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Impacts of circular approaches on emissions, jobs, and other factors

Final Report

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Executive Summary

Introduction

This report answers the research question: “What greenhouse gas emissions reductions could we anticipate from circular economy approaches in New Zealand, and what are the best areas of opportunity for emissions reduction and wider impact?”

We define the concept of the circular economy as “an economic system that promotes the continual use and reuse of resources, minimising waste through recycling, refurbishing and sustainable practices.”

The circular economy approach seeks to substantially decouple the economic value of goods and services from the impacts of extraction and waste production. This involves keeping products in use for longer, sharing access to the services they provide and maintaining, reusing, refurbishing, remanufacturing, recycling and composting them. This recovers material value and the value added to those materials through manufacturing. It also incorporates a systemic transition to renewable energy, and is closely linked with the ‘bioeconomy’: the use of renewable biological resources to produce food, products and energy.

Applying this approach requires its adaptation to local conditions. This includes community and regional level considerations, along with a national perspective. It also calls for an understanding of and response to ‘bio-regional’ areas defined by ecology and geography.

New Zealand has a relatively small, primarily biologically based economy. It is characterised by a high proportion of small and medium-sized businesses. It has a unique historical context and cultural make-up, including an increasingly robust and vibrant interplay with tangata whenua and associated indigenous knowledge systems.

Each region has different strengths, capabilities and limitations. The manner in which they can and will respond to the challenges and opportunities of developing a circular economy will differ.

Methodology

Our approach used a combination of top-down and bottom-up approaches for data collection and analysis. Various data types, including mass metrics, energy metrics and carbon emissions metrics across New Zealand, were consolidated into Sankey diagrams for the whole system, and for waste, food, energy and built environment. These diagrams provide a visual representation of the flows of materials and emissions within New Zealand’s economy.

As expected, our research encountered various limitations and gaps in the data, including variability in data collection, validation and definition. Importantly, we were unable to include non-waste, material flows such as reuse, remanufacturing or resale of used products, as there are currently no requirements to collect this information. Data on materials lost to the environment in New Zealand, for example, through laundering textiles, tyre wear, or littering, was similarly unavailable.

Key findings

The data analysis and Sankey diagrams highlighted a number of distinctive features of resource flows in New Zealand, for example:

- New Zealand’s predominance of biomass resource which, through both imports and domestic extraction of biomass grown here, makes up 64% of total mass of material flow.

- An estimated 8.5% of the material flowing into the economy ends up as waste in landfill, with less than 1% of materials recovered, indicating a low level of recovery through recycling, compared with other countries.
- Concrete and aggregate dominate the material flows into the built environment, comprising 87% of the total 11,095 kt mass flows. Timber comprises only 3.5% of the material flows by mass into the built environment.

We found a wide range of opportunities for circular economy approaches to contribute to greenhouse gas emissions reduction and wider impact in New Zealand. The best areas of opportunity were identified as:

- Resource efficient buildings and infrastructure
- Innovations in sustainable agriculture
- Critical materials.

Within these areas, estimates of the annual emissions savings ranged from a low of 1,539 kt CO_2e to a high of 1,863 kt CO_2e (1.5–1.9 Mt CO_2e) per annum (recurring not cumulative). This would represent a 2.7% - 3.4% reduction on 2021's net emissions.[88]

Estimated Annual Emission Savings Identified

Area of opportunity	Intervention	Low Estimate (kt CO_2e)	High Estimate (kt CO_2e)
Resource efficient buildings and infrastructure	Increase Building Use	120	
	Refuse Unnecessary Components	71	140
	Increase Material Efficiency	71	140
	Reduce Virgin and Non-renewable Materials	240	
	Reduce Carbon Intensive Materials	850	
Innovations in Sustainable Agriculture	Water Management	113	226
	Local Organic Fertilisers	56	112
Critical Materials	Product Durability	18	35
TOTAL		**1,539**	**1,863**

Additional emissions savings could be realised in the longer term through sustained action. By 2050, savings of 12,741 to 19,336 kt CO_2e (13–19 Mt CO_2e; total not per annum), could be achieved through vehicle sharing models that reduce materials used in vehicle manufacture, and the reuse of vehicle components such as batteries. A further saving of 1,500 kt CO_2e (1.5 Mt CO_2e) per annum was estimated to be achievable in 50 years' time if we start designing residential buildings to last 100 years, rather than 50 years.

Many variables impact the timeframe of these emission savings. There are potentially many other circular economy interventions that could reduce emissions further.

These reductions would represent a significant contribution towards New Zealand meeting its internationally declared greenhouse gas emission reduction targets of net zero emissions of all greenhouse gas (GHG) emissions other than biogenic methane by 2050.

A range of wider environmental and social impacts are also identified, though not quantified. These include enhancements in employment, training and innovation as well as ecological sustainability, resilience and regeneration.

Implications and conclusion

This initial modelling provides a benchmark for this kind of analysis in New Zealand. Greater availability and quality of data would strengthen future analysis.

It also provides insights into the impacts of circular approaches in New Zealand to guide business activity and policy.

The circular economy in New Zealand has the potential to play a significant role in meeting the nation's greenhouse gas emissions targets, domestic and international. At the same time, circular approaches can provide a range of wider positive impacts in employment, supply chain risk and resilience, and ecological sustainability. Fruitful areas for further research and action to reduce emissions and for wider impact are:

- Resource efficient buildings and infrastructure
- Innovations in sustainable agriculture
- Critical materials.

Transitioning to a circular economy is however proving challenging in many countries around the world. Key to unlocking its potential will be our understanding of the interdependencies and complexities of the systems involved.

0. Glossary of terms

Agroforestry: A land use management system that combines trees and shrubs with crops and/or livestock.

Anaerobic digestion: Biological process where microorganisms break down organic matter without the presence of oxygen, producing biogas.

Australian Packaging Covenant Organisation: An organisation in Australia focused on reducing the environmental impact of packaging through industry collaboration.

Bioadhesives: Adhesives made from natural or biological sources.

Biobased and Biochar: Products derived from biological sources, and a form of charcoal produced from organic matter, often used as a soil enhancer.

Bioeconomy: The bioeconomy refers to parts of the economy that use renewable biological resources to produce food, products, and energy.

Bioproduct, biopolymers, biochemicals: Products derived from renewable biological sources.

Biomass: Organic materials.

Built environment: Human-made structures.

Carbon footprint: The total amount of greenhouse gases, especially carbon dioxide emitted directly or indirectly by an individual, organisation, event, or product.

Cradle-to-Cradle Certification: A certification that aims to ensure a product is designed for recyclability and environmental sustainability throughout its entire life cycle.

Circular economy: An economic system that promotes the continual use and reuse of resources, minimising waste through recycling, refurbishing and sustainable practices.

Circularity: The degree to which a system follows circular economy principles, emphasising sustainability and reduced environmental impact.

Class 1 landfill: In New Zealand, these landfills are designed to accept municipal solid waste which includes household waste, commercial waste and other wastes.

Class 2 landfill: In New Zealand, these landfills are designed to accept non-putrescible wastes including construction and demolition waste such as wood products, asphalt, plasterboard, insulation and other inert industrial wastes.

Class 3 landfill: In New Zealand, these landfills are designed to accept hazardous waste such as asbestos, contaminated soil, and other hazardous materials.

Class 4 landfill: In New Zealand, these landfills accept inert materials like clay, soil and rock, as well as concrete or brick.

Class 5 cleanfill: In New Zealand, these landfills accept only virgin excavated natural material, such as clay, soil or rock for disposal.

Critical Material: A material generally deemed by business interests to be commercially essential, in which significant supply risks have been identified.

Critical Mineral: An element or material extracted from mineral ores, deemed essential by government agencies to be essential for the national economy or national security, in which significant supply risks have been identified.

Decoupling: Breaking the link between economic growth and resource consumption.

Design for disassembly: Designing products to be easily taken apart for recycling or reuse at the end of their life cycle.

Design for reuse: Designing products to be used multiple times.

Downcycling: Recycling a material in a way that decreases its quality or value.

Dysprosium: A rare earth element used in the production of various technologies.

Extended Producer Responsibility (EPR): The concept that manufacturers should take responsibility for the entire lifecycle of their products, including recycling and proper disposal.

Farm dump: In New Zealand, refers to an informal waste disposal site located on a farm for the disposal of non-natural rural waste from agricultural activities, including metal, timber, plastic, glass, batteries and construction and demolition waste.

Feedstocks: Raw materials used in industrial processes, particularly those used for biofuel or bioproduct production.

GHG: Greenhouse Gases. Atmospheric gases that trap heat from the sun, thereby warming the Earth's surface. They include carbon dioxide, methane, nitrous oxide, and fluorinated gases.

Greenwashing: Misleading practices, where an organisation exaggerates or makes false claims regarding the environmental credentials of activities, products or services.

Industrial ecology: The study of the ways in which industrial systems do and/or should mimic systems in nature.

Jevons paradox: The concept that as technology improves efficiency, resource consumption may increase due to increased use.

Life Cycle Assessment (LCA): A method of evaluating the environmental impact of a product throughout its entire lifecycle, from raw material extraction to disposal.

Linear economic model: A traditional economic approach where resources are extracted, used to make products, and then disposed of as waste.

Mātauranga Māori: Traditional Māori knowledge and wisdom, often integrated with sustainable practices in the circular economy.

Material flows: The movement of materials through the various stages of production, use, and disposal.

Material footprint: The amount of raw materials and resources used to produce goods and services, indicating the environmental impact of consumption.

MEP: Mechanical. Electrical and Plumbing services.

Methane emissions: Gases released into the atmosphere, often from organic waste decomposition, contributing to climate change.

Micro, Meso, and Macro Scales: Different levels of analysis, from small individual components (micro) to larger systems (macro).

Microcircularity: Circular economy principles applied at a small scale, such as individual products or components.

Nature regeneration: The process of restoring and renewing ecosystems to improve their health and sustainability.

Neodymium: A rare earth element used in the production of various technologies, highlighting the importance of recycling to reduce dependence on mining.

Organic waste: Biodegradable waste from plant or animal sources, such as food scraps and yard trimmings.

Product-as-a-Service: A business model where individuals or entities pay for the utility of a product rather than its ownership, encouraging a focus on durability and reuse.

Production taxes: A fiscal policy where a tax is imposed on the primary production of materials such as metals and plastics.

Quantitative indicators: Measurable data used to assess and quantify aspects of the circular economy, such as resource use or recycling rates.

Qualitative assessment: Evaluation based on non-numeric criteria, focusing on the qualities and characteristics of a system or process.

Recyclate: Recycled material derived from the processing of waste.

Regenerative design: Designing products and systems with the intention of not only reducing harm but also actively contributing to the restoration and regeneration of ecosystems.

Resource efficiency: Using resources in a way that maximises their value and minimises waste.

Sankey diagram: A visual representation of energy, material, or flow processes, often used to illustrate resource efficiency and waste reduction.

Supplemental cementitious materials: Materials added to cement to enhance its properties, often derived from industrial by-products.

Sustainability metrics: Quantifiable measures used to assess and communicate the environmental, social, and economic impacts of an activity, organisation, or product.

The Australia, New Zealand, and Pacific Islands Plastics Pact: A collaborative effort to reduce plastic waste and promote a circular economy in the Oceania region.

Triple bottom line: A business approach that considers three dimensions of performance: economic, social, and environmental.

Upcycling: The process of transforming waste materials or unwanted products into items of greater value or quality.

Volatile chemicals: Substances that easily evaporate into the air, often associated with environmental and health concerns.

Waste hierarchy: A ranking of waste management strategies in order of their environmental impact, typically prioritising prevention, reuse, and recycling, with disposal as a last resort.

Waste valorisation: The process of extracting value from waste materials, often through recycling or repurposing.

1. About this report

This report presents findings from the research project: Impacts of Circular Approaches on Emissions, jobs, and Other Factors.

It forms part of an overarching project for MBIE: "Impacts, Barriers, and Enablers for a Circular Economy."

This includes several sub-projects, including:

1. **Impacts of circular approaches on emissions, jobs, and other factors**
2. Barriers, enablers, and approaches for a more circular economy
3. International developments toward more circular economies and the implications for New Zealand (Issue brief)
4. Enabling digital technologies for New Zealand's circular and bioeconomy, including the role of digital twins (Issue brief and use case)

It answers the research question:

"What emissions reductions could we anticipate from circular economy approaches in New Zealand, and what are the best areas of opportunity for emissions reduction and wider impact."

1.1 Report Structure

This report is presented in several sections, as follows:

- **Introduction to the circular economy** – this section briefly explains the circular economy concept and the expected benefits it could bring to New Zealand.
- **Evidence of impact** – this section explores the evidence that a more circular economy reduces GHG emissions, supports employment and economic growth opportunities and mitigates supply chain risks for the New Zealand economy.
- **New Zealand material flow analysis** – this section is a comprehensive analysis, using Sankey diagrams, of the potential impacts of circular approaches on emissions, jobs and other factors in New Zealand, identifying opportunities for emissions reduction and broader impact across three sectors – Food and Agriculture, the Built Environment and Advanced Manufacturing.
- **Other relevant data** – this section notes the data we were unable to include in the analysis.
- **Identified hotspots/interventions** - this section dives deeper into the observations from the material flow analysis and seeks out interventions that could be beneficial and attempts to quantify these where possible.
- **Conclusion** – key findings.
- **Annex A** – Circular Economy Flows Methodology, provides a more detailed technical explanation of the methodology applied to the data analysis and Sankey diagrams.

1.2 Methodology

Our approach uses a combination of top-down and bottom-up approaches for data collection and analysis. Various data types, including mass metrics, energy metrics and carbon emissions metrics, are consolidated into Sankey diagrams. These diagrams visually represent the flows of materials and emissions within New Zealand's economy, highlighting key intersections between economic and environmental impacts.

Methods for the identification of opportunity areas are explained in the relevant sections.

Annex A provides a more detailed technical explanation of the methodology applied to the data analysis and Sankey diagrams.

1.3 Limitations and caveats

1.3.1 Data quality and availability

The report acknowledges certain limitations and gaps in the data, such as the variability in data collection and validation methods, the definition of waste, and the exclusion of certain elements like water use and infrastructure data.

For example, 2019 has been used as the reference year for our assessment of material flows in the New Zealand economy, as the most recent 'normal' year with the most complete data. Data for subsequent years available at the time of this work would either be incomplete or heavily influenced by the Covid-19 pandemic. We are aware of more up-to-date waste data being generated by the Ministry for the Environment, but this was not available to us at the time of this analysis.

Importantly, our analysis was not able to include some relevant, non-waste, material flows such as reuse, remanufacturing or resale of used products, which are critical elements in the emerging circular economy. This data would be relevant for a more complete picture of waste diversion in New Zealand. However, there are currently no requirements to collect this information. It is also not currently possible to source data on materials lost to the environment in New Zealand, for example, through laundering textiles, tyre wear, or littering.

This highlights the need for further work to improve vital data capture and availability in resource flow management across the country. This, in turn, would facilitate more detailed and nuanced analysis in subsequent reports of this kind.

1.3.2 Behavioural, cultural and social change

Interactions between and developments in behavioural, cultural and social change could prove instrumental in how the New Zealand economy evolves in coming years. They have the potential to play a determining role in the outcomes of many of the changes discussed in this report.

For example, many of the potential benefits of the circular economy, especially environmentally, centre around increased resource efficiency. However, the observations of the Jevons paradox suggest that in many cases cost reductions associated with increased resource efficiency can lower prices, increase access and therefore induce further demand and consumption. In the absence of other drivers, this may mean that the related resource use is increased, rather than reduced.[1]

Such effects could significantly impact the potential outcomes of many of the changes discussed here. In particular, this suggests the importance of further work to explore in more detail the processes by which the resource-efficient activities ascribed to the circular economy will replace, rather than operate in addition to, current unsustainable economic activity and the related drivers.

We have sought to indicate key ways factors such as this will impact our analysis. For example, the shift from ownership of vehicles to sharing may require a significant shift in attitudes around aspiration, cultural signalling and convenience. And nearly all of the changes we describe here will require significant public support, and therefore understanding, to succeed.

However, a comprehensive study of these dynamics was beyond the scope of this report and should be the subject of further study.

1.3.3 Modelling

Given the above limitations our modelling is necessarily relatively simplistic, and is intended to:

- Offer an initial benchmark for this kind of analysis in New Zealand
- Provide digestible information on likely trends and opportunities to inform policy creation and guide business activity
- Identify and highlight areas where further work would be appropriate and most useful.

Making elements of this report public, including its methodology, provides an opportunity for further analysis and study.

2. Introduction to the circular economy

The circular economy recognises that the current 'linear' model, in which resources are extracted, refined, manufactured into products, used and disposed of at ever-increasing rates, is highly wasteful. This waste represents a massive loss of economic, environmental and social value.

The inherent unsustainability of this traditional linear consumption pattern is increasingly associated with volatile markets, resource nationalism and accelerating environmental degradation. Demand for materials is set to outpace the ability to supply them sustainably or without exacerbating inequity.

The circular economy is based on a branch of 'industrial ecology' – the study of the ways in which industrial systems do and/or should mimic systems in nature. It is often expressed through three key principles: Eliminating waste and pollution, circulating products and materials at their highest value and regenerating nature.[2] It incorporates a systemic transition to renewable energy.

It seeks to substantially decouple the economic value of goods and services from the impacts of extraction and waste production. This is intended to be achieved by keeping products in use for longer, sharing access to the services they provide and maintaining, reusing, refurbishing, remanufacturing, recycling and composting them to recover material value and the value added to those materials through manufacturing.

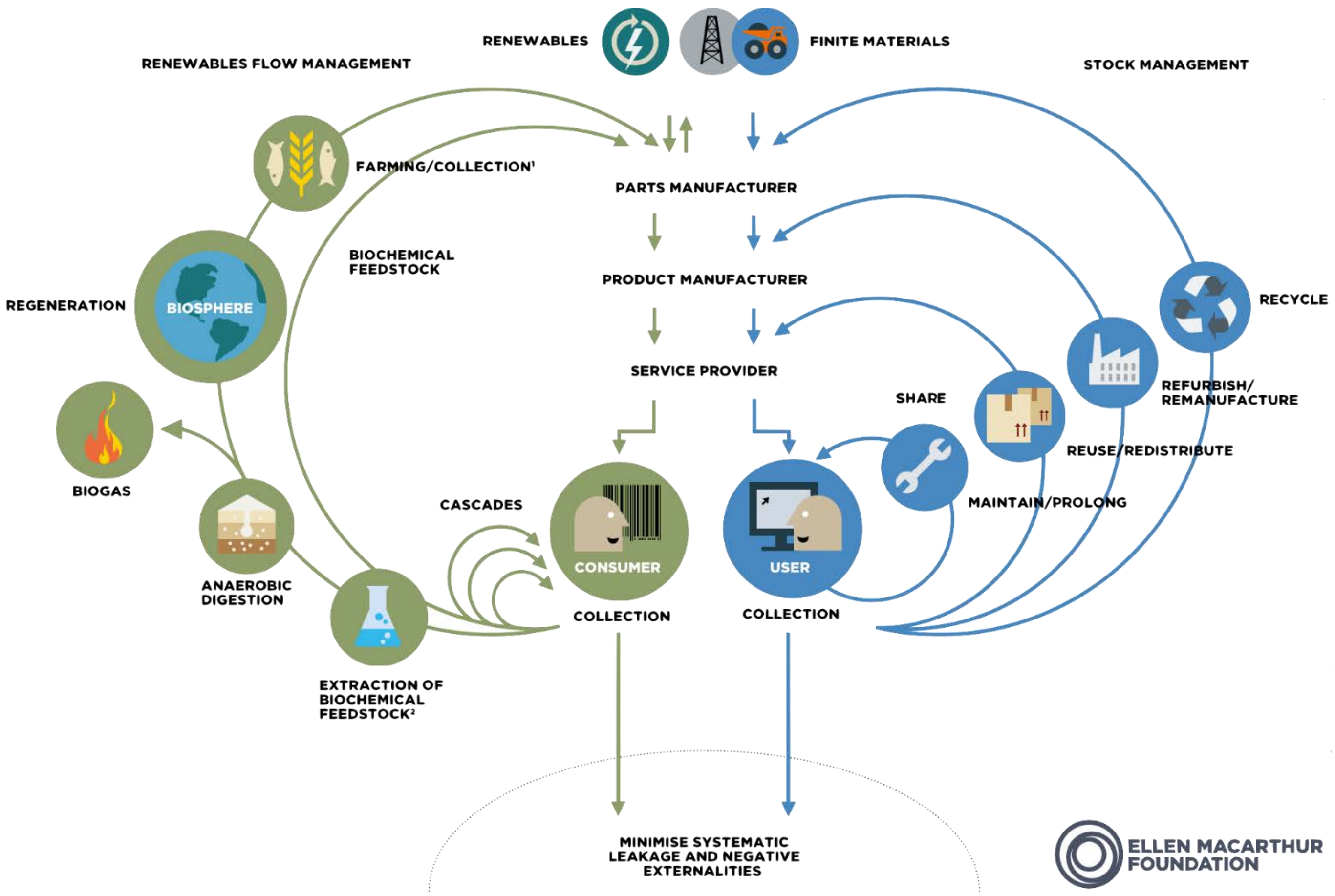

Figure 1. The Ellen MacArthur Foundation 'Butterfly' diagram[3] a stylised illustration of how value and resources flow in a circular economy.

The circular economy is also closely linked with the 'bioeconomy'. The bioeconomy refers to parts of the economy that use renewable biological resources to produce food, products, and energy. Taken together, they aim for a more sustainable and efficient use of resources. This contributes to environmental goals, like lower emissions and biodiversity protection, as well as seeking to unlock socio-economic advantages such as job creation and economic growth.

2.1 The New Zealand context

The circular economy, like any similar concept, must be adapted to local conditions. For the circular economy, this will require community and regional level considerations along with a national perspective and an understanding of, and response to, 'bio-regional' areas defined by ecology and geography.

New Zealand remains a primarily biologically based economy. The wider food chain (primary, manufacturing, wholesale, retail, food service) directly employs one in five working people in New Zealand.[4]

The economy itself is relatively small. It is distant from major markets and global centres of innovation and knowledge. It has few internationalised firms. These factors mean comparatively higher costs of trade and new market development. They also place limitations on our ability to influence changes in major markets and supply chains.

At a regional level, New Zealand has a relatively small and geographically dispersed population. There is only one global scale city. This increases the costs of infrastructure development and change, as well as the provision of services such as health care and integrated transport infrastructure.

Each region has different strengths, capabilities and challenges. This means the manner in which they can and will respond to the many different challenges of developing a circular economy will also differ.

The economy is also characterised by a high proportion of small and medium-sized business. Defined as those with fewer than 20 employees, there are approximately 546,000 small businesses in New Zealand representing 97% of all firms. They account for 29.3% of employment and contribute more than a quarter of New Zealand's gross domestic product (GDP). New Zealand has around 300 manufacturing firms that employ more than 100 workers. This provides special challenges to innovation investment, which is also illustrated by relatively average performance in international innovation indicators.[5]

From initial research and experience prior to this report it was clear that onshore benefits from circular economy approaches for New Zealand, might be expected to include:

1. Reduced methane emissions from landfills	One benefit for New Zealand could be the reduction of methane emissions from landfills. Diverting compostable waste from landfills directly impacts this. In 2019, waste contributed to 4% of the country's total emissions, with 94% of that being methane from organic materials.[6] Composting these materials reduces methane emissions, can enhance soil quality through fertilisation from domestic sources, and may aid carbon sequestration.
2. Efficient management of farm waste	Optimising the use of animal and other organic waste can improve efficiency and reduce methane emissions and waste management costs. It could also reduce emissions and costs from waste transportation if the waste is treated and used on-site or locally.
3. Product life extension and maintenance	Extending the life of products and focusing on maintenance can increase resource efficiency and provide low-cost access. Even where products are not manufactured here in the first instance, local initiatives like

	repair workshops and refurbishment facilities can reduce greenhouse gas emissions by reducing consumption and waste production.
4. Material efficiencies in power generation	Initiatives, like using advanced materials for more efficient wind turbines or solar panels, can indirectly reduce onshore greenhouse gas emissions by delivering more energy for the same or lower material footprint
5. Reduced transport impacts	Expanding shared-use models and public transport can drastically reduce emissions from the transport sector. Localised manufacturing and repair services can minimise the need for long-distance transportation of goods, thereby reducing associated greenhouse gas emissions generated from distribution and reducing reliance on complex supply chains.
6. Use of lower carbon recycled materials	Using recycled materials can often lead to a lower carbon footprint compared to new, virgin materials, as it usually requires less energy to process recycled materials. There may be cost benefits and job creation opportunities too. However, this varies depending on the material, as some recycling processes can be energy intensive.
7. Efficient industrial processes	Efficiency improvements in industrial processes include using catalysts in chemical manufacturing or closed-loop systems that minimise waste. These can significantly reduce onshore greenhouse gas emissions.

These insights have helped form initial assumptions for this research.

Some environmental benefits may accrue over long periods. This is particularly the case for service life extension. The benefits may not be felt until the point where the product would have otherwise been replaced. In these cases, the longevity of associated policies and the data required for product assurance and reuse must be carefully considered. The benefits of the system design should be regularly reassessed.

The impacts of circular economy models on developing nations within our supply chains are nuanced. They require a strong focus on the systemic benefits of a circular transition. Many developing regions rely heavily on resource extraction as an economic driver. Developed nations should be mindful of the possible impacts that reducing demand could have. However, given the scale of global markets, it is unlikely that the adoption of circular economy models will result in significant reductions in these exports in the short term.

The impacts of circular economy models also spill over into our supply chains. For example, it is important to be mindful of how our products and systems impact the circularity of the regions that import from New Zealand. It is likely to be important to work collaboratively with key trade partners to ensure that New Zealand products are perceived as durable, high-value goods that support their domestic circular economy targets. Regions such as the UK have already introduced taxes linked to recycled content,[7] and the EU is introducing digital product passports[8] to capture the sustainability of imported goods for multiple sectors.

3. Evidence of impact

This section provides an overview of what is known from research and observations of the circular economy in operation at different levels of economic scale – from organisational to regional and sector level, to national economies and the global market place. It focuses on the range of impact areas in scope for this project – greenhouse gas emissions, economic growth, employment and community engagement.

3.1.1 Using the circular economy to reduce greenhouse gas emissions

There is an undeniable link between the deployment of circular economy models and the emissions associated with producing, using and disposing of products.

In theory, circular economy practices reduce the necessity for extracting new resources and minimise waste generation, ultimately leading to lower greenhouse gas emissions associated with resource extraction, production, and disposal processes.

However, this link is not always complementary; for example, an ill-conceived reuse model might lead to higher transport-related CO_2 emissions than could be offset by the recovery of the product. The optimisation of circular economy systems to ensure that economic, environmental and social objectives are met is essential. This optimisation is widely acknowledged as 'systemic' in nature, requiring a broad view of how interconnected systems operate and seeking the widest possible benefit across the system. For example, one solution to the previously mentioned model might be an increased focus on low-carbon transportation, which may benefit other businesses and act as an enabler for other reuse-based services in the same region.

It is important to recognise that environmental benefits do (and should) manifest throughout the supply chain. For developed economies, which commonly offshore many supply chain-related environmental impacts, many environmental benefits will manifest overseas in developing countries that produce raw materials or semi-finished products.

This underlines the need to avoid considering circular economies in individual organisations and sectors in isolation. As far as possible we need to consider all the connections to the other systems around them. This includes the development of the domestic circular economy, and in our global commercial partners. For example, developed economies currently offshore many supply-chain-related environmental impacts, including greenhouse gas emissions, so the resulting emissions reductions may occur there rather than here.

Organisational and sector-level development of the circular economy is increasingly demonstrating an awareness of its potential for greenhouse gas emissions reduction, including the waste sector. New Zealand's recently released waste strategy Te rautaki para by Ministry for the Environment includes emissions reduction as a key goal enabled through circular practices.[9]

The potential impact of a transition to a circular economy in key economic sectors has also been highlighted in a study of Auckland by the Sustainable Business Network and Sapere in 2018. This found the city could reduce carbon emissions by 2,700 kt CO_2e in 2030 by shifting to circular economy approaches in the key economic sectors of food, transport and construction. The largest emissions reduction potential identified in the study was due to avoided emissions embodied in food waste, followed by the uptake of electric vehicles.

The report suggests the economic opportunity ranges from $0.8-$8.8 billion. Further analysis of data from the three key sectors in Auckland indicates a range of $6.3-$8.8 billion benefit to the economy – towards the upper end of the initial estimation.[10]

The circular economy's role in reducing emissions is highlighted in practices of companies like SungEel Hitech and Umicore, as documented in the paper 'How companies improve critical raw material circularity: 5 use cases' from the International Round Table on Materials Criticality. This study reports that SungEel Hitech's recycling of lithium-ion batteries can reduce CO_2 emissions by up to 70% compared to conventional mining. Furthermore, Umicore's actions in 2021 led to the avoidance of 9.7 million tons of GHG emissions through e-mobility products and 1.8 million tons through their material input mix and recycling. These figures underscore the environmental benefits of their circular model compared to traditional mining.[11]

The New Zealand bioeconomy sector is responsible for approximately 57% of the nation's greenhouse gas emissions.[12] Initiatives underway to reduce emissions in this sector include the conversion of coal boilers to wood pellets and commercial biogas production from food waste and landfills. New Zealand has the potential to develop high value low emission products that use our bioresources to their best economic, social and environmental value, enabled through the use of circular approaches. Some of these opportunities are identified in recent research commissioned by MBIE including biocosmetics, sports nutrition and marine bioactives.[13] These opportunities not only leverage New Zealand's natural resources, but also align with internationally agreed environmental goals.

The 2021 study by Aguilar-Hernandez, et al., expands on previous analyses of circular economy scenarios, focusing on their impacts on greenhouse gas emissions, GDP and job creation through a meta-analysis of studies up to 2050.[14] The study categorizes these scenarios into two types: "moderate" and "ambitious". Moderate scenarios typically involve incremental changes or improvements within existing economic structures. These include increased recycling rates and minor shifts towards more sustainable production practices. In contrast, ambitious scenarios envision more transformative changes. These include systemic shifts in consumption patterns, significant advancements in resource efficiency and the widespread adoption of sustainable technologies and practices.

The study reports varying potential impacts based on the level of intervention. In ambitious scenarios, the study found that by 2030 the median growth in GDP was 2.0% and employment 1.6%, while median CO_2 emissions could reduce by 24.6%. Conversely, moderate scenarios indicated a negligible change in GDP and employment, alongside a median reduction in CO_2 emissions of 4.1%. The study presents these outcomes without suggesting their broader significance, allowing for an objective interpretation of the environmental and economic impacts of different circular economy interventions.

Table 1 Summary of Aguilar-Hernandez findings on impacts of Moderate and Ambitious circular economy scenarios on GDP, Employment and Emission reductions for 2030 (Median and Inter Quartile Range).

Scenario		GDP Growth	Employment Growth	CO_2e Emission Reduction
Moderate	Median	0.1%	0.1%	4.1%
	IQR	0% to 0.3%	0% to 0.4%	10.2% to 0.3%
Ambitious	Median	2%	1.6%	24.6%
	IQR	0.4% to 4.6%	0.9% to 2.0%	34% to 8.2%

The emphasis identified in the Aguilar-Hernandez paper on production-based emissions, as seen in the majority of studies assessed, suggests that the environmental impact evaluations predominantly reflect the emissions generated within a country's own borders, potentially overlooking the global impact of consumption patterns and the emissions embodied in internationally traded goods and services.

At the global scale, in 2021 The Ellen MacArthur Foundation reported that circular economy practices focussed on cement, plastics, steel, aluminium and food worldwide had the potential to reduce greenhouse gas emissions by 9.3 billion tonnes. This equates to all the emissions from transport.[15]

The 2022 Hailemariam report, focusing on European countries, presents data indicating that advancements in a circular economy might contribute to a tangible reduction in CO_2 emissions.[16] The study found a correlation where a 1% increase in municipal waste recycling rate corresponds to an approximate 0.06% reduction in CO_2 emissions. This evidence underscores the impact of enhanced recycling and waste management practices within the framework of a circular economy.

The Hailemariam report offers empirical evidence of the impact of circular economy practices on reducing emissions in Europe. However, applying its findings to other regions requires consideration of its methodological nuances and the unique economic and environmental contexts of these regions.

The evidence and experience to date indicates that achieving these reductions in emissions requires a comprehensive approach and greater policy integration between circular economy and climate goals. This includes redesigning products, increasing resource efficiency and promoting sustainable practices across various sectors.[17] This approach is evident in European Union initiatives like the Green Industrial Plan, the Circular Economy Action Plan and the Net-Zero Industry Act.[18]

3.2 The circular economy, productivity and economic growth

3.2.1 Signs from overseas

Although widely recognised for its potential to reduce environmental impacts, the circular economy is, first and foremost, an economic model. There are undoubtedly environmental and social benefits to well-implemented circular economy models. But these benefits are almost side-effects of a transition that is designed to reduce the cost of waste and resource inputs, retain value and minimise exposure to the risks of volatile supply chains, competition for resources, regulation and consumer perception. As circularity involves more efficient use of physical resource inputs it will also improve productivity metrics.

The circular economy, as examined by Aguilar-Hernandez et al. in their 2021 meta-analysis, holds the potential to impact GDP growth significantly.[19] Their findings suggest that ambitious circular economy strategies could result in GDP growth ranging from 0.1% to 2.0%. See Table 1.

The European Union anticipates that its circular economy package will generate cost savings of approximately EUR600 billion through initiatives like waste prevention, eco-friendly design and reutilisation, and fostering job creation.[20]

However, transitioning to a circular economy comes with its complexities and challenges. As highlighted in the literature review by Mohammad Javad Ramezankhani et al[21] the economic benefits of circular economy practices may not seamlessly align with current economic and industrial structures, potentially necessitating significant investments in new technologies or processes that could impact short-term economic gains. Moreover, the interconnected nature of global supply chains means that changes in one region can have intricate effects in others, influencing the overall economic impact. It is crucial to consider immediate economic outcomes and long-term environmental and social costs and benefits when evaluating the transition to a circular economy. Addressing technological barriers, market dynamics, and regulatory requirements requires a comprehensive perspective.

