Research note

Resource use and waste generation in Aotearoa New Zealand: filling (some) gaps

May 2025

Parliamentary Commissioner for the Environment
Te Kaitiaki Taiao a Te Whare Pāremata

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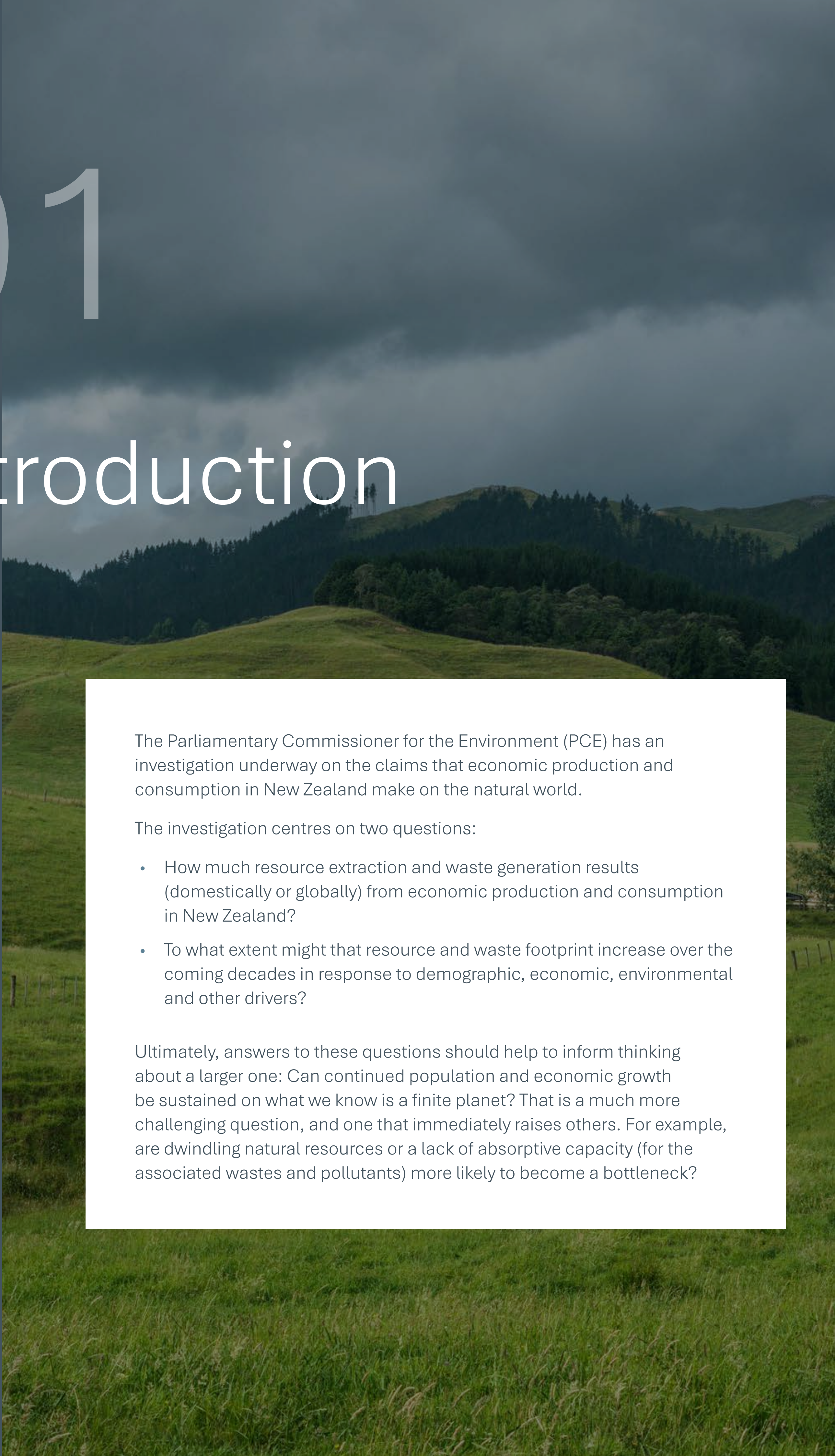


01 Introduction

The Parliamentary Commissioner for the Environment (PCE) has an investigation underway on the claims that economic production and consumption in New Zealand make on the natural world.

