primary industry silos and to integrate efforts for cross-fertilisation amongst research and industry. The research needed to transition primary sectors towards higher value production may also be outside of the mainstream areas of current industry funding priorities, whose members have significant investment in the *status quo*. Therefore ways to draw new investment into New Zealand is required to fund high-risk bioscience and novel agritech.

For New Zealand to successfully transition and emerge as a global leader in the 'new' bioeconomy, the current bioeconomic direction will need to be radically transformed, repositioned and restructured, with existing efforts and trajectories integrated into a cohesive whole. It is likely that such transformation will not come solely from within the primary sectors themselves but from new thinking and niche activities that occur on the sectoral edges, particularly if these are allowed to blur and intermingle. Connection of the strong existing regime with new niche players that emerge will enable cross sectoral interaction, new biobased activities and ideas. These will require support at governance level by a cohesive, overarching strategic direction and implementation policy for the nation. Until government presents a joined-up, whole of government strategy and implementation pathway — one that includes incentives for international investment in agro-ecology and biotechnology and new economic models of regional wellbeing that focus towards self-sufficiency— it is unlikely that industry has the impetus to radically transform their current direction towards the new bioeconomy.

Author contributions

Research project tasks were shared equally amongst team members, with the following key oversights: Bayne, market transition emphasis and manuscript lead; Wreford, adaptation emphasis, survey design and overall project lead; Edwards, policy and social licence emphasis; Renwick, resource economics emphasis.

Declaration of Competing Interest

The authors report no declarations of interest.

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