Similarly, the EU Green Deal and Circular Economy Transition report indicate that Production Taxes might have only modest impacts on CO_2 emissions and material use. However, reallocating tax revenue could potentially stimulate growth and improve welfare.[22] This underscores the importance of a nuanced and comprehensive approach when considering the economic implications of transitioning to a circular economy.

In the case of the Netherlands, the 'Integral Circular Economy Report 2023' reveals a notable improvement in resource efficiency.[23] Over the period from 2014 to 2020, there was a 12% increase in resource efficiency, as measured by GDP in EUR per kilo of Domestic Material Consumption (DMC). This represents a significant achievement within the European Union. However, it is important to note that these efficiency gains were primarily driven by the expansion of the service sector and increased value in industries such as machinery, construction and power companies. These improvements do not directly reflect a complete shift towards a circular economy.

Nonetheless, achieving the Dutch goal of halving resource use by 2030 presents challenges, as the efficiency improvements have not yet resulted in a substantial reduction in the link between resource use and economic growth. The complexities of substituting primary resources with secondary materials further complicate this transition. In 2020, secondary materials met only 24% of resource demand for domestic use and 13% overall. Limited availability of existing stocks to replace a larger share of required resources and the potential loss of some materials to waste or energy recovery contribute to these complexities.

Moreover, while the Netherlands boasts high recycling rates (78%), there has been limited progress in achieving high-quality recycling. Additionally, the increasing dependence of the Dutch economy on foreign material resources and products underscores the challenges of transitioning to a fully circular economy. Circular strategies applied during the use phase of products in the Netherlands remain limited, with certain product lifecycles, such as in furniture and electronics, even decreasing due to design complexity, spare parts availability and insufficient standardisation.

Despite these complexities, there is a growing trend towards embracing the circular economy in the Netherlands, with an increase in circular companies and employment in relevant sectors indicating a gradual shift towards circularity.

A research consortium, led by the Finnish Environment, has released preliminary results of scenarios on the use of natural resources in Finland. According to the estimate, GDP growth seems to be slightly higher due to the effect of circular economy measures, especially since it has not been possible to model all the potential effects of circular economy business models.[24] However, it should be noted that progress to date by Finland towards achieving greater circularity has been slow. This is despite being the first country to adopt a national circular economy roadmap to reduce the material footprint of its national economy in 2016.

Furthermore, a 2023 report by the European Court of Auditors found that the pace of progress towards greater circularity remains slow across the EU and its ambition of doubling its share of material recycled and fed back into the country by 2030 looks ‘very challenging’.[25]

Applied to the New Zealand context, a 2018 study estimated that for Auckland alone, the economic opportunity could be as much as $6.3-$8.8 billion by 2030 through initiatives in the construction, transport, and food sectors.[26]

In New Zealand, businesses are already integrating circular economy principles into their business models. Companies like Ethique, AgainAgain, XFrame, Medsalv, Blunt Umbrellas and Goodfor are notable examples. This transition to circularity aligns with sustainable practices and can create new economic opportunities, fostering innovation in reuse, remanufacturing and recycling.

3.3 The circular economy, employment and community engagement

A common theme across various studies and reports is the positive impact of the circular economy on employment. While this may be seen as an economic benefit, there is a greater social component to job creation, especially where those jobs may be regional or distributed and particularly where those jobs may be skilled or semi-skilled.

These strategies, especially ambitious ones, are expected to increase job opportunities, with the meta-analysis of Aguilar-Hernandez indicating an increase in employment of between 0.1% and 1.6% under moderate and ambitious circular economy scenarios respectively, see Table 1.

Jobs commonly associated with circular economy models typically include:

- materials recovery
- remanufacturing
- maintenance or repair of products
- the provision of services associated with those products

In New Zealand, circular economy related employment examples are broad, and not restricted to the waste industry. Food rescue related jobs have been created in logistics and warehousing, such as New Zealand Food Network which support 65 food hubs around the country to access bulk product donated by manufacturers and retailers.[27] In the built environment, deconstruction jobs have been created through firms such as Pasifika-owned TROW Group which dismantles and repurposes materials, often redistributing these to community projects.[28] Deconstruction (vs demolition) is supported through progressive public procurement by Auckland Council[29] and Kāinga Ora.[30] Another example are tech related jobs in the services space such as Mutu, a B2B platform that connects business stock inventories for trade or donation[31]. Initiatives like community gardens and local food production also create jobs and improve food security and access, fostering a culture of sustainability and responsible consumption.[32]

However, the transition to a circular economy is likely to be challenging. The literature suggests potential job substitution, loss, redefinition and concerns about job duration and quality[33] and also indicates that the social impacts of circular economy are varied and can be complex, with potential trade-offs between regions and sectors.[34] Training opportunities to support new and emerging circular economy related roles is crucial to adapting to changing job demands and ensuring worker safety.[35]

3.4 Distributed impacts of the circular economy

A common thread across studies of the circular economy is the recognition that while the circular economy presents numerous benefits, it also brings forth challenges and trade-offs that need careful management.

As we've seen, the circular economy has been associated with potential GDP growth and job creation, see Table 1. However, the impact on specific sectors varies. For instance, the transition could increase net employment in labour-intensive service sectors, such as repair or remanufacturing. Still, it might result in job losses in material-intensive sectors, such as mining or packaging, as well as waste management.[33] This shift in job opportunities underlines the need for targeted policies to manage the transition, especially in regions or sectors that might be adversely affected.

This is also the case with regards to environmental impacts. The implementation and effectiveness of environmentally orientated circular economy policies are not uniform across regions. This can be seen in the disparities in China's regional progress. Eastern provinces, ahead in production technology, contrast sharply with other regions still improving in environmental performance and energy intensity. A minority of provinces show efficiency in policy implementation, while the rest struggle, highlighting a disparity in the ability to enact these policies effectively. The capacity and effectiveness in resource recycling and utilisation also vary significantly across regions, as do the successes in industrial symbiosis projects and the greening of industries. Additionally, the development and performance of Eco-Industrial Parks (EIPs) and the challenges in establishing markets for secondary materials, such as in Shenzhen's Special Economic Zone, are markedly different across provinces. This uneven progress underscores the necessity for region-specific strategies to address local environmental challenges effectively and optimise the implementation of circular economy policies in China.

This example from China indicates the potential need for region-specific strategies to effectively address local environmental challenges in New Zealand.

In transitioning towards a circular economy, there is not only a need for a realignment of jobs and training but also an opportunity to address existing disparities in employment sectors. This shift could significantly impact economies reliant on specific industries, such as the mining sector in relation to electronics recycling.[36] In addition, populations highly represented in high-emission industries, such as manufacturing, utilities and construction,[37] may benefit from targeted employment opportunities in the emerging circular economy. This approach could form a key part of deliberate policies aiming to mitigate the downsides of transitioning to a low emissions economy.

3.5 Circularity and supply chain risk mitigation

The concept of a circular economy involves managing materials responsibly to enhance long-term resilience and sustainability. This could work to mitigate the risks associated with increasingly uncertain or disrupted supply chains during political instability, conflict, or a shift in emphasis away from globalization towards domestic economics.

In this report we differentiate between "Critical Minerals" and "Critical Materials," outlining governments and businesses' specific interests and strategies. This includes their importance in national security, economic stability, technological advancement, and industrial strength.

Governments prioritise Critical *Minerals* for their crucial role in national security, economic stability, and technological innovation. They aim to secure stable and reliable supplies, which geopolitical tensions, supply chain monopolies and environmental or ethical challenges can compromise. To mitigate these risks, governments may pursue diplomatic efforts, establish strategic alliances and invest in domestic mining or recycling operations.

Conversely, *the business sector* focuses more on Critical *Materials*, especially in manufacturing and technology. Businesses incorporate these materials, often derived from critical minerals, into alloys or specific compositions to achieve desired properties and performance standards for their products or technologies.

Recognising these distinctions is vital to understanding the interconnectedness of global supply chains and the strategic importance of minerals and materials. Governments aim to secure access to critical minerals for industrial and technological development, whereas businesses emphasise the need for advanced materials. This creates a mutual dependence, highlighting the need for a diverse and stable mineral supply.

Geopolitical disruptions to supply chains may encourage the adoption of circular economy practices, primarily to mitigate supply chain risks. This approach enhances economic independence and resilience against such disruptions and is relevant to both known critical minerals and critical materials and those that may emerge in the future that are vital to the New Zealand economy.

In their critical minerals strategies, the US, EU, and UK include elements of the circular economy. They focus on supporting industry to create more durable products and developing recycling infrastructure to create a secondary, domestic sources of supply. Both reduce the need for new imports and create supply chain resilience.

Crucially, there is a strong role for governments to work with businesses to establish the market conditions that enable durability, reuse, repair and recovery of critical materials to be prioritised over continuing reliance on access to critical minerals.

Key minerals in this context include rare earth elements like neodymium and dysprosium, critical to electric vehicles and power generation, both produced predominantly by China. Recent disruptions in microchip supply are also being keenly felt by increasingly technological economies, especially in cyber-security and defence.[38]

The Ministry of Business, Innovation and Employment (MBIE) in New Zealand is in the process of developing a list of critical minerals. This aims to identify the minerals that are economically important to New Zealand and vulnerable to supply chain disruptions.

A focus of the circular economy is also on diversifying and strengthening supply chains. For example, focusing on local sourcing and reducing dependency on international trade enhances stability against global market volatility. The Netherlands has also observed how this approach is further supported by promoting regional collaboration and initiatives to bring production back onshore (reshoring). In New Zealand we expect a significant change in domestic demand for scrap steel, which is currently recycled offshore, as New Zealand Steel's electric arc furnace is commissioned.[39]

The circular economy advocates for sustainable and ethical sourcing practices. This addresses reputational risks by helping companies align with growing consumer and stakeholder expectations for environmental stewardship and social responsibility – Forest Stewardship Council (FSC) certification of timber products or Conflict Free Certifications for minerals are good examples of this.

There is a growing trend in nations' policies towards sustainable and circular practices. This means businesses adapting to these changes can avoid the resulting regulatory risks. For example, France's "Right to Repair" regulations place a strong emphasis on product longevity,[40] EU standardization on USB-C mobile phone chargers significantly reduces redundancy and waste, and the UK plastic packaging tax incentivises incorporating recycled content and ensures efficient recycling, as well as supporting domestic plastic reprocessing activities.

Critical materials, encompassing both raw and processed elements, are considered vital for economic and national security. These materials play a key role in manufacturing various products - from electronics and renewable energy systems to advanced manufacturing equipment. They include primary materials like phosphates, crucial to agriculture, and rare earth elements required for renewable technologies.

For instance, the UK's Critical Minerals Strategy aims to balance supply and demand via three main objectives[41]:

1. **Fostering Sustainable Domestic Production (Supply-oriented)**: This objective targets both primary and recycled material production to establish a robust domestic supply of essential minerals. By focusing on sustainable practices, the UK seeks to increase both the market value and global acceptance of its domestically produced materials, even at a premium cost.
2. **Cultivating International Partnerships for Mutual Supply (Supply-oriented)**: Acknowledging its limitations as a resource-scarce nation, the UK aims to fortify its supply chains by forming equitable and sustainable partnerships with stable international stakeholders.
3. **Integrating Principles of the Circular Economy (Demand-oriented)**: This objective emphasises reducing dependency on external sources. The UK aims to mitigate supply-related risks by

focusing on high-quality sourcing and manufacturing through design innovations that prioritise durability, reusability and reparability.

The EU's impending Critical Raw Materials Act is set to take a similar approach.

4. New Zealand material flow

We undertook a comprehensive analysis of the potential impacts of circular approaches on emissions, jobs and other factors in New Zealand, identifying opportunities for emissions reduction and broader impact across three sectors – Food and Agriculture, the Built Environment and Advanced Manufacturing.

The work comprised the following steps:

1. An assessment of existing material flows for the target sectors in New Zealand, and the associated emissions, displayed as Sankey diagrams.
2. The identification of key material flows indicative of opportunities for circular economy intervention.

Drawing on both of these, the development of circular economy interventions and the estimation of the potential benefits of these interventions to emission reduction targets and broader impacts.

As noted, 2019 was used as the reference year for this assessment as the most recent 'normal' year with the most complete data. Data for subsequent years available at the time of this work would either be incomplete or heavily influenced by the COVID-19 pandemic.

4.1 Sankey diagrams

Sankey diagrams are a type of flow diagram that visually represent the flow of resources, energy, materials, or costs between different stages of a process. Their distinguishing feature is that the width of the arrows or lines in the diagram is proportional to the amount of flow they represent. This makes Sankey diagrams particularly useful for displaying the distribution and conservation of resources in a system, such as energy or material balances in industrial processes or the budgetary flows in an economic system.

By their nature, Sankey diagrams can contain a lot of information. When reading or interpreting a Sankey diagram, it's important to focus on the direction and thickness of the lines. The direction indicates the flow's path, starting from a source and ending at a destination. The thickness, as mentioned, is proportional to the quantity of the flow, allowing for an immediate visual comparison of the different flows within the system.

In more complex Sankey diagrams, colours can also differentiate types of flows or indicate separate systems, materials, products, or processes within the diagram. The key to interpreting these diagrams is to follow the path of the flows, noting where they originate, where they terminate and how they are distributed or transformed along the way. This provides a clear and concise visual representation of how resources move through a system.

In the Sankey diagrams presented here, flows represented by an arrow (→) denote a flow that is thought to exist but for which no data was identified. These could represent minor flows or significant gaps in published data. Some flows are annotated with an '!' which indicates that the inflow lacks a corresponding outflow.

4.1.1 New Zealand High Level Major Inputs Sankey

The high-level material flows identified in Figure 2 illustrate some of the major inputs to the New Zealand economy, the major consumers of those inputs and the outputs of those flows.

High-level material flows for New Zealand

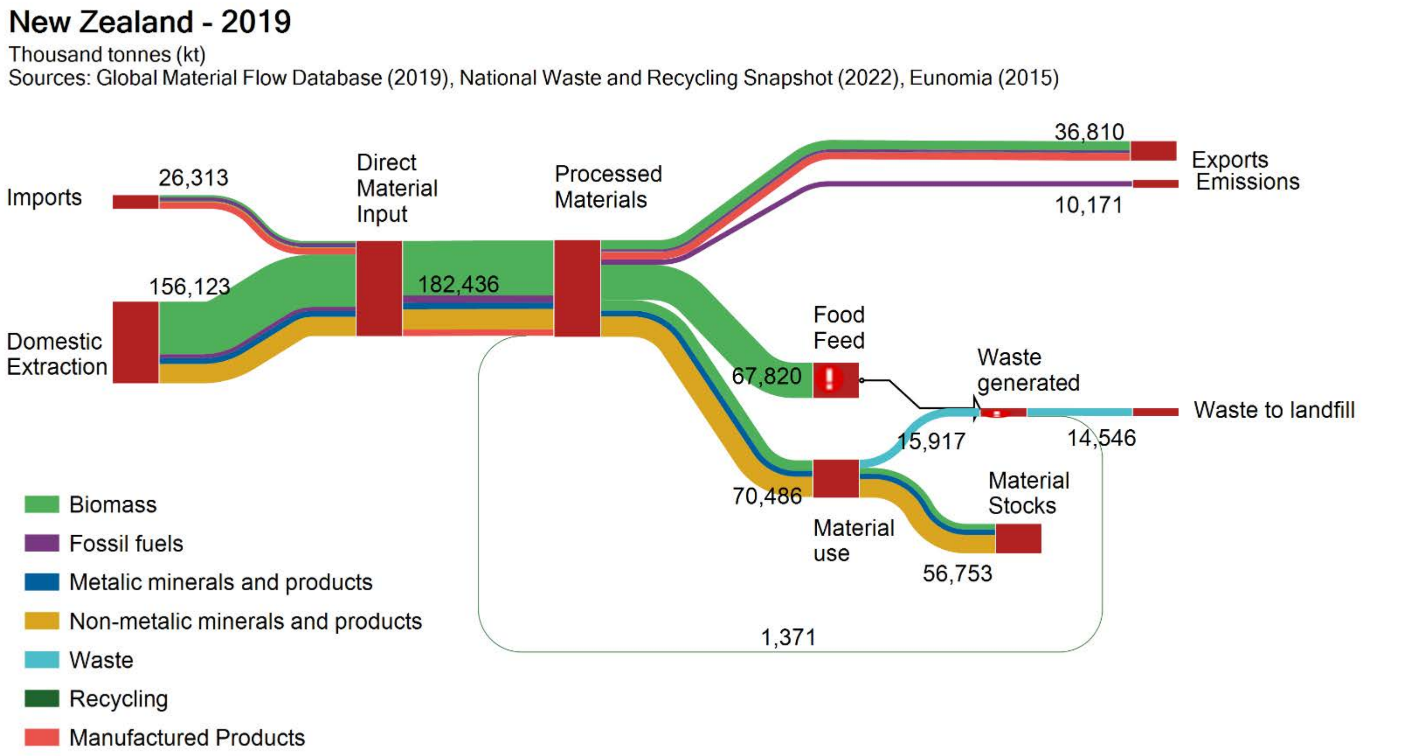

Figure 2. High-level material flows for New Zealand.

4.1.1.1 Additional observations

Whole system

- The total inflow of materials into New Zealand is 182,436 kt. This is the sum of imports (26,313 kt) and domestic extraction (156,123 kt). The dataset covers Biomass, Metal Ores, Non-Metallic Minerals, Fossil Fuels and Mixed and Complex Products.

Biomass

- Biomass (renewable organic material that comes from plants and animals) represents the most significant national material at 64% (100,499 kt) of the total inflow.
- 100,499 kt of biomass material is extracted from the New Zealand environment, most of this flowing into food and feed to support the agricultural sector, as fodder crops such as grass and grain. This is about twice that of other materials extracted from the New Zealand environment: i.e. 36,807 kt of non-metallic minerals, 11,335 kt of metal ores and 7,482 kt of fossil fuels.
- Organic farming, one indicator of regenerative practices within the sector accounts for 1.05% of dairy land and 2.45% of land for fruit and vegetable production in New Zealand.[42]
- Approximately 72% of forestry in New Zealand is FSC certified.[43]
- Marine Stewardship Council (MSC) indicates that around half of New Zealand Fisheries are “responsibly managed.”[44]

Imported Materials

- There are 13,838 kt of materials are imported into the country, 6,265 kt (45%) of fossil fuels, 4,453 kt (32%) of biomass, 1,838 kt (13%) of minerals and 1,280 kt (9%) of metal ores.

Processed Materials

- Exports from the New Zealand economy are dominated by 17,765 kt of biomass (78%) followed by 3,576 kt (20%) of fossil fuels, 1,308 kt (7%) of metal ores and 112 kt (0.5%) of minerals.
- Domestically, Food and Feed for Agriculture represents a significant flow at 67,820 kt, however, we were unable to identify how much of this ends up as waste.
- 56,753 kt flows into Material Stocks, which are products that are used by the New Zealand economy, and which will, at some future point, become an outflow that will either be captured or will become waste. A significant portion of this is likely to be concrete and aggregates used for buildings and infrastructure, with some steel and timber.
- Manufactured products, while a relatively minor flow, may reflect a technological dependency, such as electronic equipment, vehicle parts and machinery, relatively minor flows that underpin the capabilities needed for more significant economic activities.

Fossil Fuels

- New Zealand imported 6,265 kt of fossil fuels and produced a further 7,482 kt domestically, 13,747 kt in total. Exports totalled 3,576 kt, leaving domestic consumption at 10,171 kt which have been assumed to end up as emissions.
- Fossil fuels comprised almost 45% of the 13,838 kt of materials imported and 4.8% of the 156,123 kt extracted domestically. Overall comprising 7.5% of the 182,439 kt of material inflows to the New Zealand Economy.

Waste

- Of the 182,436 kt of materials that flow into the New Zealand economy, 14,546 kt ends up as waste in landfill, representing 8.5% of the total. Figure 7 provides more detail.
- Less than 1% (1,371 kt), of materials are recovered, indicating a notably low level of material recovery through recycling or composting, particularly when compared to similar-sized European nations. For instance, Norway demonstrates a substantially higher recycling rate, successfully recycling approximately 30% of its materials.[45]

4.1.2 New Zealand Waste Sankey

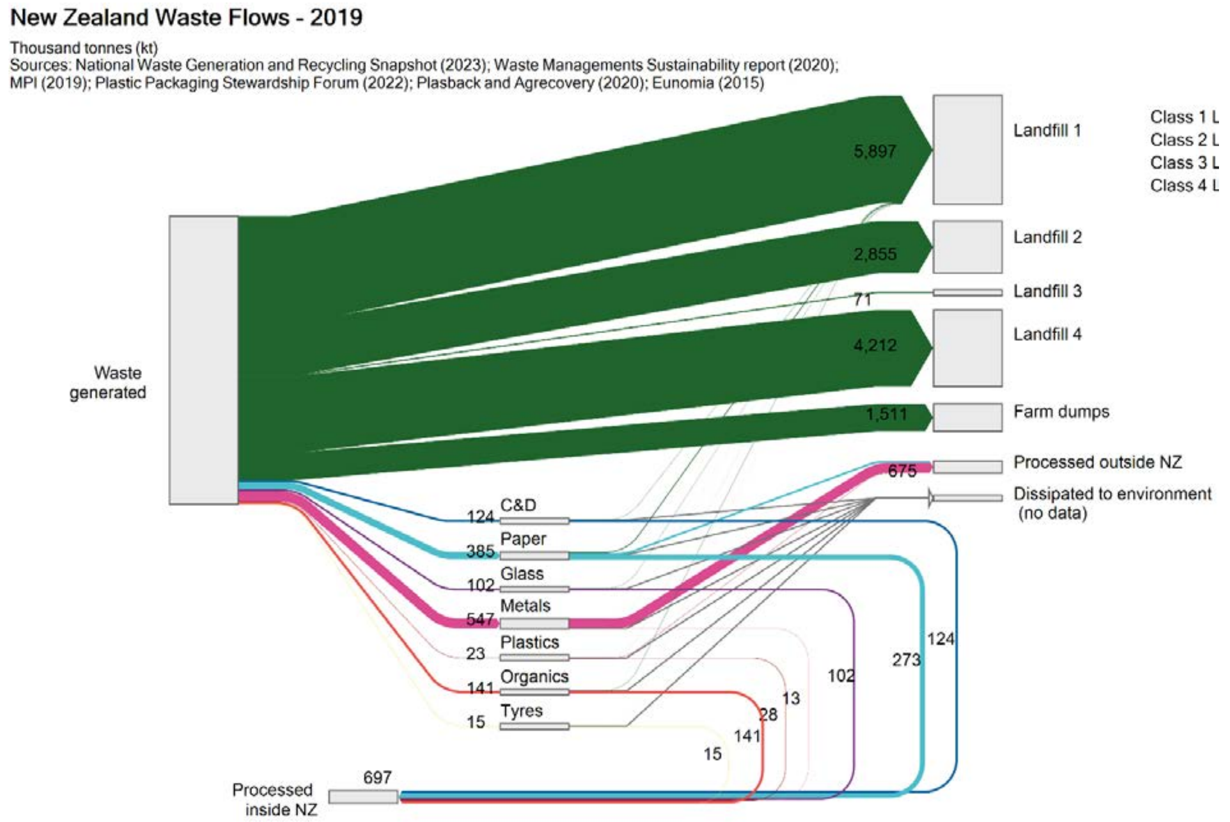

Figure 3: High-level material waste flows for New Zealand.

The high-level material flows identified in Figure 3 illustrate some of the major outputs from the New Zealand economy and the current material recovery level.

4.1.2.1 Key observations

- Of the 17,288 kt of waste generated by New Zealand in 2019, the majority (92%) ended up in landfill. This comprised 5,897 kt (34%) to Class 1 landfill, 2,855 kt (16.5%) to Class 2 landfill, 71 kt (0.4%) to Class 3 landfill, 4,212 kt (24%) to Class 4 landfill and 1,511 kt (9%) to farm dumps.

- Of the remaining 1,371 kt (8%) of waste that was either recycled or exported, this comprised 124 kt (9%) Construction and demolition waste, 385 kt (28%) Cardboard and paper, 102 kt (7%) Glass, 560 kt (41%) metal, 43 kt (3%) plastics, 141 kt (10%) Organics and 15 kt (1%) Tyres.

- Almost all metal waste, 547 kt (98%), was exported to be processed outside of New Zealand. This is something that would likely change when New Zealand Steel's planned new infrastructure is commissioned.[46]

- 697 kt (4%) of all waste was recycled in New Zealand, this comprised 124 kt (18%) Construction and demolition waste, 273 kt (39%) cardboard and paper, 102 kt (15%) glass, 13 kt (2%) metal, 28 kt (4%) plastics, 141 kt (20%) organics and 15 kt (2%) tyres.

4.1.3 New Zealand Food Sankey

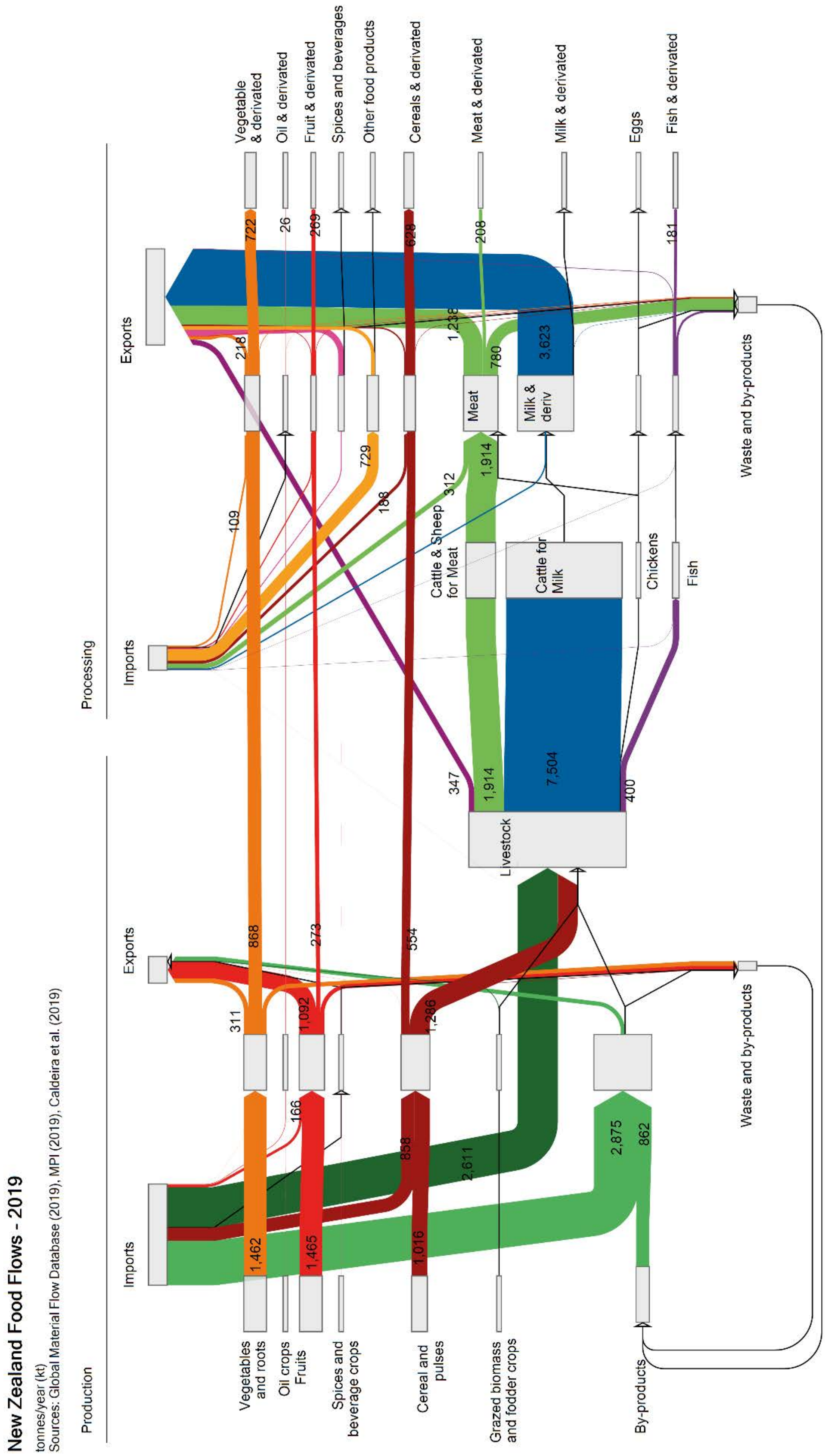

Figure 4: High-level food flows in New Zealand.

The high-level Food flows identified in Figure 4 illustrate some of the major material Inputs to the New Zealand economy, the major uses of those inputs and the outputs of those flows.

4.1.3.1 Additional observations

Grazed biomass and fodder crops

- Production of grazed biomass (i.e. pasture grass) and fodder crops for livestock represent by far the most tonnage for New Zealand at 75,922 kt/year, making up three quarters of total New Zealand grown biomass of 100,499 kt. As a result its flow on the Sankey has been omitted due to the significant impact it would have on the proportions of other flows on the diagram.

Vegetables and roots and Fruits

- New Zealand appears largely self-sufficient for Vegetables and root crops as well as Fruits, exporting 529 kt of the former and 1,092 kt of the latter in addition to serving its own needs.

Cereal and pulses

- Of the 1,874 kt of Cereal and pulses that flow into the New Zealand economy, 858 kt (46%) is imported, and 1,286 kt (70%) goes to animal feed.

Imports (for production)

- In addition to the Cereal and pulses imported 2,611 kt of imported animal feed and 2,875 kt of imported seed for fodder crops increases the food flow input footprint to around 84,000 kt of input.

Livestock

- Inputs for livestock enable the support of 1,914 kt of cattle and sheep for meat and a further 7,504 kt of cattle for milk production.

Exports

- New Zealand exports 1,238 kt of meat and 3,623 kt of Milk and Milk derivatives.
- New Zealand appears largely self-sufficient for Vegetables and root crops as well as Fruits, exporting 529 kt of the former and 1,092 kt of the latter in addition to serving its own needs.

4.1.4 New Zealand Energy Sankey

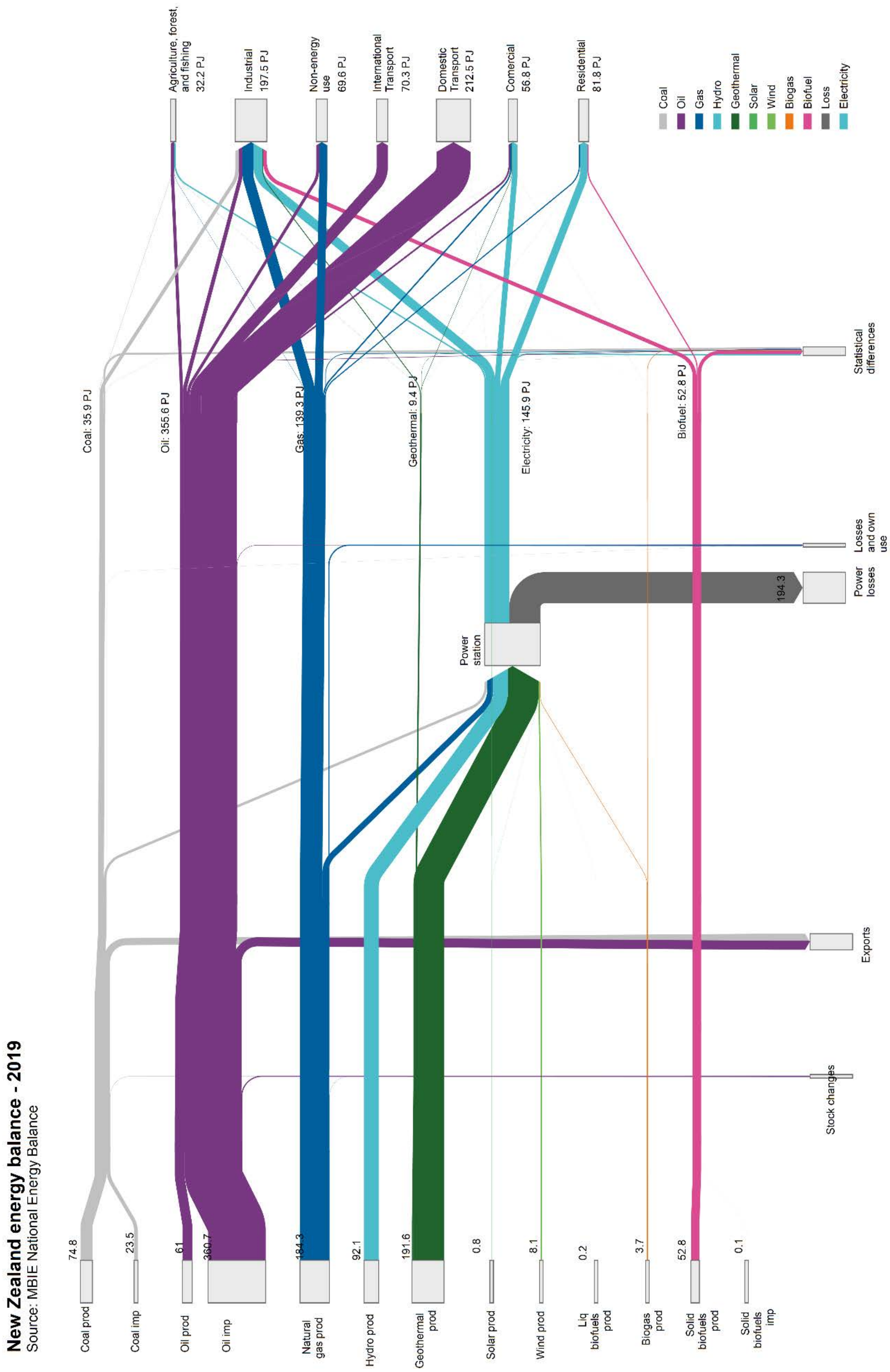

Figure 5: High-level energy flows in New Zealand.