The investigation centres on two questions:

- How much resource extraction and waste generation results (domestically or globally) from economic production and consumption in New Zealand?
- To what extent might that resource and waste footprint increase over the coming decades in response to demographic, economic, environmental and other drivers?

Ultimately, answers to these questions should help to inform thinking about a larger one: Can continued population and economic growth be sustained on what we know is a finite planet? That is a much more challenging question, and one that immediately raises others. For example, are dwindling natural resources or a lack of absorptive capacity (for the associated wastes and pollutants) more likely to become a bottleneck?

These questions would be difficult enough to answer even with perfect information on resource extraction and waste generation, and how natural systems respond to the resulting changes in resource stocks and pollutant concentrations. The reality is that this information is often non-existent.

In early 2024, PCE published a literature review centred on resource use and waste generation in New Zealand.[1] The objective was to survey existing data and research in this area and establish what is understood and, just as importantly, what is not. Three key knowledge gaps emerged from that work.

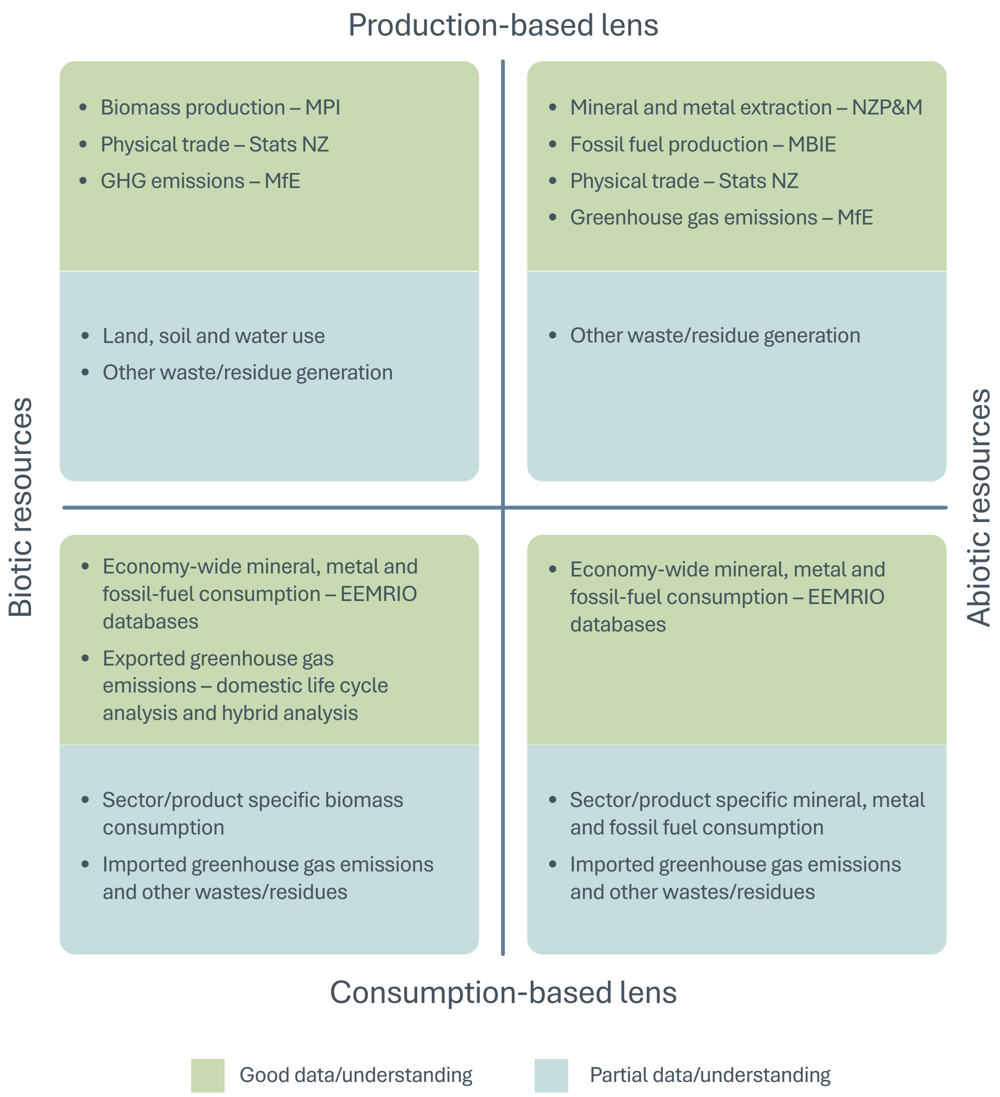
Domestic extraction of biotic natural resources: Very little is known about the biotic natural resources that underpin primary production in New Zealand. This is a remarkable conclusion given the biological nature of our economy. The quantity of water that is abstracted each year for irrigation is unknown. So is the amount of soil that is lost (or degraded) due to different land use practices. This is in stark contrast to our knowledge of abiotic natural resources (e.g. fossil fuels, metal ores and non-metallic minerals), where good data on domestic extraction exist.[2]