The high-level energy flows identified in Figure 5 illustrate some of the major sources of energy and outputs from the New Zealand economy.

4.1.4.1 Additional observations

Total energy flow

- 1,054PJ of energy flowed through the New Zealand economy in 2019
- 66% comprised non-renewable fossil fuels (40% Oil, 17% Natural Gas, 9% Coal).
- 55% of this non-renewable fuel was imported.
- Of the 915PJ of energy consumed in New Zealand, 349.4PJ (38%) was from renewable sources including biofuels.

Oil

- 85% of oil flow was imported making New Zealand heavily reliant on international oil supply chains.
- 50% of the oil used was consumed by domestic transportation and 17% by international transportation.

Natural gas

- New Zealand appeared to be self-sufficient in natural gas, which was consumed primarily by Industrial uses, non-energy uses and electricity production.

Coal

- Of the coal used, 24% was imported.
- Around half of the coal in the New Zealand economy was exported, but it was unclear how much of this was New Zealand-produced coal.
- 36.5% of coal in the New Zealand economy was used onshore primarily for industrial purposes, with a small proportion being used for power production.

4.1.5 New Zealand Built Environment Sankey (mass)

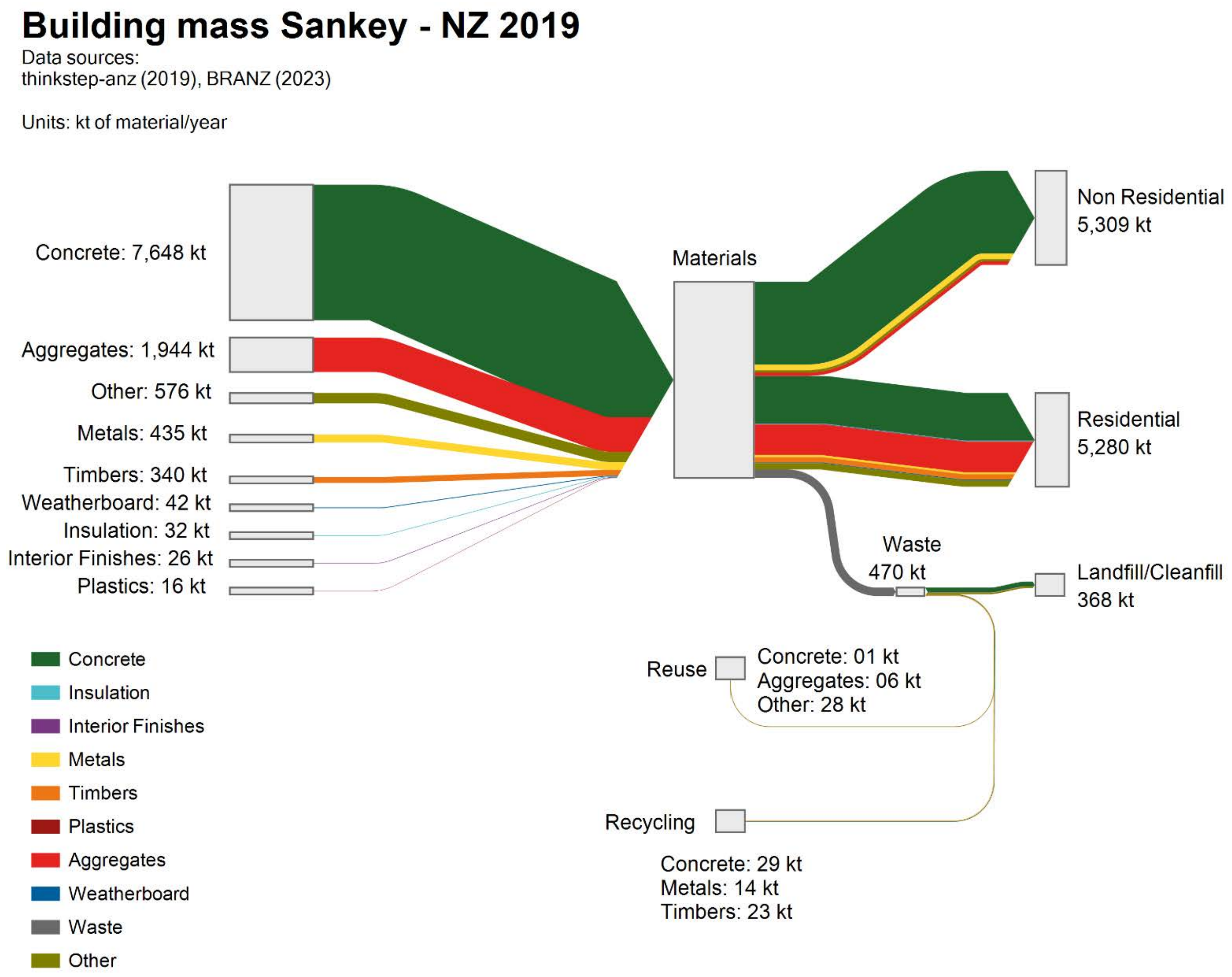

Figure 6: High-level material flows for the Built Environment sector in New Zealand.

The high-level material flows identified in Figure 6 illustrate some of the major inputs to the built environment in New Zealand, the proportions that are used by residential and non-residential activities and the level of material recovery that currently exists for construction waste. Note: These figures do not include demolition waste because there is a disconnect between materials flowing into the built environment and those becoming demolition waste linked to the lifetime of the asset, which may be 50 years or more. This means that demolition waste is more closely associated with historical construction flows than present day material consumption.

4.1.5.1 Key observations

Concrete and aggregates

- By mass, concrete and aggregates dominate the material flows, comprising 9,592 kt (87%) of the 11,059 kt of material consumed. This may not be the case as much when considering volume, as concrete and aggregate are denser than many other construction materials.

Residential and non-residential

- Residential and non-residential construction consumed similar quantities of materials.
- It is unclear why the residential use of aggregates is more significant than non-residential. Possible reasons include higher levels of supporting infrastructure such as roads, foundations, driveways or the generally lower-rise construction of residential construction, leading to more aggregate.

Metals

- Metals comprised a smaller flow by mass at 435 kt (4%), with more going into non-residential applications.

Timbers and weatherboard

- Timber and weatherboard comprised 382 kt (3.5%), with the majority being used in residential applications.

Construction waste

- Of the 470kt of construction waste, 368 kt (78%) were sent to landfill/clean fill, with 35 kt (8%) being reused and 66 kt (14%) being recycled.
- Recycling activities focused on Concrete (44%), Metals (21%) and Timbers (35%).

4.1.6 New Zealand Built Environment Sankey (emissions)

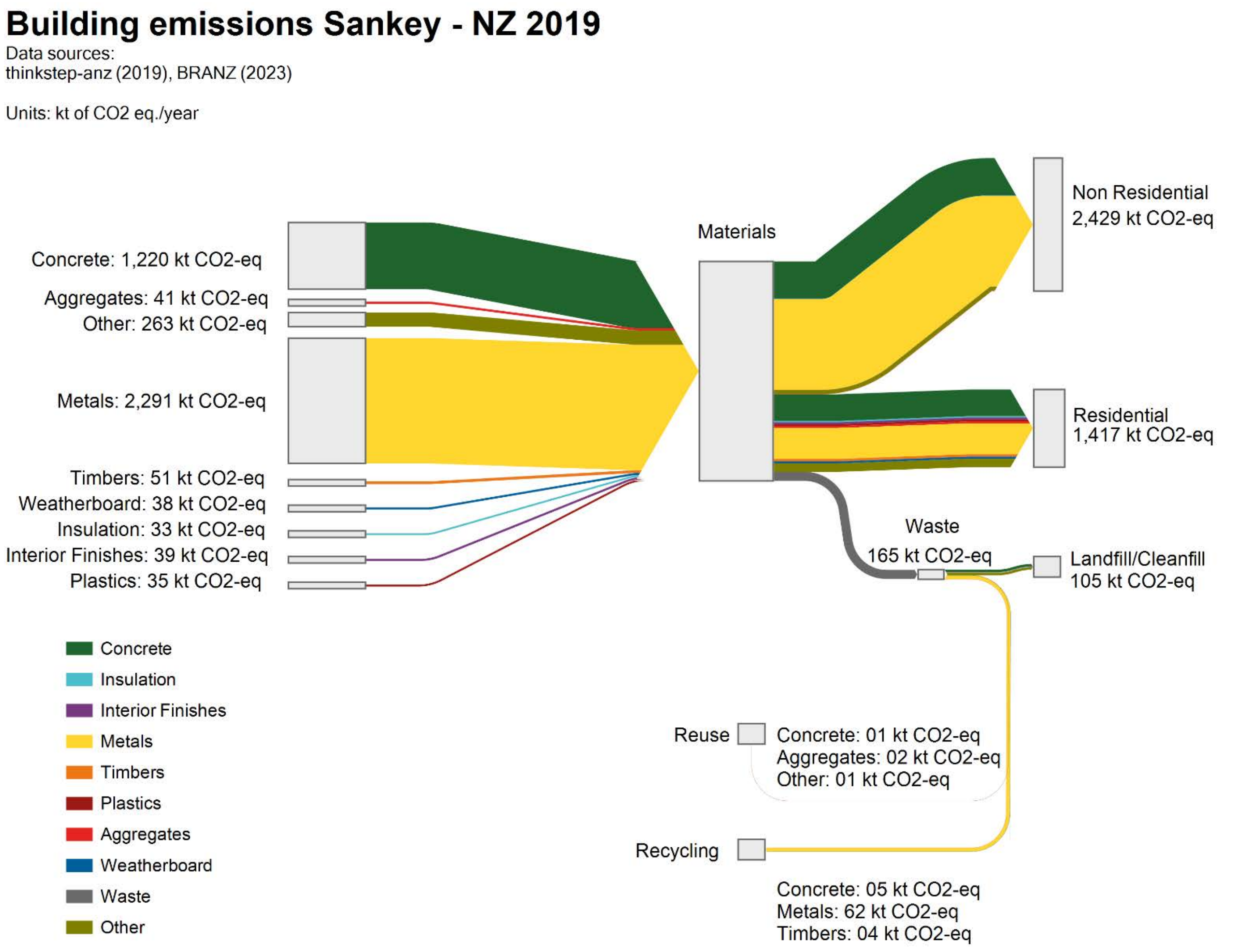

Figure 7: High-level emission flows for the Built Environment sector in New Zealand

The high-level emission flows identified in Figure 7 illustrate some of the major sources of emissions to the built environment in New Zealand, the proportions that are used by residential and non-residential activities and the level of embodied emissions that were recovered through reuse and recycling activities.[47]

4.1.6.1 Key observations

Metals

- While in Figure 6, the mass of concrete and aggregates dominated the flows, from an emissions perspective, metals have a greater role to play.
- Of the 4,011 kt CO_2 eq embodied in New Zealand building materials in 2019, 2,291 kt (57%) were from metals, 1,261 kt (31%) were from Concrete and Aggregates and 89 kt (2%) were from timber and weatherboard.

Residential and non-residential

- While the mass of materials consumed by residential and non-residential construction was similar in Figure 6, the embodied emissions of non-residential construction represented 61% of the total, with residential emissions representing only 35%. A possible explanation might be a greater proportion of metals being used in non-residential construction.

Waste

- Of the embodied emissions that flowed into the New Zealand economy as building materials in 2019, 165 kt (4%) ended up as waste. A total of 105 kt of this was sent to landfill/clean fill, primarily concrete. Metals comprised the most significant portion recovered through recycling at 62 kt.

5. Other relevant data

Waste composition data for Class 1 landfill composition was unavailable at the time of the Sankey analysis, but has been published recently by the Ministry for the Environment, see Table 2.

The total mass of Class 1 landfill reported here of 3,499.7 kt represents 59% of the 5,897 kt waste figure identified in the Waste Sankey Figure 3 using other sources. Further work would be required to reconcile these figures. The landfill composition in Table 2 does however provide a useful breakdown of waste types, indicating that the largest contributor by weight are Inert materials, which include plastics.

Table 2 Class 1 Landfill Composition, 2019 [48]

Fraction	Mass (kt)	% of Total
Inert	2,007.34	57%
Food	315.29	9%
Garden	199.68	6%
Nappies	87.58	3%
Paper	206.69	6%
Sludge	66.56	2%
Textile	175.16	5%
Wood	441.40	13%
TOTAL	3,499.70	100%

Table 3: Comparison of headline data for Built Environment with thinkstep-anz 2019 report "Under Construction" [49]

Metric	"Under Construction"	This Report
% Mass - Concrete	71%	69%
% Mass – Metals	4.4%	4%
% Mass – Timber & Weatherboard	3.8%	3.5%
Total Emissions (kt CO_2e)	2,900	4,011

6. Identified hotspots and interventions

This section presents five key hotspots identified through the Sankey development process, as outlined in Table 3. The overall method was iterative, with feedback gathered over four weeks. This included internal research working group sessions to develop a shortlist and external workshops attended by industry stakeholders and government policymakers, including representatives from the Ministry of Business, Innovation and Employment (MBIE) and the Ministry for the Environment (MfE) to test. This approach was adopted to provide a focused starting point for deeper investigation and discussion among the broader project team and stakeholders, with the understanding that further refinement and validation are required.

A rapid ideation process was used to gather initial observations in early November 2023. These insights were then collated into common themes and potential interventions explored. The draft Sankey diagrams and initial hotspot shortlist were presented externally in late November 2023 to gain feedback from a wider audience. Prioritisation was based on the criteria of: major sources of emissions, consumption, waste or supply chain risk relevant to New Zealand.

It's important to recognise the limitations of this method. The list of hotspots and corresponding interventions were developed based on the initial criteria and available stakeholder feedback, but they do not represent a consensus or an exhaustive analysis.

Table 4 Identified Circularity Hotspots, intervention areas and target benefits

#	Observation	Intervention Focus	Rationale
		Explored In detail	
1	57 million tonnes of material flowing into stocks (minerals, metals, biomass)	• Advocate for **Resource Efficiency in Material Use** to foster economic growth. • Promote infrastructure development for resource recovery and reuse.	• Encourage innovation in the construction and infrastructure sectors. • Create employment opportunities through industrial diversification.
2	Food, agriculture & biomass dominate mass & CO_2 flows and exports.	• Implement **Sustainable Agricultural Innovations** to boost export quality and reduce supply risks. • Enhance domestic supply chain efficiency to support local industry.	• Strengthen economic resilience and market competitiveness. • Prioritize efficiency in resource utilisation to bolster industry growth.
3	Heavy reliance on imports for technology products and critical materials.	• Enhance economic resilience through **Circular Critical Materials** and Local (Re)manufacturing Capabilities. • Initiate Skill Development Programs for the Circular Economy Sector.	• Foster economic resilience and technological self-sufficiency. • Cultivate a skilled workforce for a future-proof economy.
		Explored at a high level	
4	Significant volume of materials being landfilled.	• Advance efficient waste prevention and management practices to optimise resource use.	• Improve national infrastructure for waste management. • Elevate the economic value of secondary materials.
5	Heavy reliance on imported non-renewable energy.	• Develop diverse energy solutions, including renewable options. • Encourage Smart Transportation Systems with a focus on efficiency.	• Enhance energy security and reduce operational costs in transportation. • Advance the modernisation of transport infrastructure.

7. Areas of opportunities for action

Through the hotspot analysis in Section 6, five broad areas of opportunity were identified by the project team

- Resource efficient buildings and infrastructure
- Innovations in sustainable agriculture
- Critical materials
- Material reductions to landfill
- Low carbon energy and transport

In this section, we:

- Analyse these areas in greater detail including the rationale
- Outline more granular interventions within each area
- Assess their likely potential benefits and limitations

This is a high-level and necessarily speculative analysis. It provides an initial appraisal of the potential for environmental, social or economic benefits, the approximate timeframes involved and the degree of disruption the intervention might entail. Further work will be needed to refine this, including higher resolution data and a greater degree of system modelling.

The suggested interventions within each area can be viewed as taking one of two distinct forms:

- **Demand-led.** These are primarily about managing and reducing the demand for new raw materials. This is achieved by extending the life of existing assets through maintenance, repair, and adaptation. The focus is on using what we already have for longer, thereby reducing the need to extract or produce new materials. This approach not only conserves resources but also has the potential to create jobs and develop skills in the areas of maintenance and refurbishment. It's a strategy that lessens dependency on external supplies and fluctuating market prices.
- **Supply-led.** In contrast, supply-led interventions accept that some level of material consumption is inevitable but focus on making this consumption more sustainable. This involves choosing materials that are environmentally friendly, ethically sourced, and have a lower ecological footprint. The emphasis is on the initial selection of materials, ensuring that what is consumed does as little harm as possible to the environment. This approach includes strategies like recycling that minimise waste during production and throughout the lifecycle of the product.

7.1 Resource efficient buildings and infrastructure

The building and construction sector plays a vital role in New Zealand's economy. It sector employs around 300,000 people.[50] It contributed $18.1 billion, or 6.7%, of the nation's real GDP for the year ended March 2022.[51] Currently, more than 40,000 new dwellings alone are consented in New Zealand each year, to an annual value of around $10 billion.[52]

However, in recent years the sector has faced significant economic challenges. These include sharp rises in construction costs, partly driven by significant rises in material prices, especially timber and steel. Forecasts suggest these trends are likely to continue.[53]

This makes resource efficiency a crucial element of economic resilience and sustainability for the sector, as well as for environmental sustainability.

Efforts to tackle this challenge align with global environmental objectives. They have the potential to showcase New Zealand's commitment to responsible environmental stewardship. Resource-efficient buildings and infrastructure are also instrumental in creating sustainable and resilient communities in New Zealand. They have the potential to address the changing needs of an ageing population by incorporating low-maintenance, age-friendly designs that promote well-being, accessibility, and functionality.

Relevant initiatives focus on optimising material use, reducing waste and prolonging the life of assets.

Key actions involve:

- reusing existing structures
- designing for durability
- utilising recycled and renewable materials
- encouraging efficient use throughout construction

7.1.1 Rationale

In 2019, New Zealand's economy incorporated around 57 million tonnes of materials, ranging from minerals and metals to biomass, into its stock (Figure 6), primarily in the construction and infrastructure sectors. These materials, vital for developing homes, offices and other infrastructure, have a significant life cycle that can extend to more than 50 years. However, the currently available data does not detail the paths these materials take from being part of the economic stock to becoming waste and recycling.

One of the main concerns is the environmental impact of cement production, which contributes about 8% of global greenhouse gas emissions.[54] New Zealand's consumption of around four million cubic metres of concrete in 2020 was valued at around $1 billion.[55]

In recent years, the COVID-19 pandemic has exacerbated New Zealand's construction sector's cost and supply chain issues. The steep rise in the cost per square metre for consented residential units from $1,394 in 2010 to $2,360 in 2020 marked a 69.2% increase in a decade. The Consumer Goods Price Index for residential construction also witnessed a steep rise of 15.5% in December 2021, compared to the previous year.[56]

The increasing demand for energy-efficient buildings introduces additional requirements to construction practices. This is coupled with the need to comply with the Building Act 2004. This mandates minimum durability periods for building elements, reinforcing the importance of longevity in construction.[57]

Research by Āmiomio Aotearoa suggests that embracing circular economy practices could significantly reduce construction costs, potentially by $2 billion annually in the long term.[58] This is particularly relevant, given that the construction industry accounts for approximately 50% of New Zealand's waste and about 20% of its carbon emissions.[59]

In addition, the construction sector faces the challenge of catering for the demographic dynamics of an aging but still comparatively young population, with a median age in the first home buying range of the late 30s, coupled with continued high net immigration, which added 86,000 people in 2023.[60]

Over the next 30 years, New Zealand’s population of seniors is projected to grow from around 850,000 (17% of the population) to around 1.5 million (24%).[61]

The flow of materials through the New Zealand built environment is influenced by:

1. **Demand for New Housing:** particularly in Auckland and the North Island,[62] arising from housing shortages and affordability concerns, driving material consumption.
2. **Replacement of Damaged or Sub-Standard Stock:** Older or damaged buildings that are no longer cost-effective to repair or upgrade contribute to material consumption.
3. **Provision of New Infrastructure:** Roads, bridges, tunnels, and other structures, often in response to natural disasters, require significant material inputs.
4. **Population Growth and Urbanisation:** Increases demand for construction materials to accommodate demographic shifts, particularly in urban areas.

5. **Economic Development:** Broader economic growth increases demand for industrial, commercial, and recreational development, necessitating construction and material use.
6. **Technological Advancements:** New construction technologies and materials, including those focused on energy efficiency, drive construction practices and materials changes.
7. **Government Policies and Regulations:** Play a crucial role in shaping building standards and promoting sustainable construction practices.
8. **Global Economic Influences:** International market dynamics influence the availability and cost of imported construction materials, impacting material choices in New Zealand.
9. **Consumer Preferences:** Consumer trends in housing style, size, and energy efficiency contribute to the demand for specific building materials and practices.

7.1.2 Relevant opportunities

Globally, extensive efforts have been made to apply circular economy principles within the construction and building management sectors. For instance, the Ellen MacArthur Foundation has developed a Circular Buildings Toolkit,[63] detailing 10 strategies for sustainable construction and building management. Considering our understanding of material flows within the New Zealand economy and previously mentioned dependencies, we have identified specific opportunities that align with circular economy principles, based on these strategies.

We categorised these into two groups: those offering immediate benefits and those yielding benefits over a longer period. This does not imply that interventions with medium to long-term benefits should be postponed; however, it's often necessary for changes in the built environment to involve sustained, long-term efforts. Additionally, we differentiate between interventions that represent incremental changes to current practices and those that may cause significant disruption.

Table 5 Identified circular economy interventions for resource efficient buildings and infrastructure

	Intervention	Target Impact	Timeframe	Classification
1	**Increase building use:** Using buildings to their maximum capacity through multi-purpose areas and shared spaces to reduce resource consumption and improve the efficiency of existing infrastructure.	Enhanced resource efficiency and sustainability in building usage. (Demand led)	Short to Medium Term	Incremental to Disruptive
2	**Refuse unnecessary components:** Simplifying building designs to use only essential components, minimising material consumption.	Reduction in material usage and promotion of sustainability. (Demand led)	Short to Medium Term	Incremental
3	**Increase material efficiency:** More efficient use of materials to reduce waste and conserve resources.	Resource conservation and waste reduction. (Supply led)	Short to Medium Term	Incremental
4	**Reduce use of virgin and non-renewable materials:** Encouraging using recycled, reused and renewable materials to lessen environmental impacts.	Reduced environmental impact and support for sustainable sourcing. (Supply led)	Short to Medium Term	Incremental
5	**Reduce Use of carbon intensive materials:** Minimising materials with high carbon footprints to align with climate change mitigation.	Climate change mitigation and sustainable material usage. (Supply led)	Short to Medium Term	Incremental
6	**Design out hazardous/pollutant materials:** Eliminating harmful	Environmental protection and health safety.	Short to Long Term	Disruptive

	materials to focus on non-toxic, sustainable alternatives.	(Supply led)		
7	**Design for longevity:** Creating durable buildings and components that maintain value over time, reducing the need for replacements and conserving resources.	Long-term reduction in material waste and resource conservation. (Demand led)	Long Term	Incremental
8	**Refuse unnecessary new construction:** Promotes critical assessment of new building needs, prioritising the use of existing structures to reduce material consumption. Encourages adaptive reuse and renovation.	Reduction in material consumption and environmental impact. Encourages sustainable practices. (Demand led)	Long Term	Disruptive
9	**Design for adaptability:** Ensuring buildings can adapt to changing functions to extend their utility and reduce the demand for new construction.	Enhanced building lifespan and resource efficiency. (Demand led)	Long Term	Disruptive
10	**Design for disassembly:** Designing buildings for easy disassembly at the end of their life cycle to promote material reuse and minimise waste.	Waste minimisation and promotion of material reuse. (Demand led)	Long Term	Disruptive

7.1.3 Potential benefits and limitations

The benefits and limitations of the outlined opportunities under this scenario can be difficult to quantify. Some qualitative assessments are needed.

1. **Increase building use**

In New Zealand's construction sector context, increasing building utilisation presents a nuanced blend of opportunities and challenges, particularly when considering the insights from the Ellen MacArthur Foundation's Circular Buildings Toolkit.

The approach optimises the efficient use of space as integral to sustainability, highlighting the benefits of multi-use and space-sharing concepts. From an economic standpoint, this strategy could lead to notable cost savings. By optimising the total necessary floor area for various functions, the approach could stimulate job opportunities in sectors like maintenance, repair and adaptation. This is particularly relevant amidst the rising costs of materials and supply chain disruptions, offering a path towards economic resilience.

The emphasis on designing for multi-use aligns with extending the lifespans of buildings, thereby reducing the need for new materials. The approach also caters to varying demographic needs, enhancing the sustainability and resilience of communities. Adaptable design is crucial in creating buildings and public spaces that are accessible and easy to maintain, especially for an aging population.

However, the approach faces several challenges. There may be hesitancy within the building sector to explore sharing schemes, reflecting broader regulatory and industry constraints that may hinder the adoption of innovative, sustainable practices. New Zealand's unique geological conditions, including the risk of earthquakes, add another layer of complexity, potentially limiting the application of certain resource-efficient construction methods. The need for specific skills to implement complex multi-use designs may highlight skill gaps in the construction industry, necessitating substantial training and investment.

While enabling flexibility in building design might lead to increased upfront material use, it ultimately results in overall material savings, highlighting the importance of balancing initial costs against long-term benefits; or applying a lifetime costs assessment when procuring buildings. Cultural and social acceptance also presents significant challenges, with potential resistance to modern construction methods and multi-use schemes, as well as concerns about the homogenisation of neighbourhoods. Furthermore, the lack of comprehensive data on material lifecycles, efficiencies generated and environmental impacts complicates the implementation of such strategies.

From a circularity impact perspective, if a multi-use building can be designed and constructed to serve the function of two buildings that would otherwise have been needed, then the potential exists to halve the material and environmental footprint, assuming like-for-like construction. This saving extends for each additional building avoided, reducing impacts to a third, a quarter, a fifth, etc. This type of construction may come with more complexity and a higher price tag than an individual build, but most likely less than the cost of multiple builds and the costs may be funded by multiple users. This approach can potentially apply to commercial buildings, residential homes, public buildings and manufacturing spaces. Digital Twin technology could be used to overcome some of the complexity in design coming from a multi-use perspective and enable better choices in materials, enhance repairability, longevity and adaptability in such buildings.

If we assumed that 5% of non-residential construction could be built for multiple uses, displacing the need for an additional 5% of buildings that wouldn't need to be constructed, then based on Figure 6?, the estimated savings would be in the region of 120 kt CO_2e per annum, based on 2019 data. The 5% figure was selected as a starting point for calculations reflecting a qualitative judgement on the likely appetite for the approach in New Zealand; this figure would need to be refined through a broader engagement with the communities and stakeholders involved.

The benefits of increasing building utilisation are expected to manifest in the short to medium term. This timeframe is appropriate because the intervention primarily involves reconfiguring existing spaces, which can lead to immediate improvements in space efficiency. Over the medium term, as more buildings adopt this approach, broader benefits are likely to emerge. The intervention is characterised as incremental due to its reliance on optimising current spaces. At the same time, it is also disruptive, challenging traditional views on building design and usage by promoting a shift towards more flexible, multi-purpose spaces.

2. Refuse unnecessary components

Refusing unnecessary components centres on reducing material consumption in construction projects. This approach prioritises simple design and re-evaluates the necessity of components and materials, questioning whether certain elements can be omitted without compromising the project's performance or desirability. To measure the effectiveness of this strategy, conceptual material efficiency is used, considering reductions in material use not only through technical improvements but also through conceptual decisions, such as keeping wall or floor surfaces unfinished or keeping services on display. This efficiency is assessed in terms of material use per functional unit over the building's lifespan, which varies based on the building type, i.e. per workstation, hotel bed, or resident.

Implementing this approach offers several benefits, including reducing carbon emissions and minimising the extraction of new resources. It can also potentially lower upfront material costs per square metre, reducing energy consumption and operational carbon emissions and costs. However, adopting this strategy presents challenges, such as achieving the architectural vision with fewer materials, which may affect market value in some locations. Concerns may arise about the comfort of building occupants as the strategy promotes a minimalist approach.

Key actions for this approach involve critically assessing project briefs for potential redundancies, exploring digital and innovative approaches to reduce space usage, rethinking parking infrastructure by prioritising public transport connectivity and favouring adaptable parking spaces. It prioritises passive and simple servicing strategies, re-evaluating service levels and exploring natural ventilation and passive heating/cooling strategies for greater energy efficiency. Reconsidering interior finishes is another important aspect, suggesting using exposed surfaces of structural elements and MEP systems as part of the interior design to reduce the need for frequent replacements or maintenance.

Refusing unnecessary components entails a shift from traditional design thinking to a more resource-efficient approach. While it offers sustainability and efficiency benefits, it requires careful coordination among design disciplines to balance architectural objectives and a sustainable, minimalist design ethos.

Estimating the benefits of this approach can be challenging due to the variability in savings and benefits depending on the building type and the elements excluded from construction, as well as ripple effects such as energy savings from increased use of public transport. Passive heating and cooling systems involve complex trade-offs with airtightness measures that are often implemented alongside them. Therefore, passive heating and cooling systems' net environmental and economic benefits would depend on specific project parameters and design choices.

For the purposes of estimating the impact on residential properties, in 2019, residential construction in New Zealand utilised materials with an embodied carbon footprint of approximately 1,417 kt of CO_2 equivalent (Figure 7). To illustrate the potential impact of a minimalist approach, we can consider tiny homes as an extreme example. A typical one-bedroom tiny house may cost between $45,000 and $65,000. In comparison, assuming a typical build price of $4,000 per m² and a typical footprint of 40-70 m², a conventional one-bedroom property in New Zealand would cost between $160,000 and $280,000 to build. Assuming that cost savings directly correlate with reduced material and environmental impacts, potential savings could reach up to 74%, equivalent to 1,048 kt per annum.

However, only a small fraction of the 48,522 homes consented in 2021 will likely achieve such substantial savings. A more realistic estimate might fall within the range of 5% to 10% for a standard new build, resulting in savings of approximately 71 kt to 140 kt of CO_2e per annum for residential properties and 120 kt to 240 kt per annum for non-residential properties. This reflects a more conservative estimate based on a more modest implementation.

Refusing unnecessary components is expected to produce results in the short to medium term, as it involves simplifying building designs to be readily incorporated into new projects or renovations. This process leads to immediate reductions in material usage, with broader cultural shifts towards sustainability in the construction sector emerging over the medium term. Classified as incremental, this strategy represents an evolution in construction practices, focusing on streamlining design processes to prioritise efficiency and sustainability. It does not require a complete overhaul of existing practices. Still, it encourages a more thoughtful approach to material usage, making it a practical and achievable modification to the industry's standard operations.

3. **Increase material efficiency**

Like refusing unnecessary components, increasing material efficiency aligns with sustainable and minimalist design principles, extending its focus to encompass the entire material lifecycle of building projects. This approach necessitates a collaborative effort among architects, engineers and builders to harmonise efficient material usage with architectural vision.

The integration of Additive Manufacturing (AM) techniques in this approach harnesses its potential for optimising product design, minimising material waste and achieving significant part count reductions through integrated builds.[64] This approach aligns with the circular economy by producing less waste, reusing materials more efficiently, and enhancing the recyclability of construction materials. AM's role in on-demand printing further supports circular economy goals, by reducing the need for large inventories and facilitating extended product use through repair, which is essential for sustainable resource management. Adopting this strategy, particularly with the incorporation of AM, provides substantial benefits, including reduced extraction of new resources.

Introducing advanced manufacturing techniques like AM also presents challenges in transitioning from conventional architectural designs and integrating advanced digital tools. The energy efficiency of AM is improving, but environmental benefits are typically gained through significant knock-on effects enabled by the additional design freedom rather than by the AM process itself.

However, looking at material efficiency holistically, the potential for more sustainable, efficient and environmentally friendly construction practices is compelling. Key actions under this strategy include avoiding material-intensive constructions and reducing material use intensity in building structures. This involves choosing high-strength materials, applying efficient structural forms and using advanced engineering practices. Furthermore, waste reduction is achieved through off-site prefabrication and advanced manufacturing to enable precise material deployment and reduce waste.

An analysis of its potential impact is likely to be similar to for refusing unnecessary components, with a 5%-10% material reduction yielding 71 kt to 140kt of CO_2e per annum for residential properties and 120 kt to 240 kt per annum for non-residential properties, the exact savings depending on specific project parameters. It is unclear to what extent these two strategies overlap, however, meaning that implementing one may reduce the scope of the other in some cases. A 5%-10% figure reflects a Westpac observation that up to 10% of materials ended up in a skip during a traditional build.[65]

The "increase material efficiency" strategy is projected to have an impact in the short to medium term. This timeframe is realistic, because the intervention focuses on enhancing the efficiency of materials used in construction, which can be quickly implemented in both new and existing projects. The immediate benefit is seen in reduced waste and more effective use of resources, with a broader impact on sustainability practices expected as the strategy gains wider acceptance. Classified as an incremental change, this approach enhances existing construction methods by optimising material usage. It requires adjustments in planning and execution, but does not necessitate a radical departure from current construction techniques. The industry can significantly improve resource conservation without disrupting established workflows by adopting advanced manufacturing methods and more precise material allocation.

4. Switching to more renewable and recycled building materials

Reducing the use of virgin and non-renewable materials is fundamental to embracing a circular economy. This strategy aims to diminish the extraction of finite resources and their associated environmental impacts. It promotes the use of reused and recycled materials and renewable and bio-based resources, thereby shifting the focus away from consuming new materials and creating demand for materials and products that would otherwise be discarded.

The Material Circularity Indicator (MCI) developed by the Ellen MacArthur Foundation is employed to gauge the effectiveness of this strategy. The MCI considers the input of materials and their potential for reuse. Additionally, it underscores the importance of considering the separability of materials for effective recovery to avoid the creation of 'monstrous hybrids': products in which materials cannot be recovered, recycled, or composted due to the manner in which they have been combined.

Adopting this approach offers several advantages. It can potentially reduce carbon emissions linked to material production and curtail the extraction of non-renewable resources. Furthermore, it can help decrease waste resulting from demolition activities and contribute to new markets for processed materials. However, there are challenges associated with its implementation, including compliance with technical regulations, uncertainties regarding the performance of existing materials and the complexities of procurement processes. The availability of markets for reused products, especially in the construction sector and the potentially higher initial costs of bio-based materials are additional challenges to consider.

Switching to more renewable and recycled building materials encompasses various sub-strategies:

- maximising the use of reclaimed components
- utilising concrete with high secondary content
- employing engineered timber and other bio-based materials
- incorporating bio-based materials in interior design
- reducing the depletion of critical raw materials

While Europe has closely aligned the topic of critical minerals with the circular economy for over a decade, New Zealand does not currently have a list of critical minerals. These materials are commonly found in technology applications, such as heating/cooling systems, solar panels, pumps, motors, battery storage, lighting, smart home systems and home appliances. Interestingly, sand may also be considered a critical material, with growing concerns over the availability of sand required for construction. In achieving net zero targets in New Zealand, reducing critical raw material depletion may not necessarily mean avoiding them entirely but ensuring their effective use and maintenance in durable applications and prioritising recovery.

It is important to note that not all recycled materials result in lower carbon footprints under all circumstances. For instance, concrete can be beneficial when crushed and used as aggregate, but this benefit is contingent on short transportation distances. Similarly, for steel, the realised benefits depend on the distance transported and the energy mix used in recycling. Timber, while effective in sequestering carbon, should be sustainably sourced and FSC-certified to ensure environmental responsibility.

In practical terms, New Zealand's ability to influence its carbon footprint through this approach is likely to be limited. It’s estimated that 72% of all steel used in New Zealand is recycled, with this rate being even higher for structural steel – the average being lowered due to lower recycling rates of consumer goods.[66] New Zealand's onshore steel-making process is unique and doesn’t currently rely on steel scrap. However, around 74% of steel scrap in New Zealand is collected for recycling and sent offshore, offering a carbon benefit of about 1,054 kg CO_2 equivalent per tonne of scrap.[67] A New Zealand Steel electric arc furnace has also now secured funding, which should further reduce the impacts of domestic steel production. This is reflected in the comparatively high MCI for steel of 0.76. Carbon reductions are, therefore, more likely to arise from further increasing the efficiency of the recycling process and exploring innovations that further reduce the environmental impacts of domestic steel production. That said, procurement continues to have a strong role in specifying recycled steel as part of the construction and, notably, HERA has launched a zero-carbon steel program using carbon offsetting for steel used in New Zealand.

In New Zealand, supplemental cementitious materials (SCMs) are being used to reduce the carbon footprint of concrete and the industry now has a 2050 roadmap to Net Zero Carbon.[68] Research shows that replacing up to 30% of Portland cement with SCMs can achieve reasonable strength and superior durability, potentially reducing embodied carbon by as much as 20%. These SCMs include industrial waste products like fly ash and natural materials unique to New Zealand's geology, such as pumice and amorphous silica. The use of SCMs in concrete has been increasingly recognised for enhancing concrete durability, especially in severe exposure conditions, and has become mandatory for certain applications in New Zealand.[69]

While using SCMs in concrete shows promise for further reducing carbon emissions in the construction sector, challenges remain in optimising the mix designs and ensuring consistent performance in line with international standards. Figure 7 indicates that 1,220 kt of CO_2 equivalent were embodied in the use of concrete in New Zealand in 2019. A 30% addition of waste materials would increase the MCI of concrete to 0.24 and could reduce this carbon footprint by as much as 240 kt per annum, assuming wholesale adoption.

Figure 7 shows that some concrete recycling activities already exist, but that there is also scope for improvement, with waste concrete and aggregate comprising more than 75% of the material flowing to landfill/clean fill at 277 kt in 2019. Recovering this lost material as a secondary aggregate may also yield significant environmental and economic savings, but would require further investigation.

Reducing the use of virgin and non-renewable materials is anticipated to have an impact in the short to medium term. This is because the shift to using recycled, reused and renewable materials can be integrated into construction projects relatively quickly. The immediate effect will be a reduction in the reliance on new, non-renewable resources, with a gradual but cumulative impact on environmental sustainability as these practices become more prevalent in the industry. This intervention is primarily incremental in nature. It involves a shift in material sourcing and procurement practices, rather than a radical change in construction methods or design principles. By focusing on the substitution of materials, this strategy can be adopted within the existing framework of construction projects, making it a practical and attainable approach towards reducing the environmental footprint of the construction sector.

5. **Reduce the use of carbon-intensive materials**

The approach to reduce the use of carbon-intensive materials in the construction industry is pivotal in addressing embodied carbon, a substantial contributor to the overall lifecycle carbon emissions of a building. This approach champions the adoption of suppliers who prioritise renewable, bio-based, and recycled materials and use clean energy in manufacturing. This shift not only diminishes the reliance on high-carbon materials but also aligns with global efforts to mitigate climate change and adhere to sustainability benchmarks.

The effectiveness of this strategy is gauged through the Whole Life Cycle GHG Emissions metric, which focuses on the Carbon Emissions Intensity over the entire life cycle of the building. The strategy brings several advantages, including a marked reduction in embodied carbon emissions, the promotion of recycled or bio-based materials, which cuts down the demand for virgin materials, and the enhancement of sustainability benchmarks. Furthermore, it contributes to the health and well-being of building occupants through material transparency and optimisation.

However, implementing this approach presents certain challenges. These include the potential for higher initial costs due to low-carbon materials, a limitation in product choices that necessitates early incorporation of low embodied carbon goals in design stages, and the need for reliable and quality information within the supply chain.

Diving deeper into the approach involves several key components. Firstly, it emphasises tracking the embodied carbon footprint during the design phase, which includes setting ambitious embodied carbon targets for the project and employing tools like 3D modelling and Life Cycle Assessments to monitor performance. A significant aspect which could assist with this is the development of a digital twin for ongoing performance tracking during the building's design and operation.

The approach focuses on setting specific targets for the embodied carbon footprint of the building structure. This involves selecting low-carbon materials, engaging with sustainable supply chains, and prioritising materials like timber, recycled concrete and steel.

Regarding the building envelope, the approach targets specific reductions in the embodied carbon footprint. This includes conducting analyses to assess the impact on embodied and operational carbon and limiting the use of high carbon-intensive materials like metals, focusing instead on recyclable options.

Building systems are also under scrutiny, emphasising the embodied carbon footprint of these systems. This strategy component looks at selecting products based on their embodied carbon performance, considering decentralised systems, and opting for refrigerants with reduced greenhouse gas emissions.

Additionally, the approach sets out to determine embodied carbon targets for building fit-out components. This part of the strategy emphasises the importance of durability and choosing lightweight materials that are efficient for transportation.

Lastly, managing digital information for Life Cycle Assessment (LCA) is an integral part of the strategy. This involves using 3D design environments that adhere to the best practices in EC/LCA standards, generating digital material passports, and developing a project digital twin to monitor performance.

Overall, this approach aligns well with NABERSNZ, the Green Star scheme for non-residential buildings, fit-outs and communities and the Home Star scheme for residential properties. These schemes are currently voluntary in New Zealand and there is no mandated requirement or New Zealand 'Green Building Code'. However, a 2021 Building for Climate Change consultation suggested strong support for reducing the barriers that prevent businesses from taking action to reduce emissions and initiatives to reduce whole-of-life embodied carbon, as well as a cap on whole-of-life carbon for new building projects.[70]

In the UK, the embodied carbon of a typical two-bedroom home is 80 tonnes[71] CO_2 equivalent. Reductions of as much as 60% have been demonstrated using locally sourced materials. In New Zealand, homes appear to have a similar embodied carbon to the UK, with single-storey dwellings being about half of this at around 40 tonnes.[72]

A reduction of 60% in New Zealand would equate to 850 kt CO_2e in the residential market per annum, based on 2019 data in Figure 7. In the UK, significant improvements were achieved by heavily using locally sourced materials and traditional building techniques based on timber and lime. The use of timber frame construction in New Zealand is already widespread, with much of the timber required being locally sourced.[73] New Zealand is also advancing the use of timber construction in multi-storey developments.

Reducing the use of carbon-intensive materials is projected to deliver short- to medium-term impacts. This timeframe is appropriate as the strategy involves selecting and integrating lower-carbon alternatives into construction projects, which can be accomplished relatively promptly. Immediate gains are expected regarding reduced carbon emissions from construction materials, with more extensive reductions becoming evident as these materials are adopted more broadly. The intervention is classified as incremental, as it focuses on material substitution rather than comprehensive changes in construction methodologies or design. The strategy fits existing construction practices, requiring material selection and supply chain management adjustments.

6. **Design out hazardous/pollutant materials**

Focusing on non-toxic and less harmful materials ensures that building components remain valuable and recyclable over a longer period, reducing waste and making it easier to operate closed-loop systems of reuse. It aligns with the circular economy's emphasis on health and safety, as using safer materials guarantees the lifecycle of products is sustainable and safe for both people and the environment. The strategy also contributes to extending the life of products in the construction industry. Durable and non-harmful materials lead to longer-lasting building components, conserving resources by minimising the frequency of replacements.

Regarding climate change mitigation, this approach has a substantial impact. Avoiding materials with a significant environmental footprint contributes to a reduction in the overall environmental impact of buildings. This reduction is crucial in lowering emissions related to the production, use and eventual disposal of construction materials. The strategy also fosters a shift towards sustainable practices in the construction sector. Encouraging the use of renewable, bio-based, or recycled materials inherently lowers the carbon footprint associated with building materials, aligning with global efforts to combat climate change.

Moreover, the approach enhances indoor air quality by avoiding materials that emit harmful substances like volatile organic compounds. Improved air quality inside buildings is beneficial for occupant health and contributes to broader efforts to reduce air pollution, a key factor in addressing climate change. Avoiding hazardous and pollutant materials in construction is integral to the circular economy and climate change mitigation. It promotes the reuse and recycling of safer materials, supports sustainable practices and improves air quality, all vital for creating a more sustainable and environmentally responsible future.

Quantifying the potential benefits of this intervention is nuanced. There are undoubtedly chemicals in use today that are of concern, most commonly in paints, preservatives, fire retardants and adhesives, as well as some of the insulating materials and soft furnishings. For example, arsenic and creosote are used as wood preservatives, formaldehyde is often found in furniture and timber products and PFAs in roofing materials, paints, sealants, caulks, and carpets.[74]

The term 'Sick Building Syndrome' was coined in the 1980s. It describes various maladies associated with volatile chemicals and biological contaminants commonly found in homes and workplaces. Besides the downstream benefits of enhanced recovery of materials enabled by this opportunity, the benefits are likely to include enhancements to health and well-being and reductions in chronic illnesses.

This intervention is expected to have short- to long-term impacts, reflecting the immediate benefits of removing harmful materials from current projects and the gradual, more profound change in industry standards and regulations over time. Initially, the approach would lead to improved health and safety standards and better indoor air quality. In the long run, it would contribute to a significant shift towards environmentally responsible construction practices. This intervention is considered disruptive due to the substantial changes it requires in material selection, sourcing and the re-evaluation of traditional building practices. By prioritising non-toxic and sustainable alternatives, this approach ensures safer building environments and aligns construction practices with broader sustainability and public health goals.

7. Design for longevity

Sustainable and resilient building design, focused on maximising the lifespan and value of buildings, inherently aligns with the concept of circularity in construction. Increasing the durability of assets plays a vital role in reducing the demand for new materials and minimising waste generation. Extending a building's lifetime from 50 to 60 years can equate to reaping the benefits of 1.2 buildings for the cost and environmental impact of one. The benefits of this approach do not manifest at the point of construction, but at the time when the building would otherwise have been replaced, making this strategy an investment in future resource efficiency.

The benefits of the approach should not be underestimated. Increasing the durability of a structure from 50 to 60 years achieves a comparable circularity to incorporating 33% recycled content when assessed using the Material Circularity Indicator and retains the substantial economic value added through the construction of the asset.

New Zealand mandates minimum durability requirements through Building Codes of up to 50 years, but there is no incentive to exceed this benchmark. As of 2021, there were 1,954,000 private dwellings in New Zealand. Assuming an average embodied carbon of 80 tonnes of CO_2 equivalent, this amounts to 156,000 kt. If we built all those homes today with a design life of 50 years, this would equate to 3,100 kt of CO_2 equivalent per year of use. If all of those homes instead lasted sixty years, then this drops to 2,600 kt per year of use, a saving of 500 kt – equivalent to avoiding the construction of more than 6,000 homes.

According to statistics from 2020, while the oldest dwellings in New Zealand date from the 1840s, fewer than 10% of current dwellings were built prior to the 1940s. Around one third of New Zealand's homes have been built since 2000.[75] Perhaps it is not unreasonable to design for a durability of 100 years, in which case the saving in the above example increases to 1,500 kt CO_2e. A more detailed model would be needed to ascertain how these benefits would accrue over time.

The example above is hypothetical and illustrative. Still, it underlines the potential impact of this strategy on the New Zealand economy, leading to reductions in the environmental footprint and significant economic benefits, including cost savings for the construction industry and property owners and more efficient allocation of labour and resources. Given the workforce constraints and rising costs, these savings are particularly valuable.

The strategy also addresses the risk of global material shortages, such as construction sand, which influences the use of concrete and other materials like steel, timber, glass, plastics and insulation. By not having to replace these materials as quickly, the long-term demand can be reduced mitigating our exposure to these risks. A holistic approach to circularity in construction needs to encompass the entire lifecycle of buildings and materials, considering both short-term and long-term benefits.

Regarding sustainability and lifecycle management in construction, tools like residual service life assessment (predicting the remaining operating life of products, machinery and materials) and digital product passport technology that enables tracking of individual items throughout their lifecycle, may be crucial. They provide insights into the long-term usability and potential for reuse of building products.

Emotional durability is an often overlooked aspect, but is vital for sustainable construction. Architectural trends and materials, such as those seen in 1960s Europe, demonstrate that the reason for demolition is not always physical deterioration but often a failure to meet evolving functional needs or aesthetic preferences. With expected demographic changes over the remainder of this century, this could translate into the need for low-maintenance, age-friendly designs that emphasise accessibility, sustainability and ease of maintenance.

Investments in construction practices must align with the requirements of an aging population, ensuring that the built environment remains safe, accessible and functional. These investments don't just benefit the elderly; they create more sustainable and resilient communities for everyone.

In addition, taxation and accounting changes could also have an influence. Making the time to write off the cost of a building longer could incentivise extending building use.

Japan is ahead of the world on this demographic change. The Nagayama Model's emphasis on community-based integrated care systems, crucial for supporting an aging population, could benefit New Zealand. This model underscores the importance of designing age-friendly communities that are adaptable to changing demographics, enhancing social interaction and preventing social isolation.

These strategies represent a comprehensive approach to building design in New Zealand, focusing on sustainability, adaptability, circular economy principles and the unique challenges and opportunities of the region. They aim to enhance the longevity and value of buildings and their components, balancing environmental considerations with economic feasibility and demographic shifts throughout the building's lifecycle. Integrating these approaches will be pivotal in shaping a sustainable built environment that responds dynamically to evolving needs and challenges locally and globally.

Designing for longevity in construction is anticipated to manifest its impact in the long term, because the benefits of designing buildings and components for enhanced durability become most apparent over an extended period. The effect may not be immediately observable. This intervention is considered incremental, as it involves extending and enhancing existing practices rather than introducing radical new methods. It calls for an increased focus on durability and adaptability in the design phase, using materials and techniques that ensure the structure's longevity. While the concept doesn't demand a drastic departure from current design philosophies, it does require a shift in focus towards longer-term outcomes, making it a sustainable and future-focused addition to standard construction practices.

8. Refuse unnecessary new construction

The strategy of refusing unnecessary new construction and focusing on reusing, renovating or repurposing existing assets is a significant approach towards sustainable development in the construction industry. This approach centres on a deep evaluation of the initial project brief against the client's needs, questioning whether constructing a new building is indeed the optimal solution to meet these needs. The rationale behind this strategy is to circumvent the extensive material consumption and environmental impact associated with new construction.

The key performance indicator for this approach is the reuse of existing usable surfaces, measured as the percentage of reused floor area relative to the total gross floor area of the project. This indicator reflects the efficiency of utilising existing spaces and structures.

The benefits of this approach are as follows: Firstly, it reduces embodied carbon emissions, a crucial factor in combating climate change. Secondly, it minimises waste generated from demolition activities. Thirdly, it reduces the need to extract new resources, lessening the environmental footprint. Additionally, it adds value to existing processed materials, creating a market for what might otherwise be discarded. This approach also helps protect heritage buildings and can lower cost intensity.

However, there are several challenges associated with this approach. These include ensuring compliance with technical regulations, the availability and quality of information regarding existing assets and the architectural quality of these assets, which may have outdated aesthetics. Additionally, strict heritage requirements can restrict design opportunities, and confirming the residual lifespan of the main structural elements is challenging.

The sub-actions under this approach involve a thorough interrogation of the project brief against client needs, reviewing available assets for potential efficient use, engaging a sustainability consultant early in the project, raising awareness of future regulations regarding embodied carbon and the circular economy and conducting feasibility studies comparing renovation with new construction. These studies should include embodied carbon assessments, virgin material use and simplified life cycle assessments. Technical assessments of the existing structure, façade and systems are crucial to evaluate their quality and reuse potential. Moreover, reviewing the thermal insulation properties of external walls and glazing properties is essential to enhance the building's energy efficiency.

This approach advocates for a more sustainable and environmentally conscious method in the construction industry, emphasising the reuse and repurposing of existing structures over new constructions whenever feasible.

The benefits of this approach are likely to be similar to designing for longevity, as this is essentially a maintenance and refurbishment regime that keeps the building fabric in use and avoids the need to replace old with new. However, the approach is not additional to longevity and won't double the impact; rather, it is another way of complementing and achieving the same outcome.

The extent to which this model translates into the New Zealand market will likely be limited to buildings not damaged by natural disasters. Indeed, this approach can be seen as a natural complement to longevity, where a durable building fabric is repurposed to accommodate the changing needs of the occupants. Designing buildings to accommodate these changing needs is likely to be a core consideration.

Refusing unnecessary new construction is expected to yield results predominantly in the long term, because the strategy involves a fundamental shift in how construction projects are conceptualised and executed, focusing on critically assessing the need for new structures versus renovating or repurposing existing ones. While some immediate impacts may be seen in specific projects where new construction is avoided, the broader effects will accumulate over time, as this mindset becomes more ingrained in the industry. This intervention is classified as disruptive because it challenges the prevailing approach, which often favours new builds. It necessitates reconsidering existing assets and a more holistic view of meeting spatial and functional requirements, potentially leading to significant changes in planning, design and decision-making in the construction sector. By prioritising the adaptive reuse and renovation of existing structures, this strategy conserves resources and encourages more sustainable and thoughtful urban development.

9. **Design for Adaptability**

Design for Adaptability (DfA) aims to enhance the flexibility and longevity of buildings, ensuring they can adapt to new functions over time.[76] This approach is particularly relevant where changes in use are foreseeable, making it a strategic consideration for sustainable construction. It involves a holistic understanding of a building's potential for adaptability and includes several key aspects. As with designing for longevity and refusing unnecessary construction, the impacts are likely to be similar but not in addition to these approaches, as designing for adaptability has the same objective of avoiding building replacement.

The core of this approach is measured by the Adaptability Score, a metric that quantitatively assesses a building's potential to adapt, as defined in the EU Level(s) Indicator.[77] This score is pivotal in evaluating how effectively a building can transition to different uses over time.

In terms of benefits, designing for adaptability has significant long-term implications. It reduces the need for new material extraction and embodied carbon emissions, thereby contributing to environmental sustainability. Furthermore, it enables future tenants to modify spaces to meet their needs, ensuring that the building remains valuable and functional throughout its lifespan. However, this approach is not without its challenges. Initially, it might require more materials and possibly result in higher environmental impacts. Yet, these are outweighed by the long-term benefits, making this strategy an investment in future resource efficiency akin to designing for longevity.

The approach encompasses several facets, each aimed at increasing a building's convertibility. These include considerations for architectural massing, structural grids and foundational layouts, ensuring they are compatible with potential future uses. The design process involves thorough market assessments and scenario planning to anticipate and accommodate future scenarios. A particular focus is given to factors like floor plate depth, shape and core locations, which are instrumental in determining a building's adaptability. Similarly, the building envelope is designed to be flexible, allowing for window size and spacing modifications and facilitating different functional needs.

Another critical aspect of this approach is the adaptability of Mechanical, Electrical, and Plumbing (MEP) systems. Provisions are made for these systems to be easily replaced or modified, anticipating the needs of different uses. This includes ensuring accessibility for maintenance and the adaptability of components and adopting open architectures to avoid being locked into specific product lines.

An integral part of this approach is the development of an Adaptability Manual, a comprehensive guide that provides clear instructions and diagrams for adapting the building for different scenarios. This manual and detailed 3D as-built documentation forms part of the building's Material Passport, ensuring that all information regarding materials and connections is readily available for future modifications. A Digital Twin of significant buildings can help facilitate future adaptability and provides a platform for users to visually confirm or approve changes.

DfA is a forward-thinking approach that anticipates the changing needs of buildings and their occupants and aligns with the broader goals of sustainable and resilient construction. Focusing on versatility and convertibility ensures that buildings remain functional, valuable and environmentally sustainable over their entire lifecycle. This approach mirrors the ethos of designing for longevity, where the focus is not just on the immediate benefits but on the long-term impacts and contributions to a circular economy in the construction sector.

DfA is anticipated to have an impact in the long term, as the benefits of designing buildings that can adapt to changing needs and functions become most evident over extended periods. The adaptability of structures ensures their relevance and utility across different eras and requirements, leading to a sustainable reduction in the need for new construction. This approach is disruptive, because it requires a significant shift in architectural and design thinking. It goes beyond conventional construction practices by requiring foresight about future uses and flexibility in design. This means architects and developers must consider not just the immediate purpose of a building but its potential future uses, integrating elements that allow for easy modification and adaptation.

10. Design for Disassembly

The Design for Disassembly (DfD) concept in the construction industry is centred on prioritising the end-of-life disassembly potential of building components.[78] This approach aligns closely with the principles outlined in ISO 20887,[79] emphasising key factors such as ease of access, independence, simplicity and safety in disassembly. It is worth noting that this strategy emphasises what is referred to as 'Disassembly and recovery potential', a concept in line with the EU Level(s) Indicator 2.4 and DGNB TEC1.6 criteria.[80] DfD has the potential to yield substantial reductions in long-term embodied carbon emissions and facilitate the future reuse of building components. It is important to acknowledge that while implementing this strategy may initially lead to increased material usage and potential environmental impacts, the potential long-term benefits are significant and akin to those realised through a longevity-based approach but, again, are not additional to those impacts.

An illustrative example of DfD in practical application is the approach taken by New Zealand's XFrame.[81] This circular economy construction platform offers modular, demountable systems purposefully designed to facilitate easy alterations with minimal waste generation. Their system relies on reversible fixing methods and precision-milled materials to ensure efficient usage and minimal waste production. XFrame's diagonal grid geometry enables the creation of resilient and materially efficient panels that are well-suited for reversible connections. By addressing the issue of construction waste, XFrame's design enables end-of-life deconstruction, reconfiguration and reuse, ensuring the retention of material value. This serves as a tangible demonstration of how DfD principles can be practically applied, contributing positively to the overall sustainability of the construction industry.

Figure 13: Example of the XFrame modular, deconstructable system.[81]

DfD within the construction sector embodies a strategic approach that centres on enhancing the end-of-life disassembly potential of building components. It advocates for integrating design elements that facilitate the practical disassembly of components, enabling the recovery of their residual value after their service life. This strategic approach is closely aligned with the principles articulated in ISO 20887[82], which emphasise ease of access, independence, simplicity, and safety during disassembly, rendering it applicable across diverse building sites and typologies.

A central aspect of this approach involves its focus on 'Disassembly and recovery potential', which amalgamates factors such as Ease of Recovery and Ease of Reuse Recycling Scoring. These considerations align with the EU Level(s) Indicator 2.4 Design for Deconstruction and the DGNB TEC1.6 Ease of Recovery and recycling criteria.[83]

The advantages of adopting a Design for Disassembly are multifaceted, encompassing significant reductions in long-term embodied carbon emissions and reduced material extraction. It enables the future reuse of building components, preserving the value of each asset after its life cycle. Nevertheless, it is important to recognise that implementing this strategy is not without its challenges, as it may necessitate an initial increase in material usage and potentially result in higher environmental impacts. Beyond the scope of one company, it also benefits from industry-wide agreement on common architectures, which brings with it potential limitations in future design freedoms. However, the cumulative benefits across the life cycle of a building generally outweigh these initial considerations.

Developing a comprehensive Disassembly Manual Document plays a pivotal role in successfully implementing Design for Disassembly. This document serves as a guide for asset owners and facility managers, outlining effective disassembly processes and empowering them to maximise the repair and reuse of individual components.

Design for Disassembly is expected to produce significant impacts primarily in the long term. This extended timeframe is essential because the true benefits of this approach, which include facilitating the reuse and recycling of building materials, become most evident at the end of a building's life cycle. The immediate implementation of this strategy involves designing structures with future disassembly in mind, but the results are most tangible when buildings are actually disassembled and materials are repurposed. This intervention is classified as disruptive due to its fundamental rethinking of the building design process. Unlike traditional construction methods, Design for Disassembly requires planning for the end-of-life phase from the outset, incorporating modular elements, reversible connections, and materials that can be easily separated. This foresight and attention to detail disrupt the conventional approach to building design and construction, necessitating a significant shift in the industry's perspective towards a lifecycle-centric approach that prioritises material recovery and minimises waste.

7.1.4 Summary

Table 6 Summary of projected benefits (based on assumptions)

Intervention	Projected Benefits	Identified Challenges
1. Increase building use	**120 kt CO_2e per annum** Reduces material consumption; potential to halve material footprint in some cases.	**Assumes 5% of construction is multi-use.** Industry hesitancy Regulatory constraints.
2. Refuse unnecessary Components	**71 kt to 140 kt CO_2e per annum** Potential savings of up to 60% in material and environmental impact for extreme cases like tiny homes.	**Assumes 5-10% adoption in standard builds** Balancing architectural vision Comfort concerns.
3. Increase material efficiency	**71 kt to 140 kt CO_2e per annum for residential; 120 kt to 240 kt for non-residential.**	**Assumes 5-10% material reduction** Integration of advanced manufacturing. Overlap with other strategies.
4. Reduce the use of virgin and non-renewable materials	**240 kt CO_2e per annum** Reductions in the carbon footprint of concrete with 30% SCM addition.	**Assumes widespread use of SCM in concrete** Compliance with standards. Performance uncertainties.
5. Reduce use of carbon-intensive materials	**850 kt CO_2e per annum** 60% reduction in embodied carbon possible	**Assumes an ambitious 60% reduction in the residential market** Higher initial costs. Limited product choices.
6. Design out hazardous/pollutant materials	**Improved health and well-being** Enhanced recovery of materials. Challenging to quantify carbon savings.	**Requires major changes in material selection.** Assumes elimination of hazardous materials.
7. Design for longevity	**1,500 kt CO_2e per annum** with a 100-year durability assumption.	**Assumes 100-year design life** Benefits not realised for 50+ years Incremental design changes.
8. Refuse unnecessary new construction	Specific figures are similar to longevity strategy but complementary, not additional. Long-term carbon savings through reduced need for new construction.	A fundamental conceptual shift is required. The assumption is that existing structures can meet new needs.
9. Design for Adaptability (DfA)	Specific figures are similar to longevity strategy but complementary, not additional. Long-term carbon savings through reduced need for new construction.	Requirement for foresight in design. Assumption of effective adaptability implementation.
10. Design for Disassembly (DfD)	Specific figures are similar to longevity strategy but complementary, not additional. Long-term carbon savings through reduced need for new construction.	Initial increase in material usage. Assumption of industry-wide standards for disassembly.

7.2 Innovations in sustainable agriculture

Potential innovations in sustainable agricultural encompass a wide range of possible opportunities that go beyond traditional farming methods. They're promoted for their potential to make New Zealand's agriculture more balanced, adaptable and resilient.

They include:

- targeted application of fertilisers
- use of cover crops and nitrogen fixers
- automation, including land based and flying drones
- replacing pesticides harmful to pollinators
- removing non-native pest species
- managing wetlands and waterways to support water quality and abatement
- rewilding projects and the implementation of regenerative agricultural systems

The feasibility, cost and timeframes involved in these innovations are varied. Some are likely to be more disruptive than others.

Supporters argue that innovation in sustainable agriculture can bring economic benefits by boosting the value of exports in a market increasingly focused on high-quality, nutrient-dense and sustainably produced goods. It could also benefit the lives of farmers, by reducing agricultural intensity and creating resilience. Environmental benefits, including minimising emissions, restoring ecosystem services and enhancing biodiversity, are also frequently highlighted.

However, it's worth noting that adopting these practices requires sustained effort and can be financially challenging, especially for small farms. Additionally, the promised benefits of reducing emissions, such as lower methane from animals and increased carbon storage in soils, may require further validation in the New Zealand context.

Transitioning to sustainable farming practices is complex. It requires careful integration into the existing economic framework. Shifting to sustainable practices in this area must balance environmental protection and maintaining production value. The transition must also consider market readiness and consumer willingness to pay for sustainably produced goods.

7.2.1 Rationale for Intervention

New Zealand relies heavily on its agricultural sector, particularly sheep, beef and dairy farming. More than 85% of its food production destined for international markets.[84] In 2019, New Zealand extracted 156,000 kt of biomass, 84,000 kt of which supported livestock as food and feed. This was supplemented by an additional 2,600 kt of imported animal feed and 2,800 kt of imported seed to grow animal feed. This enabled New Zealand to export 1,200 kt of meat and 3,600 kt of milk and milk derivatives (Figures 6 & 8).

New Zealand's limited arable land use (2.3%)[85] and reliance on crops for animal feed highlight the opportunity for a holistic and balanced approach to sustainability in agriculture. The substantial import of additional animal feed and seed for fodder crops represents an opportunity to reduce import dependence and environmental impacts through sustainable practices.

In 2019, New Zealand imported $650 million of fertilisers, up from approximately $520 million in 2016. This comprised approximately 450 kt of Nitrogen fertilisers, predominantly urea, 165 kt of phosphorus fertilisers, 130 kt of potassium fertilisers and 1,200 kt of lime. (Preliminary figures for 2022 suggest this rose to $1.25 billion.[86] Top importing regions included China, Saudi Arabia, Canada and Malaysia. Nitrogen use in New Zealand has increased significantly since the 1990s, due to the expansion and intensification of dairy farming; a recent decrease resulted from application efficiencies. Phosphate use has almost halved since 2005, due to significant price rises resulting in more strategic use; lime use has also decreased since 2002. Potassium use remains largely unchanged. A significant proportion of fertiliser use supports the dairy, beef & sheep industry; see table below. Nitrogen fertilisers represented 4.5% of all agricultural emissions in New Zealand in 2021.[87]

Table 7: Percentage use of fertiliser types in New Zealand.

	Nitrogen	Phosphate	Potassium
Dairy Cattle	62%	49%	50%
Sheep & Beef	27%	43%	35%
Arable	7%	4%	6%
Horticulture	3%	4%	8%
Deer Farming	1%	1%	2%

The 2021 Greenhouse Gas Inventory for New Zealand indicates that New Zealand's agricultural sector emissions were 37,786 kt CO_2e in 2021, an increase of 13.4% since 1990.[88] One of the greatest contributors to this increase was a 40% increase in N_2O emissions from agricultural soils, primarily as a result of increased application of synthetic nitrogen fertiliser. These have seen an increase of 644% since 1990, partly due to an increase in dairy farming as well as more general increases in fertiliser use on farms. This was accompanied by a 118% increase in CH_4 emissions from manure management, again due to an increase in dairy cattle numbers, but which would have been more significant if not offset to some degree by a decrease in beef cattle, sheep and other mostly voluntary initiatives by farmers.

The greenhouse gas inventory also notes that emissions decreased between 2020 and 2021, a 237 kt CO_2e reduction being attributed to a decrease in the dairy cattle population and a 178 kt CO_2e reduction being attributed to a decrease in synthetic nitrogen fertiliser use.

New Zealand imported $277 million of insecticides, rodenticides, herbicides and fungicides in 2019, primarily from Australia, China and the USA.[89] This has since risen to $471 million in 2022.

New Zealand grows over 100 types of fruit and vegetables, and an MBIE report suggests the potential to reduce imports and grow more locally.[90]

The agriculture sector in New Zealand accounted for 62% of all water extractions in 2010, with the irrigated agricultural land area doubling between 2002 and 2017,[91] approximately 3.2 billion m^3.[92] This water has an estimated carbon footprint of 1,130 kt CO_2e,[93] roughly 1.4% of New Zealand's gross greenhouse emissions in 2020. At an estimated price of 14 cents per m^3,[94] this would equate to $448 million per annum (not including costs associated with irrigation).

The agricultural sector is a significant employer, with more than 366,000 individuals in primary industry jobs, including production and processing roles.[95] Transitioning to more sustainable agriculture might require workforce retraining and upskilling, presenting short-term challenges.