Wastes, residues and pollutants: With several important exceptions (greenhouse gases and some categories of municipal solid waste), little is known about the quantity of wastes, residues and pollutants that are generated each year. Even less is known about where they ultimately end up – landfill, recycling facilities, other countries or the natural environment. Less again is known about the impacts they have when they get there.

Consumption-based resource use: Detailed information on the natural resources embedded in imports and exports, and therefore on the resource footprint of New Zealand's consumption, is unavailable.

1 PCE, 2024.
2 In large part because mining firms are required to pay royalties on the tonnages produced.

The following figure summarises each of these knowledge gaps, as well as areas that are characterised by the relative availability of information and the associated administering agency.



Note:

MPI = Ministry for Primary Industries – Manatū Ahu Matua
MfE = Ministry for the Environment – Manatū mō te Taiao
NZP&M = New Zealand Petroleum and Minerals
MBIE = Ministry of Business, Innovation and Employment – Hīkina Whakatutuki
EEMRIO = environmentally extended multi-regional input–output

Figure 1.1: Key data and knowledge gaps relating to resource use and waste generation in New Zealand.

Following the publication of the literature review, PCE commissioned five pieces of external research to try and shed light on some of these issues.[3]

This research note summarises the headline findings and insights from that work. We have also taken the opportunity to update (and back-cast) the estimate of production-based resource use presented in the literature review. This information has been used to inform a preliminary assessment of the circularity of the New Zealand economy.

Since the literature review, most progress has been made in the area of consumption-based resource use. This report includes the first detailed estimate of New Zealand's resource footprint, broken down across 109 industries, 55 natural resources and five types of final demand. It provides the most complete picture to date of the quantity of natural resources required to support a 'typical' New Zealand lifestyle – regardless of where in the world those resources originated.

Less progress was made on the first and second gaps identified above: (i) domestic extraction of biotic natural resources and (ii) wastes, residues and pollutants. In some cases (e.g. for soil and waste), that reflects fundamental limitations of the data being collected by New Zealand's environmental monitoring system. In others (e.g. water), it reflects the difficulty of compiling a national-level picture using data collected by multiple regional councils for compliance, monitoring and enforcement purposes. These issues are discussed further in chapter five.

3 Connolly and Fitzgerald, 2024; Drewry et al., 2025; Palairet el al., 2024; Sense Partners, 2024; Stoner et al., 2024.

Headline findings from this report

New Zealand’s current natural resource use profile

- In 2019, **130–135 million tonnes of natural resources were extracted in New Zealand** (water excluded). Biomass and non-metallic minerals accounted for almost 90% of that, with fossil fuels and metallic ores making up the remainder.

- **Only a third of the natural resources extracted in New Zealand in 2019 were ultimately consumed here.** The remaining two thirds were exported to other countries, either directly as raw commodities (e.g. coal or logs) or ‘embedded’ in a wide variety of relatively processed products (e.g. meat or steel).