7.2.2 Key opportunities

Given what we know about the flow of materials through the New Zealand economy and the dependencies highlighted above, the following opportunities were identified that align with the circular economy principles. In classifying these, we've made a distinction between those that could provide immediate benefits and those that would manifest over a longer timeframe. That is not to say that Medium to Long-term opportunities should be left for a later date; however, many changes in agricultural systems are likely to require long-term and sustained efforts. We have also made a distinction between opportunities likely to be incremental to current practice and those likely to entail a higher degree of disruption.

Table 8: Identified circular economy interventions for Innovations in Sustainable Agriculture

	Intervention	Target Impact	Time Frame	Classification
1	**Water Management and Conservation:** Implementing water-saving technologies and practices such as drip irrigation, rainwater harvesting and wetlands management.	Better water resource management reduces the stress on water bodies and ensures more sustainable water use in agriculture. Manages drought risks and could also improve crop yields.	Immediate to Medium	Incremental
2	**Enhanced Use of Organic and Locally Sourced Fertilisers:** Promoting organic and locally sourced alternatives to reduce reliance on imported fertilisers.	Reduce environmental harm from chemical fertilisers, improve soil health, and boost local fertiliser industries. Reduce import reliance and cost for farmers.	Medium	Incremental
3	**Consumer Awareness:** Educating consumers about the benefits of sustainably produced goods and fostering a more environmentally conscious consumer base.	Increase demand for sustainably produced goods, encouraging farmers to adopt sustainable practices.	Medium	Incremental
4	**Integrated Pest Management (IPM):** Using biological pest control, habitat manipulation and other techniques to control pests with minimal ecological impact.	Enhance biodiversity, reduce chemical runoff, and improve crop health. Develop a more resilient agricultural ecosystem and reduce chemical pest control costs.	Medium	Incremental to Disruptive
5	**Waste Valorisation:** Converting agricultural waste into valuable products such as bioenergy, bioplastics, or organic fertilisers.	Reduce agricultural waste, increase farmer revenue, and reduce environmental pollution. Create new higher value bioeconomy industries/ low emissions packaging for export goods to meet new trade requirements	Medium to Long	Incremental to Disruptive
6	**Promoting Local Food Systems:** Encouraging the growth and consumption of local produce to reduce food miles and import dependency.	Reduce carbon emissions associated with transportation (food miles), strengthen local economies, and increase food security.	Medium to Long	Disruptive
7	**Crop Diversification and Agroforestry:** Encouraging a shift from reliance on imported animal feeds and seeds.	Increase resilience against market and climate fluctuations, improve soil health, and reduce erosion. Contribute to carbon sequestration and biodiversity.	Long	Disruptive
8	**Regenerative Agriculture Practices:** Adopting practices focused on soil health, water management, and ecosystem services.	Restore soil fertility, increase biodiversity, and enhance ecosystem services. Long-term sustainability, productivity, carbon sequestration.	Long	Disruptive

7.2.3 Potential benefits and limitations

The benefits and limitations of the opportunities under this area can be difficult to quantify, and some qualitative assessments are needed. There is also a need to recognise that all initiatives will require some policy support and incentives to progress.

The literature scan provided insights into various successful initiatives that can inform the development of such policies, such as the recycling of lithium-ion batteries by SungEel Hitech, which significantly reduces CO2 emissions compared to conventional mining, and Umicore's comprehensive recycling and resource efficiency strategies, which have led to substantial reductions in greenhouse gas emissions. Additionally, the Netherlands' increase in resource efficiency, as indicated by GDP growth per kilo of Domestic Material Consumption, serves as a noteworthy example of integrating circular economy principles into national economic strategies.

The impact and efficacy of these policies will largely depend on their specific design, the level of incentives provided and the way they adapt to the New Zealand context.

The literature review suggests that policy support and incentives in the agricultural sector could benefit from focusing on sustainable innovations, waste management, technological adaptation and regenerative practices. However, implementing such policies would require navigating regulatory hurdles and requiring sustained government commitment, aligning with evolving global standards and the sector's needs.

Policy Support and Incentives have been classed as overarching immediate to medium-term interventions, varying from incremental to disruptive, that will be required to support all other initiatives to some degree.

1. **Water management and conservation**

The circularity of water is a complex and emerging field and wasn't included in the scope of the Sankey diagrams in Section 6. It was still recognised as an important aspect of circularity worth considering in the context of New Zealand Agriculture and is an area worthy of additional focus. Efficient water use is crucial given New Zealand's extensive agricultural sector and its substantial requirement for water. Even modest improvements in water efficiency could significantly reduce water usage and associated costs and emissions from pumping and extraction. As noted, irrigated land use doubled between 2002 and 2017; a 10%-20% decrease in agricultural water back towards 2002 figures could result in a decreased carbon footprint in the region of 113 kt to 226 kt CO_2e and an economic saving of $45 million - $90 million per annum, benefiting both the environment and farm productivity.

Example initiative:

The Pomahaka Water Care Group aims to revitalise the Pomahaka catchment in South-West Otago. Its mission is to transform it from a place of deteriorating water quality to a thriving ecosystem suitable for various recreational activities. Initiated in 2013 by the NZ Landcare Trust, the project addressed high levels of contaminants such as sediment, phosphorous, nitrogen and E-coli. With substantial support from the Sustainable Farming Fund (now SFF Futures), the group has made significant progress. Their approach, which received a third round of funding in 2018, combines the roles of farmers as "citizen scientists" and active stakeholders in sustainable agriculture, local business, recreation and tourism.

They focus on various aspects of farming practices, including managing runoff areas, winter crop management, fertiliser application, establishing buffer zones and riparian planting and management. This comprehensive approach not only aids in reducing nutrient loss, but also promotes overall water quality improvement. [96]

The water consumed by agriculture can be significant. For example, a 2012 paper indicates a water footprint for New Zealand milk of between 882 and 904 litres per kg, compared to an international figure of 1,020 litres.[97] Further insights from this AgResearch paper reveal the complexity of this issue. Their study, focusing on the dairy industry's water footprint in the Waikato and Canterbury regions, underscores the importance of regional variations in water footprints. These variations are influenced by local climatic conditions and farming practices, with significant differences noted between non-irrigated moderate rainfall areas (Waikato) and irrigated low rainfall areas (Canterbury). Crucially, the study identifies degradative water use, primarily driven by nutrient management, as a major contributor to the water footprint in these regions. This finding suggests that enhancing nutrient management is essential for reducing the water footprint in New Zealand's dairy farming systems.

The study also brings to light the potential impact of water use practices on New Zealand's environmental image. While the country might have a lower water consumption advantage, issues related to water quality, stemming from agricultural practices, also have the potential to impact the country's 'clean and green' reputation, especially overseas.

Improvements in water efficiency might come from various strategies, including improved irrigation techniques, such as sensor-based systems, or AI-driven water management tools and soil enhancements. Additionally, demand reduction resulting from a shift in agricultural output types could be beneficial. Certain types of food are known to use more water to produce,[98] so a shift away from producing as much of these foods could result in desirable savings. However, it is recognised that the choice of what farmers produce is dependent on demand for their produce and what their land is best suited to producing. Meat consumption is declining in many western countries but growing in developing nations.[99]

The management of water sources is also critical. This involves preserving and enhancing natural water bodies, managing groundwater recharge and preventing pollution of water sources. The role of government policies and regulations in promoting water conservation practices is essential, including incentives for water-efficient technologies and penalties for excessive water usage.

Navigating this change is likely to be complex. It may require support to enable farmers to implement water-saving technologies or to adjust agricultural practices or outputs. The impacts of climate change on water availability must also be considered, necessitating resilient water management practices.

Collaboration among farmers, water management experts and researchers can foster knowledge sharing and the development of more effective water management strategies. Changes could be implemented incrementally and progressively, with benefits being realised in the short term and ongoing.

Water management and conservation has been classified as an immediate to medium-term and incremental opportunity, due to its practical approach to enhancing existing water use practices. This has the potential to yield immediate benefits by integrating water-saving technologies into existing agricultural systems, improving water efficiency and cost savings. As an incremental change, it focuses on refining and optimising current water management strategies, rather than introducing radical new systems. Over time, these gradual improvements contribute to substantial cumulative effects on water conservation and sustainability. The medium-term benefits emerge as these technologies become more embedded in daily farming operations, enhancing long-term water resource management without significantly deviating from established practices.

2. **Enhanced use of organic, locally sourced fertilisers**

With New Zealand's considerable expenditure on imported fertilisers, amounting to just under $1.5 billion in 2022,[100] a strategic transition to organic and locally sourced alternatives could offer significant cost savings, enhance environmental sustainability, and alleviate supply-related risks. Given the scale of imports, even a modest shift, meeting only 10-20% of this demand could divert between $125 and $250 million back into local businesses to produce sustainable organic alternatives.

Example initiative:

In New Zealand, Villa Maria's Sustainable Vineyard Floor Project explores an alternative approach to vineyard floor management. It involves planting native plants and cover crops instead of maintaining bare dirt using chemicals or mechanical cultivation. This method aims to establish a self-sustaining ecosystem on the vineyard floor, potentially reducing the need for tractors and chemical applications. It also seeks to evaluate the impact of these practices on soil health, yield, and wine quality. The project, spanning 13 months, received both MPI and industry funding. It represents an experimental shift in traditional vineyard practices, the results of which could provide insights into the viability and effectiveness of such sustainable methods in vineyard management.[101]

In considering New Zealand's shift from imported to locally sourced and organic fertilisers, it's vital to evaluate the feasibility of local production, the cost-effectiveness and efficiency of organic options compared to synthetic fertilisers and the potential impact on agricultural productivity in both the short and long term. Additionally, this transition would require careful planning in terms of investment, environmental implications, consumer market dynamics and regulatory support, while also being mindful of its effects on international trade relations and the broader economic landscape. Relative downstream impacts and benefits on the health of soil, waterways and wildlife would also need to be carefully weighed.

The global fertiliser market's volatility, highlighted by the surge in potash and phosphate rock prices following geopolitical events such as the conflict in Ukraine, underscores the strategic importance of fertilisers and the risks of a concentrated global supply chain.[102] This has also been linked to ethical concerns around sourcing fertiliser from contested places associated with human rights violations such as Western Sahara.[103]

The global fertiliser market's volatility, highlighted by the surge in potash and phosphate rock prices following geopolitical events such as the conflict in Ukraine, underscores the strategic importance of fertilisers and the risks of a concentrated global supply chain.[104] Major mining companies are increasingly venturing into fertiliser production in response to these dynamics and the enduring demand for these minerals. Regionally, initiatives like Chatham Rock Phosphate Limited's push to include phosphate, monocalcium phosphate, and selenium in Australia's list of Critical Minerals underline the growing recognition of these materials' strategic importance, crucial for securing regional supply chains and ensuring the availability of essential nutrients for agriculture.[105]

Synthetic fertilisers contribute significantly to greenhouse gas emissions in production and transportation. The carbon footprint of various imported fertilisers, such as ammonium sulphate and urea, ranges from 0.38 to 1.28 kg CO_2 equivalent per kg, not including additional emissions from soil after application.[106] Based on the 2019 import figures for fertilisers and these carbon emissions, the combined carbon emissions from fertiliser imports are in the region of 560 kt of CO_2e.

A 10-20% reduction in fertiliser use might, therefore, be expected to reduce carbon emissions by 56 kt to 112 kt per annum, however the impact of alternatives would need to be carefully assessed and taken into consideration.

Transitioning to organic and locally sourced alternatives or reducing fertiliser use through precision dosing could potentially mitigate these environmental impacts, reducing emissions and addressing issues like water pollution, soil contamination and eutrophication from nutritional runoff.

However, this transition is not without challenges. High initial costs for developing and sourcing local organic fertilisers, ensuring market acceptance for organically grown products and navigating global market volatility and regional supply dynamics are significant hurdles. Despite these challenges, New Zealand's move towards organic and locally sourced fertilisers aligns with both the economic imperative to reduce import dependency and environmental sustainability goals, such as capturing commercial and residential food waste for reprocessing into compost and fertiliser. This transition presents a multifaceted opportunity to enhance the resilience and sustainability of New Zealand's agricultural sector, resonating with global trends towards sustainable agriculture and efforts to secure critical mineral supply chains.

Enhanced use of organic and locally sourced fertilisers has been classed as a medium-term, incremental intervention. This intervention focuses on gradually transitioning from reliance on imported fertilisers to organic and locally sourced alternatives. The medium-term classification reflects the time needed to develop local fertiliser sources, adapt farming practices and achieve market acceptance for organically grown products. As an incremental change, it represents a gradual shift towards more sustainable nutrient management, enhancing soil health and reducing environmental harm without drastically overhauling existing agricultural practices.

3. Consumer awareness and behaviour change

Consumer awareness and behaviour change strategies can play a crucial role in promoting sustainably produced goods, with a significant potential to influence consumer behaviour. While challenging to quantify, this impact aligns with the increasing awareness and demand for environmentally responsible products. Such a trend can contribute to shifting the market towards more sustainable practices in the agricultural sector.

Addressing consumer behaviour and perceptions involves making the public aware of the benefits of sustainably produced goods and reconsidering established habits and preferences. In this context, regulatory environments, such as those in the European Union, with stringent requirements for product labelling and green claims, provide a relevant backdrop. These regulations necessitate adherence to specific environmental standards, influencing product perception in key export markets.

Effective communication and behavioural change strategies are vital in attempting to bridge the gap between consumer awareness and purchasing decisions. The challenge of greenwashing, where products are marketed as more environmentally friendly than they are, highlights the need for accurate and transparent information. This aligns with initiatives like those in the EU, emphasising verifiable standards and certifications for sustainably produced goods.

Interdisciplinary and cross-sector collaboration in this challenging and complex area is essential.

This has been classed as a medium-term, incremental opportunity. The medium-term categorisation reflects the time required to shift consumer perceptions and buying habits. As an incremental change, it builds on existing efforts, aiming to influence consumer behaviour towards more sustainable choices. This supports the transition to sustainable agriculture by fostering demand for eco-friendly products, which is crucial for encouraging farmers to adopt greener practices.

4. Integrated Pest Management (IPM)

Integrated Pest Management (IPM) strategies, applied in various agricultural sectors globally, demonstrate a range of impacts on sustainable farming practices. In horticulture, biological controls like predatory mites and parasitic wasps have been observed to manage pest populations effectively, reducing chemical pesticide use.[107] Similarly, vineyards have reported adopting IPM techniques, incorporating pheromone traps for insect control and cover cropping for soil health enhancement.[108] In dairy and pastoral farming, practices such as rotational grazing and strategic use of anthelmintic anti-parasitic drugs have been employed for sustainable pest management.[109]

Example initiative:

The "A Lighter Touch" programme is a significant example of the transition towards Integrated Pest Management (IPM) in New Zealand. The focus is on augmenting sustainable horticulture production while assisting with COVID-19 recovery efforts. This initiative aims to unite the horticulture, wine and arable sectors in a collective endeavour to meet consumer demands for sustainably produced food. It involves a shift from traditional crop protection methods to integrating biological and ecological processes in food production.

The aims of the initiative include:

- *aligning with the growing consumer preference for sustainably managed food products*
- *enhancing New Zealand's reputation as a preferred supplier of plant-based food*
- *increasing relevant investment*
- *raising the value of New Zealand's agricultural exports*

- *diversifying agricultural production*
- *maintaining the social license to farm* [110]

These examples reflect the varied application of IPM and its role in aligning agricultural practices with ecological principles. IPM is noted for potentially reducing reliance on chemical pesticides, contributing to biodiversity and supporting the sustainability of farming systems. The associated environmental benefits, alongside economic implications like cost savings and potential yield improvements, are recognised, though quantification can vary.

When considering the specific context of New Zealand, a shift towards IPM could potentially decrease the reliance on imported chemical pesticides. If IPM practices lead to an estimated reduction in pesticide use by 20-30%, this might correlate with a reduction in expenditure of $94 million to $141 million annually. The environmental impacts of such a reduction, including diminished chemical runoff and enhanced biodiversity, are acknowledged as integral to sustainable agriculture, albeit challenging to quantify precisely.

Reducing dependence on imported pesticides could also affect New Zealand's agricultural self-sufficiency and positioning within international supply chains. Such a shift is noted in the backdrop of global market dynamics and supply uncertainties.

However, the transition to IPM involves considerations beyond the ecological and economic. Implementing IPM depends on acquiring specialised knowledge and adapting to new pest management techniques. New Zealand appears well-positioned to address this challenge through its strong agricultural and forestry research institutions.

IPM has been classified as a medium-term intervention, ranging from incremental to disruptive. The approach involves adopting more ecologically balanced pest control methods like biological controls and habitat manipulation. The medium-term nature of IPM reflects the time needed to establish and observe the effectiveness of these new pest management strategies safely within agricultural ecosystems. As an incremental change, IPM can involve subtle adjustments to existing pest control practices, integrating more sustainable methods. However, it may be disruptive in some cases, requiring significant shifts away from traditional chemical-based pest control towards more complex, ecologically integrated approaches.

5. **Waste valorisation**

The scale of waste from the agricultural sector was unclear from the Sankey diagrams, and this would require further investigation. However, there are already good examples in New Zealand of converting agricultural waste into bioenergy, bioplastics, or organic fertilisers to create new revenue streams.

The scale of impact depends on the volume of waste and the efficiency of conversion processes. Scion's work in commercial bioproduct development illustrates the potential of these practices. Their expertise in developing biopolymers and biochemicals from natural resources enables the creation and commercialisation of products that support circular and bio-economies in New Zealand and globally.[111]

For example, Scion has developed bioadhesives free of petrochemicals and formaldehyde, which are used in manufacturing “green” plywood, medium-density fibreboard (MDF) and other engineered wood panel products. Scion also specialises in developing coatings that add functionality to paperboard, plastic films and other packaging materials, enhancing the value of these products while maintaining their sustainability.

These examples from Scion reflect the potential for agricultural waste valorisation in creating sustainable products. The barriers, however, remain significant.

While waste valorisation presents opportunities for generating new revenue streams and contributing to environmental sustainability, its success is contingent upon overcoming various technological, market and logistical challenges.

Initiatives like the Centre for Green Chemical Science at the University of Auckland also contribute to this field.[112] The Centre's mission is to promote and facilitate research, education and public engagement in green chemical science.

The Bioresource Processing Alliance (BPA) connects industry with scientists and engineers who specialise in adding value to low-value biological by-products of primary industry processing. They offer a suite of services, from consultancy to commercialisation and co-fund research and development projects for a variety of raw materials, ranging from forestry to microbiological sources.[113]

Waste valorisation has been classed as a medium to long-term opportunity, with both incremental and disruptive change elements. The strategy transforms agricultural waste into valuable products like bioenergy, bioplastics, or organic fertilisers. Its classification as medium to long-term acknowledges the time needed to develop and implement effective waste conversion technologies and create markets for these new products. Incrementally, it involves gradually incorporating waste conversion processes into existing agricultural systems. However, the transition can be disruptive, requiring substantial waste management infrastructure and practice changes.

6. **Promoting local food systems**

Reducing import dependency on animal feed and seeds could bring significant economic benefits. Local food systems might also reduce carbon emissions from transportation, strengthen local economies and improve food security.

Reducing import dependency on animal feed and seed for fodder crops, for example (2,600 kt of animal feed and 2,800 kt of seed imported), local food systems could significantly reduce import costs and associated carbon emissions.

The Big Food Redesign Study[114] by the Ellen MacArthur Foundation strongly promotes diversification in crop types to build food supply resilience and enhance culinary traditions around local varieties. The prominence of New Zealand lamb, Manuka honey and green-lipped mussels are good examples. Another approach to enhancing local food systems is to select lower-impact crop varieties. For example, shifting from higher-impact wheat flour to lower-impact pea flour can reduce greenhouse gas emissions by 40% and biodiversity impacts by 5% while increasing yields by 5%.[115] Beans and peas also have the advantage of being nitrogen fixers, reducing the need for fertilisers. In the case of potatoes, a shift to more resilient varieties resistant to pests and diseases has also been shown to reduce synthetic fertiliser use.[116]

Additionally, perennial varieties of wheat, such as Kernza, offer significant environmental benefits. Unlike conventional annual wheat that needs to be tilled and re-sown each year, perennial wheat builds soil health, absorbs more nutrients and water, and can sequester about 1 tonne of CO_2 equivalent per hectare per year, which is about ten times more than conventional wheat varieties.[117] The yield of some perennial crops, however, can be lower than annual varieties, highlighting a trade-off between soil health and immediate or short term productivity.

However, the success of local food systems depends on several factors, including consumer preferences and market readiness, and includes the ability of farmers and growers being able to make changes. Developing local markets and supply chains for New Zealand-grown products can be challenging and relies heavily on consumers' willingness to buy locally-produced foods.

This intervention has been classed as a medium to long-term, disruptive opportunity. This approach involves encouraging the growth and consumption of local produce, aiming to reduce food miles and import dependency. The medium to long-term timeframe reflects the substantial effort required to develop robust local food systems, including altering supply chains, consumer habits and agricultural production patterns. As a disruptive change, it represents a significant shift from reliance on imported feeds and seeds towards a more self-sufficient, locally-focused agricultural model.

7. **Crop diversification and agroforestry**

In New Zealand, the strategic implementation of crop diversification and agroforestry is directed towards optimising the limited arable land, accounting for merely 2.3% of the country's total land area.[118] This approach intends to reduce the reliance on imported animal feed and seeds, potentially leading to lower import costs and increased agricultural self-sufficiency. The financial implications of such diversification depend on selecting specific crops and their varying market values.

The transition to crop diversification and agroforestry in New Zealand faces challenges, particularly in adapting to the country's unique ecological settings. A successful adaptation requires a nuanced approach, considering the local climatic and soil conditions for appropriate crop and tree species selection. Insights from local initiatives like West Coast Agroforestry, which conducts research and collaborative efforts suited to local environments, highlight the importance of such tailored approaches.[119]

Moreover, a significant shift in farming practices would be required, moving from traditional monoculture to diversified and sustainable agriculture. This transition necessitates new skills and knowledge and a change in perspective regarding land and resource management. The experiences of organisations such as the New Zealand Farm Forestry Association demonstrate the potential and multifaceted benefits of integrating trees into agricultural landscapes for varied purposes.[120]

The concept of transitional forestry, particularly the 'triad' approach, offers a framework for balanced forest management in New Zealand. This approach combines low-intensity, multiple-use forests with conservation-focused reserves and industrialised plantations to achieve a harmony between ecological and economic values. Complementing this approach are the principles of ecological forestry, which focus on mimicking natural processes, including retaining legacy trees and ensuring biodiversity through varied stand structures and recovery periods between harvests.[121]

In an international context, agroforestry has emerged as a promising concept. Blending agricultural and forestry techniques, agroforestry seeks to diversify crop types and enhance environmental quality. The strategy is seen as a means to improve soil carbon, reduce emissions and contribute positively to water quality, furthering the goals of sustainable land management. The applicability of agroforestry in the New Zealand context does, however, appear uncertain.

Example initiative:

The Tikitere agroforestry trial in the Bay of Plenty, conducted from 1973 to 1999, was a significant study in New Zealand examining the integration of radiata pine forestry with understorey grazing. The study concluded that combining trees and pasture on the same land was generally not beneficial for wood quality, pasture production, or animal performance.[122]

A more recent publication by AgResearch highlights the decline in agroforestry involving Pinus radiate, due to negative impacts on wood quality, pasture production and animal performance, but also notes the ongoing and significant role of widely spaced trees like Populus and Salix, primarily for erosion control and other ecosystem services, in pastoral hill country landscapes.[123]

The advancement of crop diversification in New Zealand represents a multifaceted approach to agricultural development. It involves careful consideration of local ecological conditions, a shift in traditional farming practices and the integration of sustainable land management principles. The success of these strategies hinges on their effective planning and execution, drawing upon both local experiences and broader sustainable forestry practices.

Example initiative:

In the area of crop diversification, a NIWA project to assess the potential for growing specific crops and tree species in New Zealand using detailed climate, soil and topographic data has been implemented since 2003. It involves creating suitability maps to identify areas with high or low potential for certain crops and tree species. The methodology includes interpolating climate and soil data, identifying growth requirements and developing a simple additive model for suitability assessment. The results have been used in regional economic development programs, providing a tool for land-use decision-making. The process also considers other factors like market and infrastructure. It has been applied in various regions like Western Kaipara and Hokianga, Tararua District, and Gisborne District, evaluating a wide range of crops and tree species.[124]

Crop Diversification and Agroforestry have been classed as long-term, disruptive opportunities in New Zealand's agricultural sector. This strategy aims to shift from reliance on imported animal feeds and seeds towards a more diverse and sustainable cropping system. The long-term classification is due to the significant time required for changing farming practices, adapting to new crop types, and establishing agroforestry systems. As a disruptive change, it necessitates a fundamental shift from traditional monoculture systems to a more varied and integrated approach that combines agriculture with forestry. This transition involves considerable changes in land use, farming practices, and market adaptations.

8. Regenerative agriculture practices

Regenerative agriculture practices present significant potential for environmental improvement. The transition to these practices is envisaged to span an extended period, reflecting the deep-rooted changes required in farming methods and land management.

Regenerative agriculture in New Zealand represents a transformative shift from conventional farming, focusing on restoring ecosystems and enhancing soil health. This approach aligns with circular principles by reducing waste and recycling resources within agricultural systems. Key regenerative practices include maintaining living roots, reducing soil disturbance, increasing diversity, limiting synthetic inputs and strategically managing livestock. These methods offer potential for significant greenhouse gas emissions reduction through enhanced carbon sequestration and reduced methane emissions.[125]

However, as the Landcare Research points out, the transition to regenerative agriculture in New Zealand is complex and long-term, necessitating profound changes in agricultural methodologies and land use. The shift is both physical and conceptual, requiring re-evaluation of traditional farming approaches. It involves challenges such as high transition costs, the need for extensive training and education and potential ecological impacts. Strategic planning, investment in capacity building, and continuous research are crucial for successful adoption in New Zealand. The realisation of regenerative agriculture's benefits, including carbon sequestration and emissions reduction, depends on overcoming these challenges and adapting the practices to New Zealand's unique agricultural context.[125]

Terra Genesis International's research suggests that agricultural soils could sequester 2 to 3 gigatonnes of carbon per year globally.[126] If this potential maps to the New Zealand context, then regenerative practices might substantially offset the country's greenhouse gas emissions. However, the specific potential in New Zealand remains highly uncertain and contested, necessitating a detailed analysis of current farming practices and soil conditions.

Regenerative agriculture has been classed as a long-term, disruptive opportunity within New Zealand's agricultural framework. The approach involves a fundamental shift from conventional farming methods to practices focused on enhancing soil health, biodiversity and ecosystem services. The long-term nature of this intervention reflects the considerable time required to observe the full benefits of these practices, as they necessitate profound changes in soil management, crop rotation and overall land use. Being a disruptive change, regenerative agriculture demands a significant departure from traditional farming techniques, encompassing a holistic rethinking of agricultural practices. This transition will likely involve substantial training, investment, and adaptation across the agricultural sector.

The market dynamics of regenerative farming have also yet to be fully appreciated. In the short to medium term the potential higher labour costs and smaller scale of these farms might suggest a need to obtain premium prices for products, both here and abroad. In the longer term, a wholesale shift to regenerative farming may require consumer acceptance of higher prices for higher quality products, more environmentally benign products and associated reductions, for example, in red meat consumption.[127]

The shift towards regenerative agriculture in New Zealand could be navigated through manageable, incremental steps that build upon each other, such as implementing some of the other interventions mentioned above. By taking a phased and integrated approach, the journey towards regenerative agriculture may become a series of achievable steps, reducing the perceived difficulty of the transition. This would allow for adaptation and learning, ensuring that the practices are well-suited to New Zealand's unique agricultural context and contribute effectively to its environmental goals.

7.2.4 Summary

Table 9 Summary of projected benefits of identified interventions.

Intervention	Projected Benefits	Identified Challenges
1. Water management and conservation	**113 kt – 226 kt CO_2 eq per annum**. Economic saving of $45 million - $90 million per annum.	**Based on a 10%-20% decrease in agricultural water usage (2002 levels)** Investment in new technologies. Adapting current practices.
2. Enhanced use of organic, locally sourced fertilisers	**56 kt to 112 kt per annum** **$125 to $250 million in annual savings** by reducing imported fertilisers lower carbon emissions (not quantified).	**Assumes a 10-20% shift to local and organic fertilisers is feasible (impacts would need to be assessed)** High initial costs; market acceptance.
3. Consumer awareness and behaviour change	**Not Quantified** Shift towards sustainably produced goods; potential for higher profit margins.	Changing consumer habits; combating greenwashing. Assumes educated consumers will prefer sustainable products.
4. Integrated Pest Management (IPM)	**$94 million to $141 million p.a.** Estimated reduction in pesticide expenditure; enhanced biodiversity.	**Assumes 20-30% reduction in pesticide use achievable with IPM** Specialised knowledge is required. Shift from traditional methods.
5. Waste valorisation	**Not Quantified** New revenue streams from agricultural waste; contribution to environmental sustainability.	Development of processing technology; market development. Assumes agricultural waste can be efficiently converted into valuable products.
6. Promoting local food systems	**Not Quantified** Reduced carbon emissions from transportation, strengthened local economies, and improved food security.	Developing local markets and supply chains; consumer preferences. Assumes local production can significantly replace imports.
7. Crop diversification and agroforestry	**Not Quantified** Improved soil health, carbon sequestration, and reduced import costs.	Changing farming practices; adapting to new crop types. Assumes diversification and agroforestry can be integrated into existing systems.
8. Regenerative agriculture practices	**Not Quantified** Potential to offset greenhouse gas emissions, long-term soil fertility, and ecosystem services.	Substantial training and investment; a fundamental shift in farming. Assumes regenerative practices will lead to long-term sustainability gains.

7.3 Critical materials and the circular economy

Like other regions, New Zealand's reliance on imported materials and products is essential for sustaining its core capabilities, including the Advanced Manufacturing sector. This opportunity area explores strategies similar to those adopted in the UK, EU, US and Japan, focusing on leveraging the circular economy to enhance technological independence. This strategy is particularly relevant in the context of increasing global supply chain disruptions and the trend towards 'resource nationalism'.[128] It is complemented by efforts to boost domestic production and diversify supply sources.

The central aspects of this approach are demand-led. These include enhancing product durability, promoting reuse and remanufacturing and product-as-a-service (PaaS) models. Extending the lifecycle of materials and products aims to maximise the utility of imported goods, thereby reducing the need for frequent replacements. This approach aims to buffer against future supply disruptions and price volatility, while reducing environmental impacts per function delivered.

However, it is acknowledged that most products will eventually end their useful life and need replacement. Addressing this, the global necessity for supply-led initiatives is recognised, particularly in recycling practices that separate critical materials. This is crucial, to prevent the loss of these materials through dispersion in bulk recycling. This includes discussion on hosting more recycling activities within our own borders, with the aim of creating domestic secondary supplies. Yet, this raises the challenge of establishing a domestic supply chain capable of using these secondary materials, which can be a significant barrier for some products.

Given the international nature of supply chains, this approach necessitates collaboration with like-minded regions. Working with other countries with similar objectives could help overcome the challenges and maximise the benefits of this approach.

7.3.1 Rationale

Although manufactured products represent a comparatively small flow in the New Zealand economy (Figure 6), they are also likely to represent a critical flow from a capability perspective. For example, the mass of materials imported annually to provide an aerospace capability in New Zealand is vanishing small compared to the materials consumed for the built environment. However, the economic capacity enabled by aerospace products is indispensable for tourism, business and just-in-time manufacturing. The global value of aerospace is estimated to be in the region of $600 billion and growing.

The New Zealand space sector, a unique example driven almost entirely by commercial activity, was estimated at $1.7 billion in 2018-2019. This figure encompasses the direct contribution of $897 million to the GDP, with space manufacturing and applications as strong subsectors, and an indirect contribution of $789 million through expenditures on goods and services. Moreover, it supports about 5,000 full-time equivalent roles directly, and a total of 12,000 jobs including indirect effects. These figures reflect a vibrant mix of start-ups and established companies, both small and large, entrepreneur-driven and privately funded, servicing a range of government and private customers, and underscored by internationally competitive research and development capabilities within several universities across the country.[129]

In 2020, just over two thirds (66.67%) of New Zealand's GDP came from service industries, compared to just 5.65% from primary industries and 19.71% from goods producing industries dominated by construction). The service industries comprised a broad range of sub-sectors represented below:[130]

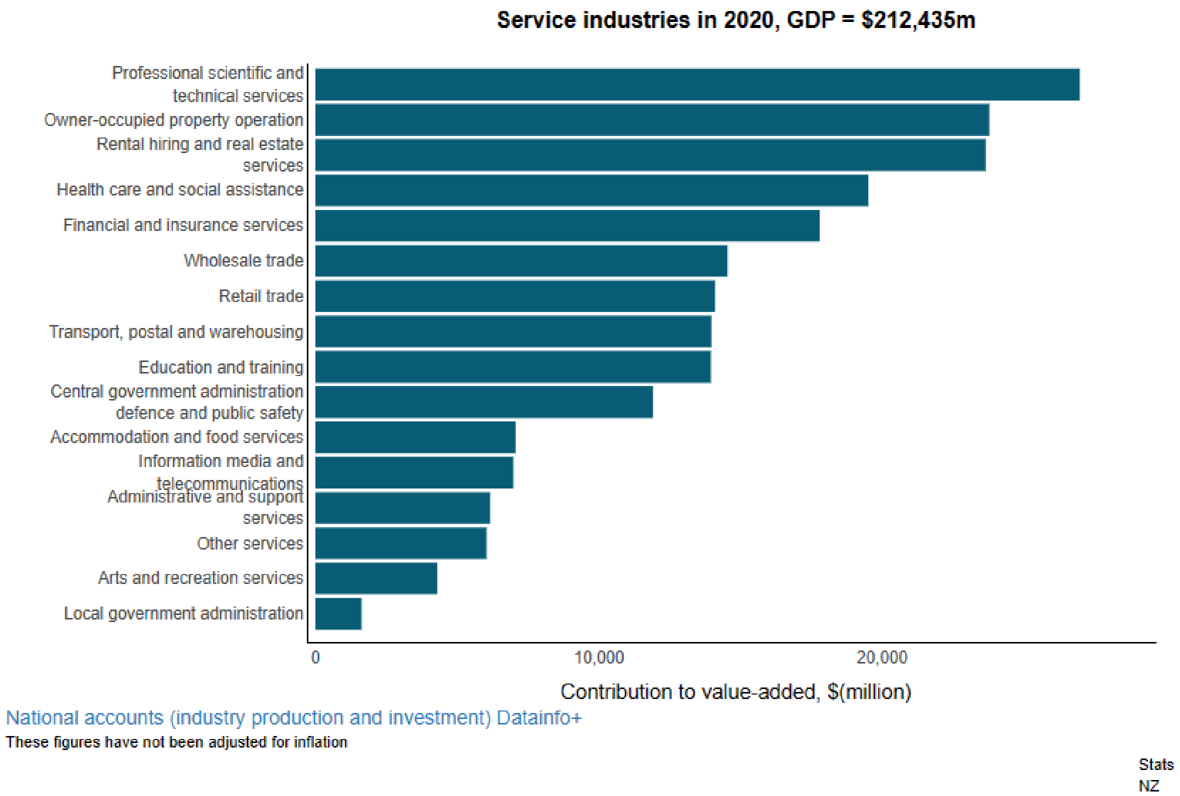

Figure 14: Breakdown of GDP in the New Zealand Service Sector 2020, Stats NZ [131]

Many of these services rely on the availability of IT equipment, which is almost entirely imported. In 2022, New Zealand imported $1.65 billion of computer equipment, mostly from China but also from the USA, Singapore, Malaysia and Taiwan.[131] In turn New Zealand exported $17 million of waste electrical and electronic waste, mostly to Korea, Japan and the USA.[132] This perhaps illustrates the value added to the raw materials through manufacturing, with the raw material value of e-waste exports being just 1% of the value of electronics imported in the same year. A 2016 case study supports this, finding that the value of the raw materials in an iPhone 6 were just US$1.03[133] vs. an initial retail price of US$199.