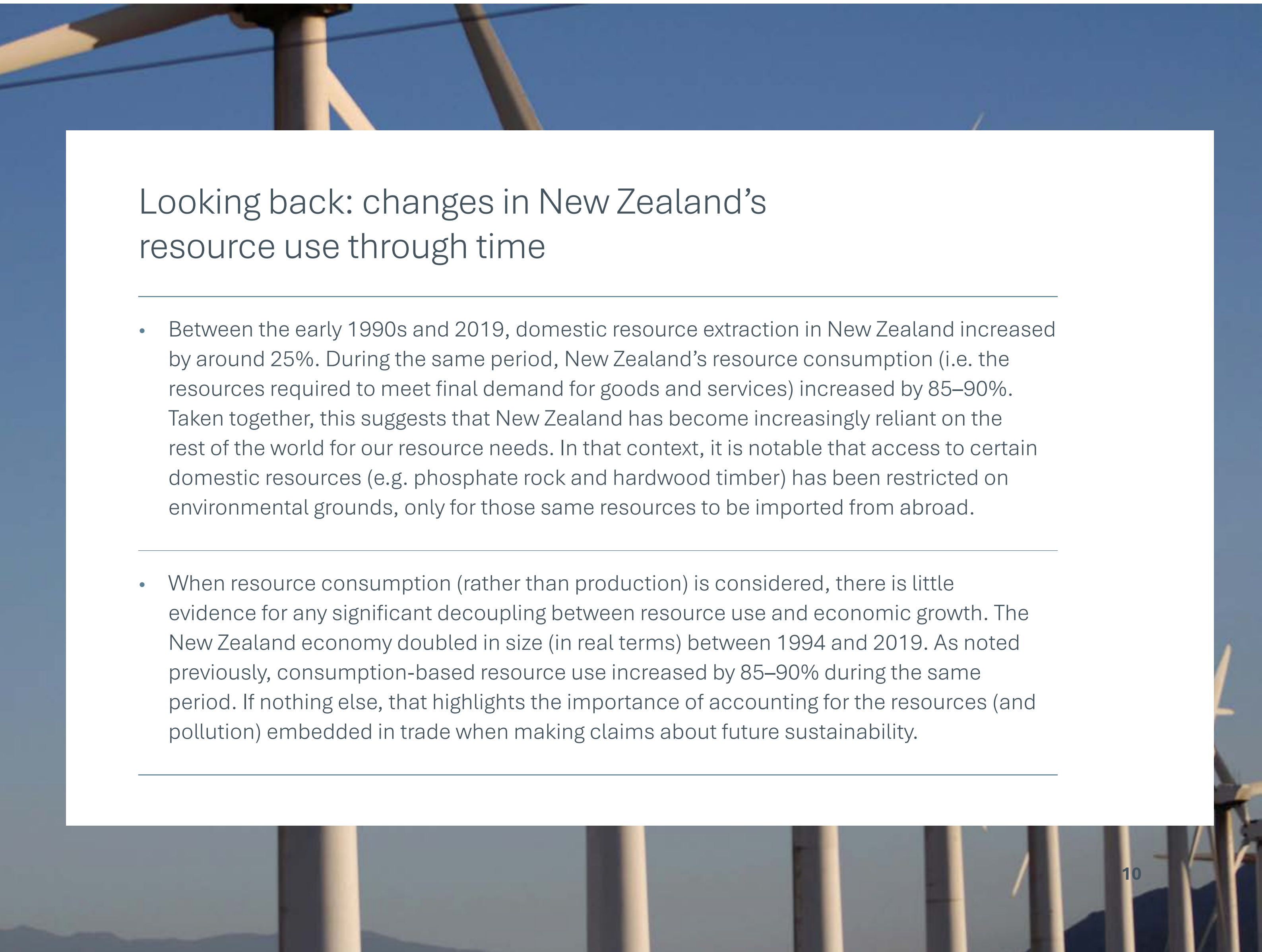
- **Grazed pasture** (in the form of dairy products and meat, for example) **and wood** (mostly in the form of logs) **account for the majority of New Zealand’s resource exports.** These products are a major source of export earnings for New Zealand. At the same time, their production is almost entirely dependent on the continued availability of healthy soil. A review commissioned for this research note highlights several potential vulnerabilities in this respect. One is the accumulation of various contaminants in New Zealand soils due to fertiliser, fungicide spray and pharmaceutical use. Another is the ongoing erosion and loss of soil associated with certain land uses and management practices.

- New Zealand also imports significant quantities of natural resources. **Around 60% of the resources required to satisfy domestic final demand in 2019 were extracted abroad.** The composition of those imports is different to our exports, however. New Zealand relies heavily on other countries for crude oil, a wide range of metal ores, phosphate rock, and some types of biomass (sugar cane and oil seeds, for example). The environmental impacts associated with the upstream parts of these supply chains can be significant but, by virtue of their remoteness, tend to remain out of sight for New Zealanders.