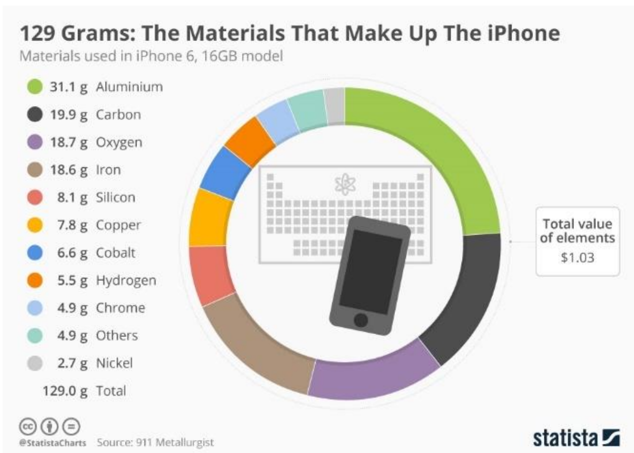

Figure 15: Value of raw materials in an iPhone 6, Statistica [134]

Estimating the embodied carbon of electronics at a national level is difficult, as product impacts will vary, and no detailed inventory exists. However, we might estimate the overall impact simplistically by taking a modern laptop as an example. A carbon footprint of 370 kg CO_2e with 86% (318 kg CO_2e) being associated with manufacturing and a retail value of $2,500 might be a reasonable set of values to use.[135] Based on the value of imports in 2022, this gives a value of 210 kt of CO_2e imported per annum, not including transport-related impacts or use-phase energy consumption.

Ensuring ongoing access to critical materials at a reasonable price will be critical for meeting national emissions targets as outlined in New Zealand's Emissions Reduction Plan.[136] The scale-up of most renewable technologies includes the use of critical materials. 'Rare Earth' permanent magnets are vital components in wind turbines and electric vehicles; lithium, cobalt and graphite are vital for battery storage and gallium, indium, antimony and tellurium are all used in solar panels. These elements are identified as critical by the EU, UK and USA. The ability to scale up production to match global demand will likely introduce supply constraints and price volatility, increasing costs for most countries.

The International Energy Agency (IEA) embodied impacts for mid-sized electric vehicles are 8-9.4 tonnes CO_2e, not including lifetime electricity use. The IEA estimate is 6 tonnes CO_2e for an internal combustion engine vehicle.[137] This suggests an estimated greenhouse gas emission break-even point for an EV, when compared to an Internal Combustion Engine (ICE) vehicle of around 22,000km, although this is based on the US electricity mix.[138]

Regarding energy generation, New Zealand currently has 19 onshore wind farms with an installed capacity of 1,045 MW. A further 2,200 MW of onshore generation is currently in various planning and consent stages.[139] These currently provide roughly 10% of New Zealand's annual power generation. Assuming a typical 2MW turbine, there are roughly 520 turbines today, with scope for an additional 1,100 more. A typical 2MW power plant from Vestas contains 6,193 tonnes of material, including 9 tonnes of rare earth magnets.[140]

Critical materials are not confined to technology applications. They extend to vital sectors like construction, as seen in New Zealand's recent efforts to address building material shortages. New Zealand imported $13 million of gypsum in 2022. New Zealand established a task force to ensure steady supply and prevent crises like the GIB plasterboard shortage.[141] In response, the development of a critical minerals list has also been proposed.[142]

7.3.2 Key opportunities

Table 10: Summary of Interventions for Critical Materials

	Intervention	Target Impact	Timeframe	Classification
1	**Domestic recycling of critical minerals**	Reduce reliance on imports, conserve natural resources and enhance waste management.	Short to Medium Term	Incremental
2	**Enhancing product durability**	Reduce waste and resource use, extend product lifespan and promote sustainable consumption.	Medium Term	Incremental
3	**Remanufacturing**	Conserve resources, reduce waste and support a sustainable manufacturing sector.	Medium Term	Incremental
4	**Product-as-a-Service**	Promote resource efficiency, reduce ownership burden and foster sustainable business models.	Medium Term	Disruptive
5	**Design for reuse**	Facilitate product reuse, minimise waste and encourage sustainable design practices.	Long Term	Disruptive

7.3.3 Potential benefits and limitations

1. **Domestic recycling**

Promoting domestic recycling of at-risk materials could focus on three levels of opportunity.

Level 1: Simple products (e.g. plasterboard)

The primary focus here is on recycling materials from simpler products to establish domestic production based on a secondary supply of materials. This involves setting up recycling processes for straightforward materials like plasterboard. The process includes collecting, segregating, and processing used plasterboard to recover materials that can be reused in new plasterboard production.

Level 2: More complex products

The goal for products of higher complexity, such as home appliances or automotive components, is to enhance segregation and invest in recycling technologies to produce high-quality secondary materials. These materials would then feed into international supply chains for manufacturing new products. This level requires more advanced recycling technologies capable of handling complex products like electronic devices. It involves detailed segregation to extract valuable materials and refine them to a quality suitable for manufacturing.

Level 3: Highly complex products with impractical domestic recycling infrastructure

For products where establishing a domestic recycling infrastructure is impractical or unfeasible, such as aerospace components, advanced medical equipment, electronics, wind turbines or solar panels, the focus shifts to ensuring adequate segregation for high-value recycling to be achieved offshore. This involves meticulous sorting and preparation of materials for export to specialised recycling facilities overseas. This might be necessary for highly complex products, low-volume products, or materials requiring specialised technology that is unavailable domestically. While this relies on international facilities, it ensures that valuable materials are not lost to landfills and are reclaimed in a manner that contributes to the circular economy.

Both Level 2 and Level 3 highlight the importance of international collaboration by enhancing the availability of high-quality secondary materials on the market. The aim would be to increase global availability and mitigate supply concentrations or bottle necks. At a business level, various businesses have employed a similar strategy. Rolls-Royce has a Revert programme in which it sells scrap materials back to its supplier and offsets the value of the scrap against the value of new materials.[143] Umicore also has a buy-back program for platinum group metals, where the value of scrap supplied back to the company is offset against the value of new materials purchased.[144] A similar model might be applied to regional trade.

These three types of opportunity in domestic recycling reflect a pragmatic approach that acknowledges the varying complexities of products and the feasibility of establishing recycling processes. They aim to maximise resource recovery and minimise environmental impact, while also considering the economic and technical realities of recycling different types of products.

This opportunity has the potential to reduce New Zealand's dependence on imported materials, by creating domestic ‘loops’ for sourcing these materials or international loops with overseas partners. Ensuring that critical materials can be recovered and reused seeks to minimise the need for continual extraction and importation of new resources from unstable markets and so has the potential to contribute to price stability.

Economically, domestic recycling initiatives could significantly reduce the cost of importing critical materials. However, each level needs to be carefully considered. For instance, New Zealand's export of computer equipment in 2022 amounted to $17 million, which may suggest that a Level 2 or Level 3 intervention would be inappropriate unless small-scale, highly efficient recycling can be established.

Mint Innovation started in New Zealand, but has since moved overseas. It extracts ‘green metals’ from waste. Green metals is a term used to describe a set of metals that are used in renewable energy applications. They include copper, nickel, zinc, cobalt, neodymium, graphite, lithium, manganese and molybdenum.

Mint is developing the commercial use of natural biomass and chemistry. It claims its process saves more than 90% of the carbon typically produced in conventional metal recovery methods and uses only a fraction of the power and water compared to traditional mining or smelting processes.[145]

Establishing a robust domestic recycling industry could create job opportunities and contribute to skill development in areas related to waste management and material recovery.

Enhanced domestic recycling is classified as a short to medium-term opportunity, reflecting the quicker implementation period for establishing and scaling up recycling facilities, compared to more complex opportunities like systemic design changes or international collaborations. The infrastructure and technology required for recycling can be developed and applied within a shorter period, allowing the potential benefits to be realised faster. The nature of this opportunity is 'Incremental' rather than 'disruptive'. This is because it builds on existing waste management and recycling practices, enhancing and expanding them rather than completely overhauling current systems or introducing entirely new concepts. It represents a natural progression in waste management strategies, aligning with current environmental and economic objectives without necessitating a radical shift in industrial or consumer behaviour.

2. **Enhancing product durability**

Enhancing the durability of products focuses on minimising exposure to market forces and reducing the environmental impacts over the product's lifetime, by ensuring that they last longer.

Increasing the lifespan of products, particularly those involving critical materials, such as electronics, renewable energy technologies and other high-value manufactured goods, reduces the replacement frequency and the associated demand for new resources.

In the context of critical materials, this approach is especially relevant, both for known critical materials and those that may emerge in the future that may be vital to the New Zealand economy. These materials are often used in products with high economic and technological significance, such as IT equipment, aerospace technologies and renewable energy systems.

Many of the products that contain these materials are, by the very nature of criticality, produced offshore. However, products containing critical materials underpin core national capabilities and we can influence our demand for them. By enhancing the durability of these products, New Zealand can reduce its dependency on imported materials and mitigate the environmental impact associated with manufacturing new products.

For consumers, longer-lasting products create opportunities for fewer replacements, which could mean lower long-term costs. For manufacturers, more durable products can create greater brand loyalty and a reputation for quality, potentially creating competitive advantage. Additionally, this approach can stimulate economic activities and job creation in product maintenance and repair sectors.

Environmentally, enhancing product durability can have a substantial impact. It can reduce waste generation and decrease the environmental impact associated with producing new products. Considering the high carbon footprint of manufacturing (as noted in the laptop example with 318 kg CO_2e of emissions), extending product life has the potential to significantly reduce overall emissions. For example, the typical replacement cycle for IT equipment is three years, based on the estimated 210 kt CO_2e of IT equipment imported into New Zealand in 2022, which works out to 70 kt per year. Increasing the replacement cycle to 4, 5 or 6 years leads to a saving of 17.5 kt to 35 kt per annum.

Based on where the emissions from manufacturing occur however, the environmental benefits from this approach are unlikely to significantly contribute to reducing New Zealand's greenhouse gas emissions, and there is also likely to be a trade-off between New Zealand emissions and global emissions.

With energy-consuming equipment, the benefits of longevity need to be balanced against improved energy efficiencies that may emerge with new technologies as well as the fitness for purpose of older technology. Some of this may be overcome by establishing secondary markets, Recycle a Device (RAD) being a good example of this in New Zealand.[146] Procurement practices are also likely to be important in managing the upgrade cycle.

Socially, there are benefits in terms of reduced waste and the promotion of a culture of sustainability. It can also create job opportunities in the repair and maintenance sectors, fostering a skilled workforce.

Enhancing product durability is classified as a medium-term opportunity, reflecting the time required to implement changes in product design, manufacturing processes and market adoption. While some improvements can be made relatively quickly, a broader shift towards producing and valuing durable products requires changes in consumer attitudes, manufacturing practices and possibly regulatory frameworks. The nature of this opportunity is described as incremental, because it involves a gradual improvement of existing products and processes rather than a radical transformation. Enhancing durability can be achieved through improvements in design, the use of more robust materials, and better manufacturing practices. These changes, while significant, represent an evolution of current practices rather than a complete departure from them. The approach aligns well with existing production and consumption patterns, making it a practical and achievable strategy.

3. Remanufacturing

Remanufacturing involves restoring used or end-of-life products to a 'like-new' condition. This process can be particularly significant for products that use critical materials, such as electronic devices, aerospace components and renewable energy equipment. The goal is to recover and reuse these materials and components, extending their useful life and reducing the need for new resources. In many ways, this achieves the same objectives as enhanced durability but requires changes at a later point in the product lifecycle, which may make it more difficult if the capability for the product is not adequately designed in.

In the context of critical materials, remanufacturing can be a valuable strategy. It allows for the efficient use of materials that are either scarce or have significant environmental impacts associated with their extraction and processing. By remanufacturing products, New Zealand could create jobs and decrease its reliance on imports of these materials, mitigating some of the associated environmental footprint of manufacturing new products from raw materials.

Economically, remanufacturing can contribute to cost savings and value creation. It reduces the need for new materials, which can be expensive and subject to market fluctuations, as seen in the case of recent supply issues with semiconductors.[147]

Remanufacturing also opens up new business opportunities and markets, potentially leading to job creation in sectors related to the remanufacturing process. In the EU, job creation in the remanufacturing space is being further enabled by Right to Repair legislation, which places the consumers' right to repair a product ahead of manufacturer warranties that tend to focus on replacement.[148] Similar legislation does not yet exist in New Zealand. However, evidence exists for its support in New Zealand. On 7 July 2022 Repair Café Aotearoa New Zealand delivered a 'Make it our Right to Repair' petition to the then Minister for the Environment signed by nearly 13,000 people.[149]

As with enhanced durability, this intervention can significantly reduce waste and the carbon footprint associated with product manufacturing by reducing the volume of waste sent to landfills and lowering the demand for energy-intensive new material production. Remanufacturing can be another element of business for traditional manufacturers, for example as undertaken by Caterpillar and Renault, however more work is required to identify what industries in New Zealand could benefit from this approach.

There are examples of emerging remanufacturing businesses in New Zealand, such as MedSalv, which remanufactures single use medical equipment.[150]

The timeframe for the remanufacturing opportunity is classified as medium-term, acknowledging the need for establishing remanufacturing facilities, developing the necessary technology and creating market acceptance for remanufactured products. While some remanufacturing aspects can be implemented relatively quickly, a broader adoption across various sectors requires time to develop the necessary infrastructure and supply chains. This is an Incremental opportunity, because remanufacturing builds upon existing manufacturing and recycling processes, enhancing and refining them, rather than completely replacing current systems. It could mean a step forward in the evolution of product lifecycle management, as it supports the further integration of sustainability into existing design and manufacture. The approach is about improving and extending the current product use and disposal model, rather than introducing a wholly new system.

4. **Product-as-a-Service**

The Product-as-a-Service (PaaS) opportunity represents a shift from the traditional model of product ownership to a service-based model. In this approach, consumers pay for the use of a product rather than owning it. This model is particularly relevant for products incorporating critical materials, such as IT equipment, electronics and renewable energy technologies, as it has the potential to radically reduce the number of products required.

Well-discussed examples of PaaS include tool hire services, where an electric drill can be hired by hundreds of people on an occasional basis, preventing each of them buying their own that would be largely unused. Platforms like “Share my Tools”[151] and community tool libraries represent examples of this approach outside of established tool hiring businesses.

PaaS platforms place value on the access to the product or the service that it provides, rather than the product itself. In the case of vehicles, the average car spends 95.8% of its time parked,[152] representing a massive expenditure for the level of utility provided. Services like Lime or Uber have attempted to tap into this challenge by offering mobility as a service in various forms. Similar examples exist for homes in AirBnB and entertainment with the shift from CDs and DVDs to streamed content,[153] as well as clothing rental companies.

Another example that is commonly described in circular economy discussions is the Philips ‘Pay per lux’ model for commercial lighting, where Philips provide the equipment, maintenance and replacement of bulbs and pays for the electricity, while the user pays for the lighting they consume.[154] The acknowledged benefits of this approach have included enhancements in product design to extend product efficiency, durability and reusability, as these became a concern for Philips in operating this business model efficiently.

The Philips model provides valuable insight into the role of procurement in enabling PaaS-based circular models. It was the willingness of Schiphol Airport, in this case, to procure lighting as a service that enabled the model to be validated, whereas most businesses would, as a matter of routine, purchase lighting hardware and then pay to maintain it themselves.

PaaS can reduce the demand for new resources in the context of critical materials. Participating manufacturers are incentivised to design for longevity, ease of repair and recyclability when they maintain ownership of the products, as this enables valuable resource recovery. This shift could lead to more sustainable use of critical materials, reducing the need for constant replacement and new material extraction.

PaaS can also lead to a more stable and predictable revenue stream for some businesses with properly aligned business models, where they operate ongoing service contracts rather than relying solely on one-time sales. It can also open new market opportunities and business models. It might also mean lower upfront costs and access to higher-quality products for consumers.

Where PaaS replaces ownership, rather than operates in addition to it, it can also reduce waste and resource use. It can encourage participating manufacturers to design durable, easy-to-repair, and upgradeable products. This opens up design options that can reduce the environmental impact associated with their production and disposal.

Properly framed and promoted in the public consciousness, PaaS could support a cultural shift towards more sustainable consumption. It may also create new jobs in sectors related to product servicing, maintenance and recycling. In the case of transport, accompanied by appropriate policy and infrastructure provision, it could lead to fewer vehicles on the road and resulting decreases in future roading requirements.

Environmentally, the benefits of PaaS models can be significant. Let's take an electric vehicle as an example.

A mid-size EV has a carbon footprint of 8-9.4 tonnes CO_2e at the point of manufacture[155] and has been estimated to have a 'breaks-even' on its embodied and operational greenhouse gas emissions after 22,000 km (albeit based on the US energy mix).[156] Globally the user penetration for car-sharing is projected to be 0.7% in 2024 and 0.8% by 2028 with an annual growth rate (CAGR 2024-2028) of 4.37%.[157] If this growth rate persists, we might expect to see a market penetration of 0.9% by 2030 and 1.7% by 2050.

The number of private cars replaced by each car in a car share scheme has been estimated in various studies to be between 5 and 15.[158]

Using these figures, we can estimate the potential benefits to New Zealand as this model is adopted.

New Zealand currently has a fleet of 4.5 million vehicles travelling a combined 47 billion km per year.[159] The lifetime vehicle emissions for a combustion engine vehicle are around 35.9 tonnes CO_2e over a 200,000 km lifecycle.[137]

A market penetration of 1.2% by 2035 would equate to taking 54,000 combustion engine vehicles off the road. Based on private car replacement by each car share car by 5 to 15 these would be replaced by between 10,800 and 3,600 vehicles respectively, which we'll assume are all electric vehicles. A current EV is capable of 14.73 kwh per 100 km[160] and the New Zealand grid currently generates 0.000149 tonnes of CO_2e per kwh, or 4.39 tonnes for 200,000km. This means that the combined environmental savings from vehicle replacement and a shift to electric vehicles could be somewhere between 1,790 and 1,894 kt CO_2e.

A market penetration of 1.7% by 2050 would equate to taking 76,500 combustion engine vehicles off the road and replacing them with between 15,300 and 5,100 shared vehicles, again based on a car share car replacement of private cars of 5 to 15 If we again assume that these are all electric and that EV technology stays the same as today, this means that the combined environmental savings from vehicle replacement and a shift to electric vehicles would save between 2,535 and 2,830 kt of CO_2e.

The projected long term emissions savings of 1,790 kt and 1,894 kt of CO_2e by 2035 and between 2,535 and 2,830 kt CO_2e by 2050, respectively, through the adoption of car-sharing models, represent a gradual accumulation over time, rather than instantaneous benefits.

These savings are contingent on the progressive market penetration of car-sharing, the lifecycle and usage intensity of electric vehicles (EVs) in the shared fleet, and the evolving energy mix powering these vehicles. As such, the actual manifestation of these savings will likely be a continuous process, accelerating with factors like faster adoption rates, increased vehicle turnover, and a shift towards greener energy sources.

This gradual realisation of benefits underscores the dynamic nature of environmental impact in the transition to more sustainable transportation models. More detailed modelling would be required to calculate the expected annual benefits that could be expected.

Such a model could reduce the carbon footprint associated with the manufacturing of individual vehicles and amplify the environmental benefits of EVs through more efficient use.

Additionally, if properly managed this model could open up associated opportunities for other environmental and social benefits, such as reduced traffic congestion and lower air pollution levels. It might also be used to support efforts to shift consumer behaviour towards shared mobility, which can benefit urban planning and sustainability in the long term.

However, implementing such a model would require careful consideration. This includes ensuring adequate charging infrastructure, addressing range anxiety and social norms around ownership, and managing the logistics of vehicle sharing well. Public acceptance and changes in consumer behaviour are also crucial factors for the success of this model. The potential for significant environmental benefits seems clear, but the practical challenges must be addressed to realise these benefits fully.

The timeframe for the Product-as-a-Service opportunity is classified as medium-term. Implementing a PaaS model requires significant changes in business operations, consumer behaviour and regulatory frameworks. While some businesses can adopt PaaS models relatively quickly, a wider acceptance and transition across various sectors is not certain, and will take time.

The nature of this intervention is described as disruptive. Unlike incremental changes that build upon existing practices, PaaS represents a fundamental shift in how products are consumed and valued. It challenges the traditional notion of ownership and requires rethinking product design, business models and consumer attitudes. PaaS is not just an enhancement of existing practices but a radical change in the approach towards product lifecycle management.

5. **Design for reuse**

The 'Design for Reuse' opportunity involves creating products with an inherent ability to be easily reused, either in their current form or through minimal refurbishment. This approach is particularly crucial for products that incorporate critical materials, such as electronics and renewable energy technologies, many of which are designed and manufactured outside New Zealand. By focusing on reuse, the goal is to extend the product lifecycle, reduce waste and decrease the reliance on new materials, including imported critical resources.

Electric vehicles again make a good example scenario, although the durability of EV parts is still a bit unknown due to the maturity of the technology and the technology itself is still rapidly evolving along with the infrastructure required to support use and end of life recovery.

Tesla has revealed its Model 3 drive system performs well in test conditions (rather than on road) for more than one million simulated miles (1.6 million km).[161] Tesla also claims to be developing a car battery that will endure one million-miles of operation. But let's assume that the battery needs to be replaced every 200,000km. In a typical vehicle, losing a core component like the engine or the battery after 200,000 km would lead to the vehicle being scrapped.

The New Zealand Climate Commission draft advice to inform the government's second Emissions Reduction Plan puts forward the scenario that more than 14% of New Zealand's vehicle fleet could be fully electric by 2030.[162]

Given that New Zealand currently has 4.5 million passenger vehicles, this means 630,000 electric vehicles in New Zealand by 2050. A typical electric vehicle has an embodied carbon footprint of 8-9.4 tons, with 2.6-4 tons being the battery.[163] This means the combined footprint of the 630,000 EV's expected in New Zealand by 2050 would be 5,040 to 5,922 kt CO_2e. Putting aside premature removals through vehicle accidents, under the existing model of retiring the whole vehicle when the battery expires, this impact would be recurring and represent a significant contribution to New Zealand's offshore carbon impact.

Say we imagine a model wherein either the battery or the whole vehicle was leased and the battery could be more easily replaced. We wouldn't need to replace the rest of the vehicle when the battery expired. This could avoid the at least 5.4 tons of emissions per electric vehicle being scrapped, or 3,402 kt across the fleet of 630,000 electric vehicles, a saving of between 57% and 68%. If we were able to replace the battery in this way four or even eight times, perhaps using the vehicles more intensively through a shared ownership scheme, the avoided impacts would be even greater. Rising to 10,206 kt CO_2e for four battery replacements and 16,506 kt for eight battery replacements.

There are, of course, both technical and social barriers that would need to be overcome to implement such a system, but the technology certainly already exists. Nio, a Chinese EV maker, already has a service that can swap out a vehicle battery in minutes, performing over 40,000 battery swaps at more than 2,000 automated stations.[164] There is also a growing market for used vehicle batteries as grid-attached storage, where the reduced capacity is less of a concern. Ensuring that the need to replace the critical minerals in the motor could be avoided would also shelter New Zealand against price volatility and export constraints for rare earth materials and would mean more could be done with existing rare earth production capacity globally. Naturally other vehicle systems such as computer hardware, upholstery, etc would also require replacement or refurbishment periodically but this might create job opportunities locally.

7.3.4 Summary

Table 11:

Intervention	Potential benefits	Identified challenges
Domestic recycling	**Not Quantified** • Reduce reliance on imports • Job creation • Enhanced security of supply	Requires careful consideration of the level of intervention needed. International collaboration
Enhancing product durability	• **17.5 kt to 35 kt CO_2e p.a.** • Greater resilience to supply disruptions	• **Assumes IT equipment replaced less frequently** • Requires changes in consumer attitudes, manufacturing practices, regulatory frameworks and procurement. Fitness for purpose
Remanufacturing	**Similar to Durability** • Job creation • Cost savings • Enhanced security of supply • Less landfill and waste	• Right to repair • Training and facilities • Market acceptance
Product-as-a-Service (PaaS)	• **between 2,535 kt and 2,830 kt CO_2e by 2050** • Reduced ownership burden • Reduced infrastructure. • Lower costs • Accelerated adoption of EVs	• **Assumes projected car share market penetration of 1.2% by 2035 and 1.7 % by 2050 with all vehicles electric, and private car replacement ration of between 5 and 15** • Requires significant changes in business operations, consumer behaviour, and regulatory frameworks • Charging infrastructure

Design for reuse	• **10,206 kt and 16,506 kt CO_2e long term emission saving**
	• Reduced exposure to price volatility
	• Local job creation
		• Assumes:
		  o 14% of New Zealand's vehicle fleet will be fully electric by 2030
		  o Increased use per vehicle through car sharing
		• Requires a significant shift in global manufacturing and design practices. Additional part replacements likely

7.4 Material reductions to landfill

7.4.3 Plastic material reductions to landfill

Figure 7 and Table 3 reveal a large amount of materials, especially plastics, are disposed of in New Zealand's landfills. To improve waste management, especially for plastics in Class 1 landfills, it's essential to adopt a measurable and effective framework. The Australia, New Zealand and Pacific Islands Plastics Pact (ANZPAC),[165] initiated by the Australian Packaging Covenant Organisation (APCO) serves as a foundational model for this strategy. The New Zealand government is an ANZPAC member.

The ANZPAC goals are to eliminate problematic plastic packaging through redesign and innovation, aiming for all plastic packaging to be reusable, recyclable or compostable by 2025. This includes phasing out unnecessary plastic packaging, ensuring that 100% of plastic packaging meets these criteria by 2025, increasing the rate of plastic packaging collection and recycling by at least 25% within the ANZPAC region, and incorporating an average of 25% recycled content in plastic packaging across the region. These specific targets align with broader environmental objectives, emphasising the importance of clear and achievable goals in reducing the environmental impact of packaging.

Circularity metrics are valuable because they provide a clear score reflecting various waste management efforts, such as recycling, composting and reuse. This unified approach allows for a fair comparison of different strategies, making it easier to track progress, communicate achievements and prioritize actions.

The National Plastics Action Plan for New Zealand[166] plays a significant role, as it phases out specific plastic items like plastic bags and PVC containers, marking a significant move to cut down plastic waste. The strategy calls for nationwide standardisation in collection and labelling, crucial for promoting proper recycling habits. This standardisation was implemented on 1 February 2024. Such measures should reduce the volume of plastic entering landfills and improve the overall efficiency of recycling processes.

7.4.4 Capturing biological waste from food and agriculture

The significant amounts of biological waste shown in the materials flow and food flow diagrams (Figure 2 and Figure 4), along with landfill composition data (Table 2), underline both challenges and opportunities for innovation, soil health improvement, renewable energy generation and increased agricultural efficiency at reduced costs.

There is currently insufficient data, monitoring and reporting of these waste flows. However, the volumes involved underscores the importance of investigating further development and scaling of technologies to convert organic waste into biofuels, bioplastics, biochar and fertilizers, which can help reduce emissions and fossil fuel use. Encouraging research and collaboration among research institutions, tech companies, and waste management entities is essential for driving advancements in this area, aligning with the principles of a circular economy by transforming waste into resources.

A critical aspect of this approach is managing agricultural residues to maintain soil health, despite current gaps in data regarding their use or disposal. Better information and discussions on sustainable management practices, such as composting and mulching, are necessary. These practices recycle nutrients back into the soil and reduce the need for synthetic fertilizers, with financial incentives and technological support playing a key role in promoting their adoption.

Additionally, tapping into the potential of organic waste for renewable energy through anaerobic digestion facilities could significantly cut greenhouse gas emissions.[167]

Adopting policy frameworks and investment incentives like those in other countries could accelerate renewable energy projects that utilise organic waste, with set standards and guidelines ensuring sustainability and efficiency in energy production from these sources.

For example, landfill taxes and levies, which are in effect in approximately 25 European countries,[168] can reduce landfill usage. However, there is an associated risk of an increase in waste incineration. Incineration-related taxes and levies are not as widespread as landfill taxes, but recent years have seen several implementations and amendments.

In New Zealand a levy is currently set at $20 per tonne (excluding GST) on all waste sent to class 1 municipal landfills. The rate for class 1 landfills is progressively increasing over the next couple of years up to $60 per tonne from 1 July 2024. Class 2 construction and demolition fills are subject to a levy of $20 per tonne (excluding GST) on all waste sent to landfill from 1 July 2022, and $30 per tonne from 1 July 2024. Class 3/4 (managed and controlled fills) have been subject to a levy of $10 per tonne from 1 July 2023.[169]

Half of the levy money goes to territorial authorities (city and district councils) to spend on promoting or achieving the waste minimisation activities set out in their waste management and minimisation plans. The remaining funds are put towards the Waste Minimisation Fund (WMF) which is 'focused on accelerating New Zealand's transition towards a low emissions and low waste circular economy'.[170]

A study commissioned by the Irish Environmental Protection Agency found that in eight European countries, incineration taxes/levies varied significantly.[171] Particularly in France, Spain (specifically Catalonia), and Belgium (specifically Flanders), evaluation reports verified the success of these measures in diminishing the volume of waste incinerated, enhancing recycling, and lowering emissions from energy-from-waste facilities. A salient aspect of these successful measures was the incentivised tax rates, which encouraged pre-sorting prior to incineration and spurred the development of facilities with improved efficiency and emission profiles. Additionally, there were instances where taxes were specifically redirected back into other organisations to support improvements in circular economy performance. This included investments in separated food waste collection for anaerobic digestion and innovations in waste sorting, which expanded recycling potential and economic opportunities.

By focusing on waste valorisation, sustainable residue management, renewable energy and agricultural efficiency, New Zealand could decrease the volume of biological waste in landfills, thereby supporting environmental sustainability and advancing towards a circular economy. This aligns with one of the New Zealand Waste Strategy[172] focus areas on organic waste management, aiming to minimise the disposal of organic materials. The strategy advocates for integrated systems to divert and treat organic waste efficiently, turning it into valuable resources. Initiatives to divert organic waste from landfills are highlighted to reduce methane emissions, with an emphasis on leveraging technologies like anaerobic digestion and composting for resource recovery. Policy support and regulatory frameworks are crucial for enabling these processes and fostering market growth for organically derived products. Collaboration across the waste management spectrum is vital for successful implementation, as is innovation in treatment and valorisation technologies to enhance organic waste management's effectiveness and potential. Education and public awareness campaigns are also fundamental in promoting responsible waste practices, supporting the transition to a sustainable, circular economy.

7.4.5 Enhancing recycling through design and infrastructure

In 2019, New Zealand generated approximately 14,500 kt of waste (Figure 3), a considerable amount of which was disposed of in landfills, while a minimal percentage was recycled or exported. This situation calls for an improved waste management strategy. Notably, the export of a significant volume of metal waste and the insufficient data on losses from textiles or tyres may reveal opportunities for enhancing domestic recycling capabilities and filling gaps in the waste tracking system.

The concept of enhancing recycling through design and infrastructure aims to tackle waste issues comprehensively, focusing on elevating recycling practices and achieving more effective waste management. The existing New Zealand Waste Strategy advocates for revising and improving national recycling policies to better align with current practices. This includes adopting advanced recycling technologies and methods to boost the efficiency and value of processed waste, positioning New Zealand in line with global best practices for sustainable waste management and reduction.

Construction and demolition waste, potentially accounting for up to half of all waste in New Zealand, brings attention to the necessity of sustainable building practices. This includes prioritising waste avoidance and the use of recyclable and sustainable construction materials. The strategy also promotes setting circular economy targets for the building sector, encouraging a broad approach to circularity that extends beyond recycling.

Efforts to enhance local recycling capabilities, especially for materials currently destined for landfills or export, are crucial. This includes investing in the local recycling industry to foster economic opportunities and reduce landfill reliance, alongside exploring best practices in industrial symbiosis.

Improving recycling infrastructure and optimising material lifecycle management will lead to more efficient waste handling, reducing costs and landfill dependency. Success hinges on the collaborative efforts of government, industry, and communities, as well as the development of supportive policies and infrastructure.

7.5 Shift to low carbon energy and transport

Figure 5 illustrates the ongoing reliance on imported oil for transport, and domestic gas for electricity generation and industrial heating. This intervention aims to address the issue of high energy consumption from non-renewable sources, with a particular focus on the transport sector. The approach places an emphasis on integrating renewable energy sources, including solar, wind and hydro into the energy mix, reducing the reliance on imported non-renewable sources. This transition is complemented by the development of waste-based biofuels, aimed at better utilising organic and agricultural waste. Financial incentives and policy mandates are suggested to support this integration, encouraging both public and private sector participation in renewable energy initiatives. Reducing reliance on imported oil aims to lower emissions and protect New Zealand's industry from market volatility.

New Zealand's dependency on imported oil for transport and domestic gas for electricity generation and industrial heating is a significant concern. This issue is problematic not just for environmental reasons but also for the economy. Transitioning to renewable energy sources, such as waste-based biofuels, tackles both environmental and economic challenges.

Encouraging the use of renewable energy through financial incentives and policy changes can reduce the need to import oil. This could help reduce New Zealand's trade deficit by decreasing the money spent on energy imports. Focusing on local renewable energy could lead to job creation, boost local industries, and provide protection against global oil price changes. This approach can enhance economic stability and offer new growth opportunities.

The proposal recommends implementing smart transport systems focused on efficiency. This includes investing in efficient public transport systems, like electrified buses and trains and developing smart traffic management systems to optimise routes and reduce congestion. It supports the promotion of non-motorised transport, such as cycling and walking, through the enhancement of relevant infrastructure. Additionally, adopting new technologies, such as apps that combine different modes of transport and make payments easier, aims to create a more integrated and user-friendly transport experience.

To enhance energy security and reduce operational costs in transport, adopting waste-based biofuels where appropriate is suggested, decreasing reliance on imported fossil fuels. Collaborative efforts with the agricultural sector are envisioned to establish a stable biofuel supply chain. Early attempts at this within New Zealand include Z Energy's abortive Te Kora Hou biofuels plant, which ran into difficulties with escalating construction costs and rising global prices for its feeder tallow, increasing competition for its use.[173] Internationally, back in 2008, Air New Zealand trialled biofuel made from jatropha nuts grown on marginal land in India, Mozambique, Malawi and Tanzania and is continuing to explore Sustainable Aviation Fuel options.[174]

Despite the obvious challenges, implementing energy efficiency measures across all transport modes is a key strategy, transitioning to more fuel-efficient vehicles and adopting practices that enhance safety and reduce environmental impacts.

8. Conclusion

Taken together, we found significant potential opportunities for circular economy initiatives to contribute to greenhouse gas emissions reduction in New Zealand.

The best areas of opportunity were identified as:

- Resource efficient buildings and infrastructure
- Innovations in sustainable agriculture
- Critical materials.

Within these areas, estimates of the annual emissions savings ranged from a low estimate of 1,539 kt CO_2e to a high estimate of 1,863 kt CO_2e (1.5–1.9 Mt CO_2e) per annum (recurring not cumulative). This would represent a 2.7%-3.4% reduction on 2021's net emissions.[88] (Table 12).

Additional emissions savings could be realised in the longer term through sustained action. By 2050, savings of 12,741 to 19,336 kt CO_2e (13–19 Mt CO_2e; total not per annum), could be achieved through vehicle sharing models (that reduce the materials needed to enable transport including critical materials used in vehicle manufacture), and the reuse of vehicle components such as batteries. A further saving of 1,500 kt CO_2e (1.5 Mt CO_2e) per annum was estimated to be achievable in 50 years' time if we start designing residential buildings to last 100 years, rather than 50 years.

These calculations represent only a small number of possible interventions in each category. The savings estimated would be a mix of domestic emission savings, through changes to what and how things are produced in New Zealand, and global emissions savings occurring in upstream supply chains through changes in what we import and consume.

Table 12: Estimated Annual Emission Savings Identified

Intervention Area	Intervention	Low Estimate (kt CO_2e)	High Estimate (kt CO_2e)	Estimated Disruption
Built Environment	Increased Building Utilisation	120		Incremental to Disruptive
	Refuse Unnecessary Components	71	140	Incremental
	Increase Material Efficiency	71	140	Incremental
	Reduce Virgin & Non-renewable Materials	240		Incremental
	Reduce Carbon Intensive Materials	850		Incremental
Agriculture	Water Management	113	226	Incremental
	Local Organic Fertilisers	56	112	Incremental
Critical Materials	Product Durability	18	35	Incremental
TOTAL		**1,539**	**1,863**	

We also identified, but did not quantify, associated potential benefits in employment, supply chain risk and resilience, and ecological sustainability.

It seems clear from our analysis that the circular economy in New Zealand has the potential to play a significant role in meeting the nation's greenhouse gas emissions targets. At the same time, these initiatives have the potential to provide a range of further benefits, in employment, supply chain risk and resilience, and ecological sustainability.

However, based on progress from overseas, the implementation and transition to a circular economy for New Zealand is likely to be slow unless a comprehensive and coordinated set of measures is introduced across government, business and civil society.

Annex A: Circular Economy Flows Methodology

This annex covers the scope, limitations, data sources and methods used to create Sankey diagrams showing the flows of materials and emissions in the New Zealand economy. These Sankey diagrams are visual representations of the data. The following Sankey diagrams were created for New Zealand:

1. Macro overview - mass metrics
2. Food flows of primary industries - mass metrics
3. Waste flow - mass metrics
4. Building and construction materials - mass metrics
5. Building materials and construction - carbon emissions metrics
6. Energy flows - energy metrics

These Sankey diagrams represent a high level view across New Zealand's production and consumption systems and highlight key intersections between economic and environmental impacts.

Scope

Reporting period

The reporting period selected is the financial year 2019 (1 April 2018 – 31 March 2019). FY-2019 was selected because the reporting period varied between sectors due to data availability and consistency. It was identified that the FY-2021 (1 April 2020 – 31 March 2021) was likely to be affected by COVID-19 restrictions and was therefore avoided. Across all data sets, data from the year 2019 was used, even when a more recent data set was available. This enabled all data to be on the same year basis, allowing us to cross reference data, as well as considering data pre-Covid.

Framework of the study

The focus area is Aotearoa New Zealand and the production and consumption within the country, but also including imports and exported products where data is available.

The framework is based on Economy-wide Material Flow Accounts (EW-MFA)[175] using data from the Global Material Flow Database[176]. EW-MFA are a statistical accounting framework recording, in thousand tonnes per year, material flows into and out of an economy. They cover solid, gaseous, and liquid materials, except for bulk flows of water and air. The general purpose of EW-MFA is to describe the physical interaction of the national economy with the natural environment and the rest of the world economy in terms of flows of materials.

Material inputs into national economies include:

- Domestic extraction of material originating from the domestic environment
- Physical imports (all goods) originating from other economies
- Balancing items input side.

Material outputs from national economies include:

- Domestic processed output to the domestic environment
- Physical exports (all goods) to other economies
- Balancing items output side.

The objectives of this study are:

- To adapt the economy-wide monitoring framework to Aotearoa New Zealand;
- To use publicly accessible data to quantify materials and energy use, and the resulting waste and emissions;
- Attempt to understand the current state of circularity of the economy;
- To present potential opportunities for intervention to transition towards circularity.

Limitations and gaps

The following general limitations and gaps are noted:

General

- Various data sources show different data collection, calculations, and validation methods; these were adapted when possible or feasible to show comparable information.
- The definition of waste depends on the entity or source. For example, tyres retired from the road could be categorized as stocks or as waste, depending on the entity. This not only brings limitations in how the data can be interpreted, but also explains current gaps in data around waste generation and management[177].
- Infrastructure data is included only in the Sankey for the macro-overview of New Zealand (mass metrics). Data around mass and emissions of materials in infrastructure are not included in the buildings Sankey because of a lack of disaggregated data.
- Water use is not included in the Sankey diagrams as per the definition of EW-MFA. The team is aware of the importance of this resource, and could be included as a further development to this work.
- Production based data include the resources within manufactured goods (for example, weight of metal for a car). However, this, same as the other flows, might be overestimated because of the modern complexity of supply chain and the diversity of products containing metals.
- Data aggregation from top-down data collection shows little granularity. Although some granularity was identified in the bottom-up approach and integrated when feasible. Much data that was collected couldn't be aggregated and therefore is not shown in the diagrams. Unused data is shown in the workbook, nonetheless.
- Visual representations of various gaps in the Sankey: Data gaps in the Sankey diagrams are shown as straight lines with arrows at the end (as opposed to coloured flows for existing data)

Macro overview of New Zealand - mass metrics

- The main source of data is the Global Material Flow Database (GMFD)[178] from the International Resource Panel at the United Nations Environmental Programme (UNEP-IRP, 2023). Due to the nature of a material flow database, it might be that some information is overestimated.
- Estimations of Aotearoa New Zealand's food waste are limited. Food waste is estimated based on a similar study in Europe (Caldeira, De Laurentiis, Corrado, van Holsteijn, & Sala, 2019). This data assumes that Aotearoa New Zealand and Europe have similar wastage in food production systems.
- Waste diverted from class 1 landfill, that is mass of recycling, is the only consistent data we have diversion of waste from landfill.
- Calculation of additions to stocks is largely limited due to lack of information. For now, additions of material stocks are calculated as the difference between input of material use and waste generated.

Agri-Food flows of primary industries in Aotearoa New Zealand - mass metrics

- A visual limitation of this Sankey is that we didn't show grazed biomass for animal feed, by choice. Since the number is so large, it would overshadow all other flows. Grazed biomass for animal feed was provided by IRP Database and estimated at 75,922,121 tonnes for 2019. The value was cross-checked with other literature sources, and it seems to be correct for a higher range of grazed biomass consumed. Depending on the consumption scenario this value could be reduced by 25%.
- Estimations of Aotearoa New Zealand's food waste are limited. Food waste is estimated based on a similar study in Europe (Caldeira, De Laurentiis, Corrado, van Holsteijn, & Sala, 2019). This data assumes that Aotearoa New Zealand and Europe have similar wastage in food production systems.
- Data gap in the flow of agricultural waste including manure.
- Limitation for food waste: it was not detailed for New Zealand supply chain. European waste generation were assumed.

Waste flow of New Zealand -mass metrics

- The calculation on waste sent to landfill classes 2–4 and farm dumps was estimated from MfE data from 2013. The values were updated based on GDP variance, as these landfill types mostly receive industrial waste.
- Limitation is the plastic waste data found. We found that the total amount of plastic waste sent to recycling used in the diagrams is similar to another source that gives information on domestic plastic packaging only, so waste plastic data might be underestimated.
- Limitation regarding the management of open landfill or dumps included due to lack of reporting and data.
- Data gap of waste lost to environment (microplastics from textiles & tyres for instance).
- Data gap around E-waste. Excluded from this diagram. It would be part of landfill class 3. We have estimates from 2015 (95 000t/year (UNSD, 2016b)) published by OECD for Aotearoa New Zealand – similarly for batteries from electric vehicles, but these have not been included.

Building materials of New Zealand -mass and emissions metrics

- Due to a lack of official data, we based these diagrams on a previous thinkstep-anz report (thinkstep-anz, 2022).
- Data from 2021 is assumed to be representative of the year 2019. Given the estimations in the report are done considering building consents, and not the actual construction, COVID-19 restrictions may play a limited role in the estimations.
- In the thinkstep-anz report, some building products will be underrepresented, while others will be overrepresented. Their methodology considered scaling up a small number of archetypal buildings and material carbon footprints to the national level, which will not represent the full range of buildings constructed and building products used to construct them.
- Construction waste fractions may not adequately reflect average performance in the Aotearoa New Zealand construction industry in 2021.
- Building consents are an available metric but are not the actual representation of buildings built.
- The three building archetypes used in thinkstep-anz modelling is a simplification of the types available in reality. Those three archetypes are: a standalone residential house, a multi-storey building, and a warehouse-type building.
- Since the Christchurch earthquakes, the market share of structural steel being used as framework in non-residential buildings has increased and the market share of reinforced concrete as a framework has decreased (BRANZ, 2022). It is hypothesised that this is likely due to structural steel having greater seismic-resistance properties than concrete. The reference buildings used for non-residential construction were from several papers that were published prior to the earthquakes, one of which was specific to a Melbourne concrete and steel mid-rise building. While

this reference building is not specific to New Zealand conditions (likely to have different seismic-resistance requirements), the concrete and steel mix is likely to be representative of New Zealand's non-residential building stock in 2019.
- The study from which the data was used was looking at the impact of buildings only, hence excluding infrastructure. Data on the construction of infrastructure is scarce. This gap is noted here and would be important to address in future work considering the importance of material flow that goes into infrastructure and material stock.

Energy flows in New Zealand -energy metrics

- The Sankey diagram is based on the MBIE Energy trade sheets. No gaps or limitations are noted.

Assumptions

General

Timeline: This study doesn't look at historical data and the evolution of resource use across Aotearoa New Zealand.

Accuracy: We acknowledge that data from GMFD is likely to overestimate some flows. This might make some flows from other sources seem low. For instance, although the import data for fossil fuels seems low, it seems correct when comparing to EU countries, based on similar energy mix and population. Data from GMFD is still used as it is the most consistent set of data available.

Data sets & specifics

1. MPI (2023), Overseas Merchandise and Trade data (OMT Ext) - import/exports Tonnes
    - Limitation: Not publicly available data.
    - Data is from a census of all farmers and foresters every 5 years, and sample surveys for the years in between. The programme is fully funded by MPI and administered by StatsNZ.
    - GAP: Missing mass of domestic production consumed domestically by primary industry.
    - GAP: Covers primary industries only.
2. Global Material Flows Database (UNEP-IRP, 2023)
    - The Global Material Flows Database (GMFD) gives the mass of raw materials that are extracted directly from nature, imports and exports of processed materials and products. Data from 2019 was used from this source.
    - Reference-Disclaimer: WU Vienna (2022): Domestic extraction by material sub-/group. Visualisation based upon the UN IRP Global Material Flows Database. Vienna University of Economics and Business.
3. National Waste and Recycling Snapshot (Waste & Recycling Industry Forum, 2023)
    - Used for some bottom-up data to fill the gaps around waste sent to landfill class 1.
    - Waste management - covering close to 100% of household waste and recycling collected at kerbside & 90% of municipal landfill waste.
    - Annual review of waste sector activity and performance based on a nine-member sample size. The total waste generated per person is assumed to represent the waste sent to landfill class 1 (municipal solid waste). Recycling rates are assumed to be representative of the whole country.
    - Waste generated per person. Total of waste recycled per material. Shares of recycling onshore (in Aotearoa New Zealand) and offshore (waste exported) are used.
    - GAP: There is around a 10% gap relating to municipal waste.
    - GAP: Excludes industrial and commercial waste.

4. Eunomia Waste disposal levy research (Wilson, Chowdhury, Elliott, Elliott, & Hogg, 2017)
    - Waste generation per landfill class, based on 2013 data from MfE.
    - Data from this report used: waste received in Landfills class 2-4 and Farm Dumps.
    - Other assumptions (such as recovered waste) are not taken from this report given the low confidence in their estimations.
5. Stats NZ (StatsNZ, 2023)
    - New-Zealand population – for population growth.
    - New-Zealand GDP – for GDP growth.
    - Livestock population in NZ.
6. New Zealand Dairy Statistics 2019-20 (LIC & Dairy NZ, 2020)
    - Milk information. Table 2.1 consisted of milk production statistics that were processed into export products (i.e., town milk supply was excluded). These statistics on milk, milkfat, protein and milk solids processed were provided by the New Zealand Dairy Board.
    - Weighted average livestock weight per dairy cattle. Table 4.7: Liveweight by age and by breed category of cow in 2019/20.
7. Global human appropriation of net primary production doubled in the 20th century: Feed intake for animals (Krausmann, Erb, Gingrich, & Haberl, 2013)
    - Used supporting info Tables M3-M4.
8. NZ Survey of Cereal areas and volumes_(Arable Industry Marketing Initiative, 2023)
    - Used table 2.1 Grain and pulses tonnes sold, tonnes to farmers and tonnes to industry p.13.
9. Figure.nz (figure.nz, 2023)
    - Weight of sheep and cattle graded in New Zealand (graded animals' weight).
    - The data from this figure was not used in a Sankey but used as a sense check for other data.
10. Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. (Caldeira, De Laurentiis, Corrado, van Holsteijn, & Sala, 2019)
    - Material Flow Analysis (MFA) of the food supply chain in the European Union.
    - Food waste per material type and supply chain stage (production, processing, and distribution).
    - Food waste generated in EU is assumed to be representative of Aotearoa New Zealand.
11. Research to Support the Co-design of a Plastic Packaging Product Stewardship Scheme for New Zealand (Skidmore, et al., 2023)
    - Identifies tonnages of plastic packaging placed onto the market from consumer and non-consumer sources and internal flows.
12. Environmental Report card 2019_(MfE, 2023)
    - Municipal solid waste composition.
13. Steel scrap (Hera, 2021)
    - Steel scrap exported (based on exports of secondary materials in Harmonised Trade Exports).
14. Plastic diverted from farm dumps (N. Shaw, personal communication, November 15, 2023)
    - Plasback and Agrecovery figures assumed to be representative for NZ.
15. Auckland city council: Waste data (J. Griffin, personal communication, November 20, 2023)
    - Spreadsheet summary waste data for Auckland City council, including Construction and Demolition breakdown.
16. Low carbon circular construction report (thinkstep-anz, 2022)
    - Bottom-up assessment to calculate material flows and emissions based on a small set of archetypal buildings. The results based on the sample size were then extrapolated nationally using the building consents issued for 2021.
    - Background data used within the Low carbon circular construction report, and additional sources used to build the data.

- For residential buildings, the total installed material was based on a single reference building: the Waitakare NOW Home (Beacon, 2010) and scaled up to reflect the total consents of residential buildings (Stats NZ, 2022) in New Zealand. The Waitakere NOW Home® (Beacon, 2010) is a single storey, three-bedroom home with garage and a gross floor area of 146 m^2. The composition of this house was adjusted to reflect the standalone home market in New Zealand using the same approach as in the thinkstep-anz Under Construction report (thinkstep-anz, 2019).
- For non-residential buildings, two reference buildings were used to determine total installed material, derived from (John, Nebel, Perez, & Buchanan, 2009) and the report *Under Construction: Hidden emissions and untapped potential of buildings for New Zealand's 2050 zero carbon goal* (thinkstep-anz, 2019), the former reflecting mid-rise (concrete) buildings and the latter reflecting low-rise (steel warehouse) buildings in New Zealand. Input material per reference building was scaled up to reflect the total consents of residential buildings (Stats NZ, 2022) in New Zealand. High-rise buildings were excluded from analysis.

17. On-site construction waste data spreadsheet, module A5 (BRANZ, 2023)
    - On site construction waste percentage for individual materials.
18. Energy balances from MBIE_(MBIE, 2022)
    - The energy balance tables reflect how energy supply and demand by sector varies by energy fuel type.
    - Supply, demand, losses, and inefficiencies are reflected in balanced energy supply and demand tables.

Table 0-1 References used per Sankey

	(MPI, 2023)	(UNEP-IRP, 2023)	(Waste & Recycling Industry Forum, 2023)	(Wilson, Chowdhury, Elliott, Elliott, & Hogg, 2017)	(StatsNZ, 2023)	(LIC & Dairy NZ, 2020)	(Krausmann, Erb, Gingrich, & Haberl, 2013)	(Arable Industry Marketing Initiative, 2023)	(figure.nz, 2023)	(Caldeira, De Laurentiis, Corrado, van Holsteijn, & Sala, 2019)	(Skidmore, et al., 2023)	(MfE, 2023)	(Hera, 2021)	(N. Shaw, personal communication)	(J. Griffin, personal communication)	(thinkstep-anz, 2022)	(BRANZ, 2023)	(MBIE, 2022)
Macro mass	x	x	x	x	x													
Food mass	x	x			x	x	x	x	x	x								
Waste mass	x	x	x	x							x	x	x	x	x			
Building mass																x	x	
Building emissions																x	x	
Energy																		x

Boundaries

Macro overview of Aotearoa New Zealand - mass metrics

From extraction of raw materials (domestic extraction and imports) until the waste production, emissions, additions to stock, and exports.

Agri-Food flows of primary industries in Aotearoa New Zealand - mass metrics

From raw food and feed extracted from nature to processed food and feed products. This also includes the import of processed and unprocessed food and feed. Left side of the flows represents the production for the food flows, and the right side the processing of those flows. Exports and imports are represented on both sides. Flows don't cover final consumption, thus excluding consumption waste downstream.

Waste flow of Aotearoa New Zealand - mass metrics

From the waste generated to the final destination in landfill or waste treatment.

Building materials of Aotearoa New Zealand - mass and emissions metrics

Materials input for the construction of residential and non-residential buildings flowing as stocks or on-site waste. Excludes end-of-life of the buildings.

Energy flows in Aotearoa New Zealand - energy metrics

From domestic production and import of different types of energy sources to the final use of energy in New Zealand economy or export of energy carriers.

Overview of methods

We used a top-down approach in the first phase of Project one to identify the mass, emissions, and energy flows in the economy, considering domestic production, imports, and exports first for an economy wide view at the macro level, followed by each priority sector. Some Sankey diagrams required a bottom-up approach to fill gaps.

This section goes through the methodology for each Sankey diagram created. The data used across most diagrams as well as general limitations and gaps have been covered in the previous section.

Macro overview of Aotearoa New Zealand - mass metrics

GMFD data sets were used first in a top-down approach to create this Sankey diagram. Some gaps had to be filled using a bottom-up approach:

- National Waste and Recycling Snapshot. 2023: Fills gap for waste of type class 1 using the follow data without further calculation (as is):
  - Waste generated per person and extrapolated based on population estimation in 2019. A linear relationship between waste generated per person in 2022 and 2021 is assumed to be representative to waste generated in 2019.
  - Total waste recycled per material.
  - Shares of recycling in- and off-shore.
- Eunomia – NZ waste disposal levy 2015 & Stats NZ – GDP growth
  - From Eunomia, data for waste received in landfills class 2, 4 and Farm Dumps is extrapolated using Stats NZ GDP change as a referential change for this type of landfill, as they do not receive domestic waste.

Agri-Food flows of primary industries in Aotearoa New Zealand - mass metrics

MPI and GMFD data sets were used first in a top-down approach to create this Sankey. Metrics relating to food flows previously calculated were also used here. GMFD provides the mass of raw material extracted directly from nature, we used other sources as factors to estimate the mass of livestock, for instance. Additional sources were used to fill gaps as a bottom-up approach or as 'factors' to estimate other gaps.

- We used data from New Zealand Dairy Statistics (LIC & Dairy NZ, 2020) to estimate data around dairy cattle (using Table 4.7) and the production of milk, milkfat, protein, and milk solids that were exported (Table 2.1)
- We used data from Table 2.1 of NZ Survey of Cereal areas and volumes (Arable Industry Marketing Initiative, 2023) to estimate the share of grain/cereals going either for human consumption or for livestock feed.
- We used the MFA of the food supply chain of the European Union to estimate food waste in NZ (Caldeira, De Laurentiis, Corrado, van Holsteijn, & Sala, 2019).

Waste flow of Aotearoa New Zealand - mass metrics

The waste data either used as is or estimated previously for the macro view of mass flows was reused here (coming from Recycling Snapshot and the Eunomia report). The following references were also used in a bottom-up approach to fill gaps:

- Mass of plastic packaging (Skidmore, et al., 2023)
- Municipal solid waste composition (MfE, 2023)
- Steel scrap exported (Hera, 2021)
- Plasback and Agrecovery figures, assumed to be representative for NZ (N. Shaw, personal communication, November 15, 2023)

Building materials of Aotearoa New Zealand - mass and emissions metrics

The underlying data of the Low carbon circular construction report (thinkstep-anz, 2022) was used for this Sankey. Below are the main elements from the methodology of this study:

1. Bottom-up assessment to calculate material flows and emissions based on three archetypal buildings. The results based on the sample size were then extrapolated nationally using the building consents issued for 2021. The small pool of archetypal buildings chosen will not fully reflect the diversity of real buildings. Further, using consents to estimate construction is an approximation and not all consented buildings will be built.
2. The carbon footprint of construction waste was calculated as follows:
    a. Estimate total national construction waste per material type.
    b. Take material quantities from three archetypal buildings: a standalone residential house, a multi-storey building, and a warehouse-type building.
        i. Note: the high-rise building was not included since very few buildings of this type is built in NZ. Only mid-rise and low-rise are included.
    c. Normalise these material quantities to 1 square metre of gross floor area per building type.
    d. Classify national building consent statistics for 2021 into these three archetypal building categories.
    e. Calculate 'installed materials' by multiplying the material quantities per square metre per building type by the total floor area consented per building type in 2021.
    f. Calculate 'construction waste' by multiplying 'installed materials' by typical waste fractions per material type.

g. Multiply the 'construction waste' quantity per building product by:
   i. The carbon footprint of manufacturing that product (modules A1-A3), and
   ii. The carbon footprint of waste treatment (modules C1-C4).

Background data used within the Low carbon circular construction report, and additional sources used to build the data covered above:

1. For non-residential buildings, two reference buildings were used to determined total installed material, derived from John et al. (2009) and thinkstep-anz's 2019 report "Under Construction: Hidden emissions and untapped potential of buildings for New Zealand's 2050 zero carbon goal" , the former reflecting mid-rise (concrete) buildings and the latter reflecting low-rise (steel warehouse) buildings in New Zealand. Input material per reference building was scaled up to reflect the total consents of residential buildings (Stats NZ, 2022) in New Zealand. High-rise buildings were excluded from analysis.
2. To get the total input material and the total construction waste, the total installed material at the national level was multiplied by the construction waste percentage for individual materials. This data was derived from BRANZ construct database and included common materials used in residential and non-residential construction. (BRANZ, 2023)

Energy flows in NZ - energy metrics

The energy balance from MBIE was the only document used to create this Sankey. No further calculation was required to produce the Sankey.

Annex sources

Arable Industry Marketing Initiative. (2023). New Zealand survey of cereal areas and volumes. AIMI. Retrieved from https://assets.far.org.nz/AIMI-July-2023-Cereal-Report.pdf

Beacon. (2010). The environmental impact of the Waitakere NOW Home®: A Life Cycle.

BRANZ. (2022). Physical characteristics of new non-residential buildings 2020. The Building Research Association of New Zealand.

BRANZ. (2023). Data. Retrieved from BRANZ: https://www.branz.co.nz/environment-zero-carbon-research/framework/data/

Caldeira, C., De Laurentiis, V., Corrado, S., van Holsteijn, F., & Sala, S. (2019). Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. Resources, Conservation and Recycling, 479-488. doi:10.1016/j.resconrec.2019.06.011

figure.nz. (2023). Weight of sheep and cattle graded in New Zealand. Retrieved from https://figure.nz/chart/KCpk2ziF9Ktvi0dq

Hera. (2021). Steel Recycling Report. Retrieved from https://www.hera.org.nz/steel-recycling-report/

John, S., Nebel, B., Perez, N., & Buchanan, A. (2009). Environmental Impacts of Multi-Storey Buildings Using Different Construction Materials.

Krausmann, F., Erb, K.-H., Gingrich, S., & Haberl, H. (2013). Global Human Appropriation of Net Primary Production Doubled in the 20th Century. Retrieved from https://www.researchgate.net/publication/237018054_Global_Human_Appropriation_of_Net_Primary_Production_Doubled_in_the_20th_Century

LIC & Dairy NZ. (2020). New Zealand Dairy Statistics 2019-20. Hamilton: Livestock Improvement Corporation Limited & DairyNZ Limited. Retrieved from https://d1r5hvvxe7dolz.cloudfront.net/media/documents/NZ_Dairy_Statistics_2019-20_WEB_FINAL.pdf

MBIE. (2022). Energy balances. Retrieved from Ministry of business innovation & employment: https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-balances/

MfE. (2023). Waste generation and disposal data. Retrieved from Ministry for the Environmen : https://environment.govt.nz/facts-and-science/waste/waste-generation-and-disposal-data/

Skidmore, J., McCoach, H., Goodman, Z., Moxham, S., Stirrup, R., & Grimshaw, M. (2023). Research to support the co-design of a plastic packaging product stewarship scheme for New Zealand. Stratford-upon-Avon: Valpak. Retrieved from https://ppps.org.nz/wp-content/uploads/2023/10/NZ-Plastic-Flow-Report-released-as-part-of-PPPS-research.pdf

Stats NZ. (2022, September). Building Statistics. Retrieved from Tatauranga Aotearoa: Statistics New Zealand: https://www.stats.govt.nz/topics/building

StatsNZ. (2023). StatsNZ Tatauranga Aotearoa. Retrieved from https://www.stats.govt.nz/

thinkstep-anz. (2019). Under Construction: Hidden emissions and untapped potential of buildings for New Zealand's 2050 zero carbon goal. Wellington, NZ.

thinkstep-anz. (2022). Low Carbon Circular Construction.

UNEP-IRP. (2023, October 01). Global Material Flows Database. Retrieved from Resource Panel: https://www.resourcepanel.org/global-material-flows-database

UNSD. (2016b, November). Environmental Indicators: Waste. Municipal Waste Treated. Retrieved from United Nations Statistics Division (UNSD): http://unstats.un.org/unsd/ENVIRONMENT/qindicators.htm

Waste & Recycling Industry Forum. (2023). National Waste and Recycling Snapshot. Auckland. Retrieved from https://aucklandchamber.co.nz/wp-content/uploads/2023/09/National-Waste-and-Recycling-Snapshot-2022-FINAL.pdf

Wilson, D., Chowdhury, T., Elliott, T., Elliott, L., & Hogg, D. (2017). A Wasted opportunity; Using the waste disposal levy to create economic & environmental advantage for Aotearoa New Zealand. Eunomia. Retrieved from https://eunomia.co.nz/wp-content/uploads/2017/07/A-Wasted-Opportunity-NZ-Waste-Disposal-Levy-Summary-Report.pdf

References

[1] William Stanley Jevons, an English economist authored a book in 1865 titled *The Coal Question* that first spoke of the increase in energy production efficiency leading to more and not less consumption.

[2] Ellen MacArthur Founder. No date. What is a circular economy? [Online]. Available at: https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview [17 October 2023]

[3] Ellen MacArthur Foundation, Circular Economy Systems diagram, February 2019, based on Braungart & McDonough, Cradle to Cradle (C2C)

[4] Ministry of Business, Innovation & Employment and Coriolis Research Group. Regional Growth Outcomes (2019) [Online] Available at: https://www.mbie.govt.nz/dmsdocument/7250-regional-growth-outcomes-in-employment-in-the-new-zealand-food-and-beverage-industry [12 February 2024]

[5] The World Intellectual Property Organization (WIPO). Global Innovation Index. [Online] Available at: https://www.wipo.int/global_innovation_index/en/2023/ [12 February 2024]

[6] Ministry for the Environment, Aotearoa New Zealand's first emissions reduction plan, 16th May 2022, [Online] Available at: https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/waste/ [12 February 2024]

[7] GOV.UK Environmental taxes, reliefs and schemes for businesses. [Online] Available at https://www.gov.uk/green-taxes-and-reliefs/plastic-packaging-tax [12 February 2024]

[8] WBCSD Enabling circularity through transparency: Introducing the EU Digital Product Passport, January 2023. [Online] Available at https://www.wbcsd.org/Pathways/Products-and-Materials/Resources/The-EU-Digital-Product-Passport [12 February 2024]

[9] Ministry for the Environment, 2023 Te rautaki para waste strategy: Getting rid of waste for a circular Aotearoa New Zealand. [Online] Available at https://environment.govt.nz/assets/publications/Te-rautaki-para-Waste-strategy.pdf [12 February 2024]

[10] Blick, G., & Comendant, C. (2018). A circular economy for Auckland – scoping the potential economic benefits. Sapere Research Group – prepared for the Sustainable Business Network. [Online.] Available at https://srgexpert.com/resource/a-circular-economy-for-auckland-scoping-the-potential-economic-benefits/ [12 February 2024]

[11] Hool, A., Schrijvers, D., van Nielen, S., Clifton, A., Ganzeboom, S., Hagelueken, C., Harada, Y., Kim, H., Ku, A.Y., Meese-Marktscheffel, J. and Nemoto, T., 2022. How companies improve critical raw material circularity: 5 use cases. Mineral Economics. [Online] Available at: https://doi.org/10.1007/s13563-022-00315-5 [12 February 2024]

[12] MBIE, Bioeconomy Research: Key Findings, [Online], Available at: https://www.mbie.govt.nz/dmsdocument/27526-bioeconomy-opportunities-research-executive-summary-pdf [7 March 2024]

[13] Ibid

[14] Aguilar-Hernandez, G.A., Dias Rodrigues, J.F. and Tukker, A., 2021. Macroeconomic, social and environmental impacts of a circular economy up to 2050: A meta-analysis of prospective studies. Journal of Cleaner Production, 278, p.123421.

[15] The Ellen MacArthur Foundation. Completing the Picture: How the Circular Economy Tackles Climate Change reveals the need for a fundamental shift in the global approach to cutting emissions. [Online] Available at: https://www.ellenmacarthurfoundation.org/completing-the-picture [12 February 2024]

[16] Hailemariam, A. and Erdiaw-Kwasie, M.O. (2022) 'Towards a circular economy: Implications for emission reduction and environmental sustainability', Business Strategy and the Environment, [Online]. DOI: 10.1002/bse.3229.

[17] Boonman, H., Verstraten, P., & van der Weijde, A. H. (2023). Macroeconomic and environmental impacts of circular economy innovation policy. Sustainable Production and Consumption, 35, 216-228. [Online] Available at: www.elsevier.com/locate/spc [12 February 2024]

[18] Hool, A., Helbig, C. & Wierink, G., 2023. Challenges and opportunities of the European Critical Raw Materials Act. Mineral Economics. [Online] Available at: https://doi.org/10.1007/s13563-023-00394-y [12 February 2024]

[19] Ibid

[20] UNEP. 2018. Circular economy indicators: what do they measure? [Online] Available at https://www.unep.org/news-and-stories/blogpost/circular-economy-indicators-what-do-they-measure [16 October 2023]

[21] Ramezankhani, Mohammad Javad and Spiegler, Virginia and Acquaye, Adolf Akwei and Papadopoulos, Thanos, Transition Towards the Circular Economy: A Critical Review of Macroeconomics Models and Methods. [Online] Available at http://dx.doi.org/10.2139/ssrn.4583989 [12 February 2024]

[22] Chepeliev, M., Aguiar, A., Farole, T., Liverani, A. & van der Mensbrugghe, D., 2022. EU Green Deal and Circular Economy Transition: Impacts and Interactions. Center for Global Trade Analysis, Purdue University; The World Bank. [Online] Available at: https://www.gtap.agecon.purdue.edu/ [12 February 2024]

[23] PBL Netherlands Environmental Assessment Agency. 2023. Integral Circular Economy Report 2023 Assessment for the Netherlands. [Online]. Available at: https://www.pbl.nl/sites/default/files/downloads/2023-pbl_integral-circular-economy-report2023-assessment-for-the-netherlands_5109_0.pdf [17 Oct 2023]

[24] STT info. Kiertotaloudella on mahdollisuus taittaa luonnonvarojen käytön kasvu ja edistää ilmastotavoitteiden saavuttamista taloutta heikentämätt [Online] https://www.sttinfo.fi/tiedote/70061573/kiertotaloudella-on-mahdollisuus-taittaa-luonnonvarojen-kayton-kasvu-ja-edistaa-ilmastotavoitteiden-saavuttamista-taloutta-heikentamatta?publisherId=69819243&lang=fi [12 February 2024]

[25] European Court of Auditors. Special report 17/2023: Circular economy – Slow transition by member states despite EU action [Online] Available at: https://www.eca.europa.eu/en/publications?ref=SR-2023-17 [17 October 2023]

[26] Sapere. 2018. The economic benefits of a circular economy in Auckland. [Online]. Available at: https://srgexpert.com/2023/08/30/the-economic-benefits-of-a-circular-economy-in-auckland/ [17 October 2023]

[27] NZ Food Network (2024) Our Impact. [Online] Available at https://www.nzfoodnetwork.org.nz/our-impact/#impact-stats [12 February 2024]

[28] TROW Group, 2024. [Online] Available at https://trowgroup.co.nz/about-us/ [12 February 2024]

[29] Auckland Council Group Deconstruction Panel. [Online] Available at https://www.gets.govt.nz/AC/ExternalTenderDetails.htm?id=27772259 [12 February 2024]

[30] Kāinga Ora 'Minimising construction waste' 20November 2023. [Online] Available at https://kaingaora.govt.nz/en_NZ/about-us/sustainability-at-kainga-ora/minimising-construction-waste/ [12 February 2024]

[31] Mutu, 2024. [Online] Available at https://mutu.co.nz/ [12 February 2024]

[32] ICLEI Circulars. (n.d.). City Practitioners Handbook: Circular Food Systems. ICLEI Local Governments for Sustainability. Retrieved from https://circulars.iclei.org/ [12 February 2024]

[33] Laubinger, F., Lanzi, E. and Chateau, J. (2019) 'Labour market consequences of a transition to a circular economy: A review paper', OECD Environment Working Papers, No. 162, Organisation for Economic Co-operation and Development, 13 May 2020. Available at: https://dx.doi.org/10.1787/e57a300a-en [12 February 2024]

[34] Aguilar-Hernandez, G.A., Dias Rodrigues, J.F. and Tukker, A., 2021. Macroeconomic, social and environmental impacts of a circular economy up to 2050: A meta-analysis of prospective studies. Journal of Cleaner Production, 278, p.123421.

[35] HCH. (Year of Publication). Circular Batteries: Charging the Future. [pdf] [Online] Available at: https://hollandcircularhotspot.nl/publications/ [12 February 2024]

[36] Schröder, P. (2020) 'Promoting a Just Transition to an Inclusive Circular Economy'. Chatham House, The Royal Institute of International Affairs. Available at: https://www.chathamhouse.org/2020/04/promoting-just-transition-inclusive-circular-economy Accessed: [1 November 2023]

[37] Ministry of Business, Innovation & Employment, June 2021, Maori in the Labour Market, [Online] Available at: https://www.mbie.govt.nz/dmsdocument/16892-maori-in-the-labour-market-june-2021-quarter-unadjusted [12 February 2024]

[38] World Economic Forum (2022) 'When the chips are down: How the semiconductor industry is dealing with a worldwide shortage', Supply Chain and Transport. [Online] Available at: https://www.weforum.org/agenda/2022/02/semiconductor-chip-shortage-supply-chain/ [12 February 2024]

[39] NZ Steel [Online]. Electric Arc Furnace: The future of steel making. [Online] Available at: https://www.nzsteel.co.nz/assets/EAF/NZS-EAF-Fact-Sheet.pdf [12 February 2024]

[40] Ministry of Ecological Transition and Territorial Cohesion. 2023. Repairability Index. [Online]. Available at: https://www.ecologie.gouv.fr/indice-reparabilite [12 February 2024]

[41] UK Government. 2023. UK Critical Minerals Strategy. [Online] Available at: https://www.gov.uk/government/publications/uk-critical-mineral-strategy [17 Oct 2023]

[42] Organics New Zealand, (2020/2021), New Zealand Organic Sector Report [Online] Available at: https://www.oanz.org/market-reports [12 February 2024]

[43] FSC International Center, 2019, Centralized National Risk Assessment for New Zealand, [Online] Available at: https://anz.fsc.org/sites/default/files/2022-11/FSC-CNRA-NZ%20V1-0%20EN_2019-08-29.pdf [12 February 2024]

[44] Marine Stewardship Council, August 2019, Learnings from New Zealand: a leading seafood faring nation, [Online] Available at: https://www.msc.org/en-au/media-centre-anz/news-views/news/2019/08/19/learnings-from-new-zealand-a-leading-seafood-faring-nation [12 February 2024]

[45] Circle Economy, 2020, Circularity Gap Report: Norway, [Online] Available at: https://www.circularity-gap.world/norway#wf-form-CGR-NOR-Report-Downloads [12 February 2024]

[46] The New Zealand Government. NZ's biggest ever emissions reduction budget hits milestone. [Online] Available at: https://www.beehive.govt.nz/release/nz%E2%80%99s-biggest-ever-emissions-reduction-project-hits-milestone [12 February 2024]

[47] thinkstep-anz (2020) Under Construction – Hidden Emissions and Untapped Potential of Buildings for New Zealand's 2050 zero carbon goal. [Online] Available at: https://www.thinkstep-anz.com/resrc/reports/hidden-emissions-and-untapped-potential-of-buildings-for-new-zealands-2050-zero-carbon-goal/

[48] Ministry for the Environment, 2019, Class 1 waste data, [Online] Available at: https://environment.govt.nz/facts-and-science/waste/waste-facilities-and-disposal/ [12 February 2024]

[49] thinkstep-anz (2020) Under Construction – Hidden Emissions and Untapped Potential of Buildings for New Zealand's 2050 zero carbon goal. [Online] Available at: https://www.thinkstep-anz.com/resrc/reports/hidden-emissions-and-untapped-potential-of-buildings-for-new-zealands-2050-zero-carbon-goal/

[50] Ministry of Business, Innovation & Employment , Construction Workforce Projections [Online} Available at: https://www.mbie.govt.nz/building-and-energy/building/building-system-insights-programme/construction-workforce-projections/ [12 February 2024]

[51] Ministry of Business, Innovation & Employment , Building and Construction Sector Annual Report 2022 [Online] Available at: https://www.mbie.govt.nz/dmsdocument/25439-building-construction-sector-trends-annual-report-2022 [12 February 2024]

[52] Statistics New Zealand. Building consents issued: September 2023 [Online] Available at: https://www.stats.govt.nz/information-releases/building-consents-issued-september-2023/ [12 February 2024]

[53] Ministry of Business, Innovation & Employment , Building and Construction Sector trends biannual snapshot: May 2022, [Online] Available at: Building and construction sector trends biannual snapshot: May 2022 | Ministry of Business, Innovation & Employment (mbie.govt.nz) [12 February 2024]

[54] ARUP, How recycling concrete could accelerate sustainable construction, [Online] Available at:https://www.arup.com/perspectives/how-recycling-concrete-could-accelerate-sustainable-construction [12 February 2024]

[55] Assuming a typical price of $250/m3

[56] Ministry of Business, Innovation & Employment . Building and Construction Sector Trends Biannual Snapshot. [Online] Available at: https://www.mbie.govt.nz/assets/building-and-construction-sector-trends-biannual-snapshot-may-2022.pdf [12 February 2024]

[57] Building Performance, B2 Durability, [Online] Available at: https://www.building.govt.nz/building-code-compliance [12 February 2024]

[58] Amiomio Aotearoa, University of Waikato, Leading New Zealand to a more sustainable future, [Online] Available at: https://www.waikato.ac.nz/news-opinion/media/2021/Leading-New-Zealand-to-a-more-sustainable-future [12 February 2024]

[59] Thinkstep-anz. The Carbon Footprint of New Zealand's Built Environment. [Online] Available at: https://www.thinkstep-anz.com/resrc/reports/the-carbon-footprint-of-new-zealands-built-environment/ [12 February 2024]

[60] StatsNZ National population estimates: At 30 June 2023 [Online] Available at: https://www.stats.govt.nz/information-releases/national-population-estimates-at-30-june-2023/ [13 February 2024]

[61] Te Tūāpapa Kura Kāinga | Ministry of Housing and Urban Development. The long-term implications of our ageing population for our housing and urban futures. [Online] Available at: https://www.hud.govt.nz/news/the-long-term-implications-of-our-ageing-population-for-our-housing-and-urban-futures/ [12 February 2024]

[62] StatsNZ, Annual number of new homes consented up to 20 percent, [Online] Available at: Annual number of new homes consented up 20 percent | Stats NZ [12 February 2024]

[63] Ellen MacArthur Foundation, Circular Buildings Toolkit, [Online] Available at: Circular Buildings Toolkit (ellenmacarthurfoundation.org) [12 February 2024]

[64] NZ Manufacturer, Additive Manufacturing: Re-thinking how we use materials in a circular economy, [Online] Available at: https://nzmanufacturer.co.nz/2021/03/additive-manufacturing-re-thinking-how-we-use-materials-in-a-circular-economy/ [12 February 2024]

[65] Westpac, The ins and outs of buying a prebuilt home, 1st March 2023, [Online] Available at: https://www.westpac.co.nz/rednews/the-ins-and-outs-of-buying-a-prebuilt-home/ [12 February 2024]

[66] HERA, Recycling Report, 19th January 2022, [Online] Available at: https://www.hera.org.nz/2021-recycling-report/ [12 February 2024]

[67] HERA, Sustainable Steel, [Online] Available at: https://www.hera.org.nz/sustainablesteel/ [12 February 2024]

[68] ConcreteNZ, A NetZero Carbon Concrete Industry for Aotearoa New Zealand: Roadmap to 2050, July 2023, [Online] Available at: https://cdn.ymaws.com/concretenz.org.nz/resource/resmgr/docs/cnz/c_roadmap_concrete.pdf [12 February 2024]

[69] BRANZ, Removing the barriers to the use of significant levels of SCMs in concrete production in New Zealand, ER66, 2021. [12 February 2024]

[70] Building Performance, Building for Climate Change update: January 2021, [Online] Available at: https://www.building.govt.nz/about-building-performance/all-news-and-updates/building-for-climate-change-update/ [12 February 2024]

[71] Hudson Architects, An introduction to embodied Carbon, [Online] Available at: https://hudsonarchitects.co.uk/journal/post/an-introduction-to-embodied-carbon/ [12 February 2024]

[72] BRANZ, Passive Design, A carbon budget for New Zealand houses, [Online] Available at: https://www.level.org.nz/passive-design/climate-change/a-carbon-budget-for-new-zealand-houses/ [12 February 2024]

[73] Building Performance, Timber Construction, [Online] Available at: https://www.building.govt.nz/getting-started/smarter-homes-guides/construction-and-materials/timber-construction/ [12 February 2024]

[74] International Living Future Institute, Red List, [Online] Available at: https://living-future.org/red-list/ [12 February 2024]

[75] StatsNZ. Housing in Aotearoa: 2020. [Online} Available at: https://www.stats.govt.nz/reports/housing-in-aotearoa-2020 [12 February 2024]

[76] Askar R, Bragança L, Gervásio H. Design for Adaptability (DfA)—Frameworks and Assessment Models for Enhanced Circularity in Buildings. Applied System Innovation. 2022; 5(1):24. https://doi.org/10.3390/asi5010024

[77] European Commission. Level(s) indicator 2.3: Design for adaptability and renovation. [Online] Available at https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/2020-10/20201013%20New%20Level(s)%20documentation_2.3%20Adaptability_Publication%20v1.0.pdf [12 February 2024]

[78] S. Suffian, R. Dzombak, K. Mehta, 3 - Future directions for nonconventional and vernacular material research and applications, Editor(s): K.A. Harries, B. Sharma, Nonconventional and Vernacular Construction Materials, Woodhead Publishing, 2016, Pages 63-80, ISBN 9780081008713, https://doi.org/10.1016/B978-0-08-100038-0.00003-2.

[79] Iso.org. ISO 20887:2020 Sustainability in buildings and civil engineering works Design for disassembly and adaptability Principles, requirements and guidance [Online] Available at: https://www.iso.org/standard/69370.html [12 February 2024]

[80] European Commission. Level(s) indicator 2.4: Design for deconstruction [Online] Available at: https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/2021-01/UM3_Indicator_2.4_v1.1_18pp.pdf [12 February 2024]

[81] XFrame, [Online] Available at: https://xframe.com.au/xframe-system/case-studies [12 February 2024]

[82] Iso.org. ISO 20887:2020 Sustainability in buildings and civil engineering works Design for disassembly and adaptability Principles, requirements and guidance [Online] Available at: https://www.iso.org/standard/69370.html [12 February 2024]

[83] European Commission. Level(s) indicator 2.4: Design for deconstruction [Online] Available at: https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/2021-01/UM3_Indicator_2.4_v1.1_18pp.pdf [12 February 2024]

[84] Circularity in pastoral agriculture systems in New Zealand, Vicki Burggraaf, AgResearch.

[85] World Bank. "Agricultural Land (% of Land Area) - New Zealand." World Bank. [Online] Available at: https://data.worldbank.org/indicator/AG.LND.ARBL.ZS?locations=NZ [12 February 2024]

[86] StatsNZ, 31 Fertilisers, 2022, [Online] Available at: https://statisticsnz.shinyapps.io/trade_dashboard/ [12 February 2024]

[87] Fertiliser Association, Fertiliser use in NZ, [Online] Available at: https://www.fertiliser.org.nz/Site/about-fertiliser/fertiliser_use_in_nz.aspx [12 February 2024]

[88] Ministry for the Environment. New Zealand's Greenhouse Gas Emissions Inventory. {Online} Available at: https://environment.govt.nz/facts-and-science/climate-change/new-zealands-greenhouse-gas-inventory/ [12 February 2024]

[89] StatsNZ, 3808, Insecticide, rodenticides, herbicides, and fungicides, 2022, [Online] Available at: https://statisticsnz.shinyapps.io/trade_dashboard/ [12 February 2024]

[90] Coriolis. 2023. Thirty Opportunities: Emerging and future platforms in New Zealand's bioeconomy. [Online]. Ministry of Business, Innovation, and Employment. [Online] Available: https://www.mbie.govt.nz/assets/thirty-opportunities-emerging-and-future-platforms-in-new-zealands-bioeconomy.pdf [2 October 2023].

[91] OECD, New Zealand, 2019, [Online] Available at: https://www.oecd.org/agriculture/topics/water-and-agriculture/documents/oecd-water-policies-country-note-new-zealand.pdf [12 February 2024]

[92] Worldometer, New Zealand Water, 2010, [Online] Available at: https://www.worldometers.info/water/new-zealand-water/ [12 February 2024]

[93] Assumes a carbon footprint of 351.95g m3, based on a UK figure of 0.2g per pint

[94] Rural News, Farmers are already paying for water use, 4th August 2017, [Online] Available at: https://www.ruralnewsgroup.co.nz/rural-news/rural-opinion/farmers-are-already-paying-for-water-use [12 February 2024]

[95] Ministry for Primary Industries. 2021. Primary industries Workforce 2019. [Online]. Available: https://www.mpi.govt.nz/dmsdocument/29270-Primary-industries-workforce-fact-sheets. [2 October2023]

[96] Pomahaka Water Care Group. [Online] Available at: https://www.pwcg.co.nz/ [7 March 2024]

[97] AgResearch, Marlies Antoinette Zonderland-Thomassen et al., 2012, Water use assessment- a comparison of methods using New Zealand dairy farming as a case study, DOI: 10.1016/j.agsy.2012.03.006

[98] Herath, I., (2013). The water footprint of agricultural products in New Zealand: The Impact of Primary Production on Water Resources. [Online] Available at: https://mro.massey.ac.nz/server/api/core/bitstreams/3416ee08-0a8d-4245-be39-79bebcb5035d/content [12 February 2024]

[99] OECD-FAO. Agricultural Outlook 2021-2030. [Online] Available at: https://www.fao.org/3/cb5332en/Meat.pdf [12 February 2024]

[100] USDA Foreign Agriculture Service New Zealand Fertilizer and Products (2023) [Online] Available at: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=New%20Zealand%20Fertilizer%20and%20Products%20_Wellington_New%20Zealand_NZ2023-0023.pdf [12 February 2024]

[101] Ministry of Primary Industries. Sustainable Vineyard Floor Project – SVFP [Online] Available at: https://www.mpi.govt.nz/dmsdocument/59479-Sustainable-Vineyard-Floor-Project-Final-Report [7 March 2024]

[102] FT, Ukraine war thrusts fertiliser minerals to centre of food security debate. 21st August 2023, [Online] Available at: https://www.ft.com/content/638d6913-fec9-490f-90b0-5e6d3269d093 [12 February 2024]

[103] Human Rights Watch. World Report 2024. Morocco and Western Sahara. Events of 2023 [Online] Available at https://www.hrw.org/world-report/2024/country-chapters/morocco-and-western-sahara [7 March 2024]

[104] FT, Ukraine war thrusts fertiliser minerals to centre of food security debate. 21st August 2023, [Online] Available at: https://www.ft.com/content/638d6913-fec9-490f-90b0-5e6d3269d093 [12 February 2024]

[105] NZX, CRP to push for 3 additions to list of Critical Minerals, 4th August 2023, [Online] Available at: https://www.nzx.com/announcements/415836 [12 February 2024]

[106] NZ Fertiliser Association, Update of the carbon footprint of fertilisers used in New Zealand, August 2019, [Online] Available at: https://www.fertiliser.org.nz/Site/news/articles/update-of-the-carbon-footprint-of-fertilisers-used-in-new-zealand.aspx [12 February 2024]

[107] A Lighter Touch. Learning from the experiences of other sectors. [Online] Available at: https://a-lighter-touch.co.nz/resource/learning-from-the-experiences-of-other-sectors/ [12 February 2024]

[108] A Lighter Touch. Cover Cropping Initiative – Workshop Presentations (2021) [Online] Available at: https://a-lighter-touch.co.nz/resource/cover-cropping-initiative-workshop-presentations/ [12 February 2024]

[109] NZ Herald. Caution for sheep owners – barber's pole season is here! [Online] Available at: https://www.nzherald.co.nz/horowhenua-chronicle/news/caution-for-sheep-owners-barbers-pole-season-is-here/ABMAOOD3MVDALCG6G5OFJTCGXU/ [12 February 2024]

[110] A Lighter Touch. New Zealand's crop production is changing for the better. [Online] https://a-lighter-touch.co.nz/ [7 March 2024]

[111] SCION, Bio-based products & technologies, [Online] Available at: https://www.scionresearch.com/science/bio-based-products-and-technologies [12 February 2024]

[112] University of Auckland, Centre for Green Chemical Science, [Online] Available at: https://greenchemicalscience.blogs.auckland.ac.nz/ [12 February 2024]

[113] Bioresource Processing Alliance, [Online] Available at: https://bioresourceprocessing.co.nz/about/doing-business-with-us/ [12 February 2024]

[114] The Big Food Redesign Study, Ellen MacArthur Foundation, [Online] Available at: https://www.ellenmacarthurfoundation.org/resources/food-redesign/overview [12 February 2024]

[115] Chaudhary A, Marinangeli CPF, Tremorin D, Mathys A. Nutritional Combined Greenhouse Gas Life Cycle Analysis for Incorporating Canadian Yellow Pea into Cereal-Based Food Products. Nutrients. 2018 Apr 16;10(4):490. doi: 10.3390/nu10040490. PMID: 29659497; PMCID: PMC5946275.

[116] Potato News. The Evolving Landscape of the Global Potato Industry: Trends, Challenges and Innovations in 2023. [Online] Available at: https://www.potatonewstoday.com/2024/01/21/the-evolving-landscape-of-the-global-potato-industry-trends-challenges-and-innovations-in-2023/ [12 February 2024]

[117] The Land Institute. Kernza Grain. [Online] Available at: https://landinstitute.org/our-work/perennial-crops/kernza/ [12 February 2024]

[118] The World Bank. Arable land (% of land area) – New Zealand. [Online] Available at: https://data.worldbank.org/indicator/AG.LND.ARBL.ZS?locations=NZ [12 February 2024]

[119] West Coast Agroforestry, [Online] Available at: https://agroforestry.co.nz/research/ [12 February 2024]

[120] New Zealand Farm forestry Association, [Online] Available at: https://www.nzffa.org.nz/ [12 February 2024]

[121] Jones, A.G., et al., 2023. Transitional forestry in New Zealand: re-evaluating the design and management of forest systems through the lens of forest purpose. Biological Reviews, 98(4), pp.1003-1015. [Online] Available at: https://doi.org/10.1111/brv.12941 [12 February 2024]

[122] Farm Forestry New Zealand Agroforestry – the Tikitere experience [Online] Available at: https://www.nzffa.org.nz/farm-forestry-model/resource-centre/tree-grower-articles/may-2011/agroforestry-the-tikitere-experience/ [7 March 2024]

[123] Balancing pastoral and plantation forestry options in New Zealand and the role of agroforestry, Grant B Douglas et.al : https://www.grassland.org.nz/publications/nzgrassland_publication_2577.pdf [3 April 2024]

[124] NIWA. Assessment of crop and tree species growing potential using climate, soil and topographic information. [Online] Available at https://niwa.co.nz/climate/research-projects/assessment-of-crop-and-tree-species-growing-potential-using-climate-soil-and-topographic-information [3 April 2024]

[125] Landcare Research, 2021, Determining the greenhouse gas reduction potential of Regenerative Agricultural practices, [Online] Available at: https://ourlandandwater.nz/wp-content/uploads/2021/10/Lauback2021_ApproachesAssessPotentialRegenerativeAgricultureReducingGHG-1.pdf [12 February 2024]

[126] Our Land and Water. Regenerative agriculture in Aotearoa New Zealand– research pathways to build science-based evidence and national narratives. [Online] Available at: https://ourlandandwater.nz/wp-content/uploads/2021/03/Grelet_Lang_2021_Regen_Ag_NZ_White_ePaper.pdf [12 February 2024]

[127] Pure Advantage. Insight into Regenerative Agriculture in New Zealand: The Good, the Bad and the Opportunity. Alina Siegfried. (2020) [Online] Available at: https://pureadvantage.org/insight-into-regenerative-agriculture-in-new-zealand-the-good-the-bad-and-the-opportunity/ [7 March 2024]

[128] Koch, N., & Perreault, T. (2019). Resource nationalism. Progress in Human Geography, 43(4), 611-631. https://doi.org/10.1177/0309132518781497 [12 February 2024]

[129] MBIE, Developing the Aotearoa New Zealand Aerospace Strategy, September 2023, [Online] Available at: https://www.mbie.govt.nz/dmsdocument/23715-developing-the-aotearoa-new-zealand-aerospace-strategy-pdf [12 February 2024]

[130] StatsNZ, Which industries contributed to New Zealand's GDP, [Online] Available at: https://www.stats.govt.nz/tools/which-industries-contributed-to-new-zealands-gdp [12 February 2024]

[131] StatsNZ, New Zealand International Trade, [Online] Available at: https://statisticsnz.shinyapps.io/trade_dashboard/ [12 February 2024]

[132] Ibid

[133] Statistica, The materials that make up an iPhone, 17th August 2017, [Online] Available at: https://www.statista.com/chart/10719/materials-used-in-iphone-6/ [12 February 2024]

[134] Ibid

[135] Dell, Latitude 9520, PCF, [Online] Available at: https://www.dell.com/en-uk/dt/corporate/social-impact/advancing-sustainability/climate-action/product-carbon-footprints.htm#tab0=1 [12 February 2024]

[136] Ministry for the Environment. Emissions Reductions [Online} Available at: https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/emissions-reductions/ [12 February 2024]

[137] IEA, Comparative life-cycle greenhouse gas emissions of a mid-size BEV and ICE Vehicle, 5th May 2021, [Online] Available at: https://www.iea.org/data-and-statistics/charts/comparative-life-cycle-greenhouse-gas-emissions-of-a-mid-size-bev-and-ice-vehicle [12 February 2024]

[138] Reuters, When do electric vehicles become cleaner than gasoline cars?, 8th July 2021, [Online] Available at: https://www.reuters.com/business/autos-transportation/when-do-electric-vehicles-become-cleaner-than-gasoline-cars-2021-06-29/ [12 February 2024]

[139] New Zealand Wind Energy Association, New Zealand's onshore wind farms, [Online] Available at: https://www.windenergy.org.nz/wind-energy/nz-onshore-wind-farms [12 February 2024]

[140] Vestas, LCA, V90-2.0 MW Gridstreamer Wind Plant, [Online] Available at: https://www.vestas.com/content/dam/vestas-com/global/en/sustainability/reports-and-ratings/lcas/LCA_V902MW_version1.pdf.coredownload.inline.pdf [12 February 2024]

[141] New Zealand Government, Taskforce set up to protect construction industry from product shortages & delays, 24th November 2022, [Online] Available at: https://beehive.govt.nz/release/taskforce-set-protect-construction-industry-product-shortages-delays [12 February 2024]

[142] Ministry of Business, Innovation and Employment Responsibly Delivering Value, a Minerals and Petroleum Resource Strategy for Aotearoa New Zealand: 2019–2029, November 2019. [Online] Available at: https://www.mbie.govt.nz/dmsdocument/7148-responsibly-delivering-value-a-minerals-and-petroleum-strategy-for-aotearoa-new-zealand-2019-2029 [12 February 2024]

[143] Rolls-Royce, Revert, [Online] Available at: https://www.rolls-royce.com/media/our-stories/discover/2017/revert.aspx [12 February 2024]

[144] Umicore, [Online] Available at: https://pmm.umicore.com/en/ [12 February 2024]

[145] Mint. New generation circular green metals. [Online] Available at: https://www.mint.bio/ [12 February 2024]

[146] Recycle a Device, [Online] Available at: https://www.recycleadevice.nz/ [12 February 2024]

[147] World Economic Forum, 9th Feb 2022, When the chips are down, [Online] Available at: https://www.weforum.org/agenda/2022/02/semiconductor-chip-shortage-supply-chain/ [12 February 2024]

[148] European Parliament, Why is the EU's right to repair legislation important, 23rd November 2023, [Online] Available at: https://www.europarl.europa.eu/news/en/headlines/society/20220331STO26410/why-is-the-eu-s-right-to-repair-legislation-important [12 February 2024]

[149] Repair Cafe Aotearoa New Zealand 'Makit it our Right to Repair' petition'. [Online] Available at https://www.repaircafeaotearoa.co.nz/petitions# [12 February 2024]

[150] MedSalv. https://www.medsalv.com/ [12 February 2024]

[151] Share my Tools, [Online] Available at: https://sharemytools.com/ [12 February 2024]

[152] The High cost of free parking, Donald Shoup, June 2011, ISBN: 978-1932364965

[153] See iea.org The carbon footprint of streaming video: fact-checking the headlines [Online] Available at: https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines [12 February 2024]

[154] Circular economy snapshot: Philips Light as a service, [Online] Available at: https://sustainablepurchasing.issuelab.org/resources/26209/26209.pdf [12 February 2024]

[155] IEA, Comparative life-cycle greenhouse gas emissions of a mid-size BEV and ICE Vehicle, 5th May 2021, [Online] Available at: https://www.iea.org/data-and-statistics/charts/comparative-life-cycle-greenhouse-gas-emissions-of-a-mid-size-bev-and-ice-vehicle [12 February 2024]

[156] Reuters, When do electric vehicles become cleaner than gasoline cars?, 8th July 2021, [Online} Available at: https://www.reuters.com/business/autos-transportation/when-do-electric-vehicles-become-cleaner-than-gasoline-cars-2021-06-29/ [12 February 2024]

[157] Statistica, Car-sharing – Worldwide, Available at: https://www.statista.com/outlook/mmo/shared-mobility/shared-rides/car-sharing/worldwide. [12 February 2024]

[158] 'Does sharing cars really reduce car use?' 2017 A briefing by Transport and Environment. [Online] Available at https://www.transportenvironment.org/discover/does-sharing-cars-really-reduce-car-use/ [15 February 2024]

[159] NZ Annual Fleet statistics 2021, Ministry of Transport, Nov 2022, [Online] Available at: https://www.transport.govt.nz/assets/Uploads/Report/AnnualFleetStatistics.pdf [12 February 2024]

[160] PUshEVs Tesla Model 3 efficiency is impressive. [Online] Available at: https://pushevs.com/2017/08/01/tesla-model-3-efficiency-impressive/ [12 February 2024]

[161] Electrek, 15th October 2018, Tesla releases impressive pictures of Model 3 drive unit after test, Musk says they drove 1M miles, [Online] Available at: https://electrek.co/2018/10/15/tesla-drive-after-million-miles-test/ [12 February 2024]

[162] Climate Change Commission. 2023 Advice on the direction of policy for the Government's second emissions reduction plan. [Online] Available at: https://www.climatecommission.govt.nz/our-work/advice-to-government-topic/advice-for-preparation-of-emissions-reduction-plans/2023-advice-to-inform-the-strategic-direction-of-the-governments-second-emissions-reduction-plan-april-2023/ [12 February 2024]

[163] IEA, Comparative life-cycle greenhouse gas emissions of a mid-size BEV and ICE Vehicle, 5th May 2021, [Online] Available at: https://www.iea.org/data-and-statistics/charts/comparative-life-cycle-greenhouse-gas-emissions-of-a-mid-size-bev-and-ice-vehicle [12 February 2024]

[164] YouTube. A robot just swapped my electric car's battery. [Online] Available at: https://www.youtube.com/watch?v=hNZy603as5w&ab_channel=TomScott [12 February 2024]
[165] ANZPAC Plastics Pact [Online] Available at: https://anzpacplasticspact.org.au/ [12 February 2024]

[166] Ministry for the Environment, National Plastics Action Plan, September 2021. [Online] Available at https://environment.govt.nz/publications/national-plastics-action-plan/ [15 February 2024]

[167] UK Government. Anaerobic digestion – realising the potential. [Online] Available at: https://www.gov.uk/government/news/anaerobic-digestion-realising-the-potential [12 February 2024]

[168] Confederation of European Waste to Energy Plants (CEWEP).2021. [Online] Available at: https://www.cewep.eu/wpcontent/uploads/2021/10/Landfill-taxes-and-restrictions-overview.pdf, [16 October 2022]

[169] Ministry for the Environment. Overview of the waste disposal levy. June 2022. [Online] Available at https://environment.govt.nz/what-government-is-doing/areas-of-work/waste/waste-disposal-levy/overview/ [16 February 2024]

[170] Ministry for the Environment. Waste Minimisation Fund. October 2022. [Online] Available at https://environment.govt.nz/what-you-can-do/funding/waste-minimisation-fund/ [15 February 2024]

[171] Irish EPA. 2023. Circular Insights Series, Comparative Study of Waste Recovery Taxes/Levies In Europe - EPA Research Report. [Online]. Available online at: https://www.epa.ie/publications/circular-economy/resources/Comparative-study-of-waste-recoverytaxes-levies-in-Europe.pdf [16 October 2023]

[172] Ministry for the Environment. Aotearoa New Zealand Waste Strategy. March 2023 [Online] Available at https://environment.govt.nz/what-government-is-doing/areas-of-work/waste/aotearoa-new-zealand-waste-strategy/ [14 February 2024]

[173] Z Energy. Z confirms closure of Te Kora Hou biofuels plant (2022) [Online] Available at: https://www.z.co.nz/about-z/news/z-confirms-closure-of-te-kora-hou-biofuels-plant/ [12 February 2024]

[174] Air New Zealand. Sustainable Aviation Fuel [Online] Available at: https://p-airnz.com/cms/assets/PDFs/Airnz-sustainable-aviation-fuel-in-new-zealand-may-2021.pdf [12 February 2024]

[175] European Union. 2018. Economy wide material flow accounts: Handbook. Online. Available at: https://ec.europa.eu/eurostat/documents/3859598/9117556/KS-GQ-18-006-EN-N.pdf/b621b8ce-2792-47ff-9d10-067d2b8aac4b?t=1537260841000

[176] UNEP. Global Material Flows Database. Online. Available at: https://www.resourcepanel.org/global-material-flows-database

[177] New guidelines regarding landfill categorizations will be implemented as of July 2024 by MfE. They will help ensure better quality data around Class 3 and 4 landfills.

[178] UNEP. Global Material Flows Database. Online. Available at: https://www.resourcepanel.org/global-material-flows-database