- **In total, 107 million tonnes of natural resources were mobilised in the production of the goods and services consumed by New Zealanders in 2019.** Put differently, around 20 tonnes of natural resources were required to support the lifestyle of a ‘typical’ New Zealander. The largest contributions to that footprint were sand, gravel and crushed rock (26%), grazed biomass (12%) and crude oil (8%). While the research undertaken for this report has not sought to quantify it, the lifecycle environmental impacts associated with a tonne of each of those resources (and with different resources more generally) varies widely.

- New Zealand's resource requirements continue to be met largely by the extraction of virgin resources. A preliminary analysis presented in this report suggests that **recycled materials only account for perhaps 2% of all resource inputs**. On the one hand, that highlights the opportunity associated with moving towards a more circular economy. On the other, it reflects the fundamental difficulty of capturing and repurposing many volumetrically large waste streams that New Zealand produces (consider greenhouse gas emissions, sewage sludges, mine tailings and nutrient leachates, for example).

- Plastics offer a useful example. At present, **around 1.5 million tonnes of plastics make their way into the New Zealand economy each year**. Most of that – probably around two thirds – becomes part of an 'in-use stock' (think vehicles; textiles and clothes; and electronics and appliances, for example). At the same time, around 450,000 tonnes of plastic emerge as waste each year. While data is limited, only around 15% of that is thought to be recycled (either domestically or abroad), with the remainder making its way to landfill or at large into the natural environment.



Looking back: changes in New Zealand's resource use through time

- Between the early 1990s and 2019, domestic resource extraction in New Zealand increased by around 25%. During the same period, New Zealand's resource consumption (i.e. the resources required to meet final demand for goods and services) increased by 85–90%. Taken together, this suggests that New Zealand has become increasingly reliant on the rest of the world for our resource needs. In that context, it is notable that access to certain domestic resources (e.g. phosphate rock and hardwood timber) has been restricted on environmental grounds, only for those same resources to be imported from abroad.

- When resource consumption (rather than production) is considered, there is little evidence for any significant decoupling between resource use and economic growth. The New Zealand economy doubled in size (in real terms) between 1994 and 2019. As noted previously, consumption-based resource use increased by 85–90% during the same period. If nothing else, that highlights the importance of accounting for the resources (and pollution) embedded in trade when making claims about future sustainability.

What might the future bring?

How New Zealand's resource use and waste generation profiles might evolve in future is the subject of ongoing work by PCE. The final chapter of this research note provides more detail on that.

- Population and economic growth will almost certainly be key drivers of future resource demand, but a wide range of structural and sector-specific changes will also play a role. The continued adoption of core renewable technologies (e.g. solar photovoltaic (PV), wind generation, battery storage, and electric and plug-in hybrid vehicles) is one such example. Modelling undertaken for this report indicates that an energy transition akin to that described by He Pou a Rangi Climate Change Commission's demonstration pathway would require 7.5 million tonnes of finished metal by 2050.[4] The quantity of metal ore that will need to be mobilised to furnish that metal will be many times larger again.

- Growing natural resource use is not necessarily a bad thing in and of itself. Natural resources provide the material basis for the many goods and services that enable people to live decent lives. What is problematic, however, is the waste, pollution and environmental destruction that almost inevitably results from resource extraction and use. Over the past few decades, green growth – the idea that the benefits of resource use can be decoupled from environmental damage – has been widely viewed as the solution to that. Three main strategies have been promoted in practice:
  - using resources (and products) more efficiently
  - substituting polluting resources with less polluting ones
  - capturing and storing harmful wastes and pollutants before they enter the environment.

- Whether these strategies are sufficient to head off the various environmental challenges facing humanity remains an open question. The evidence presented in this report is mixed. While some resource (and impact) decoupling has taken place in New Zealand over the last 30 years, it has been very much of the relative variety. Furthermore, once the resources embedded in international value chains are accounted for, the magnitude of the observed decoupling decreases. However, whether this lack of progress reflects fundamental limitations in each of the strategies mentioned above or a simple lack of implementation remains unclear.

4 For technical information regarding the Climate Change Commission's demonstration pathway see Climate Change Commission (2024).

02

Measuring natural resource use: a quick primer

Choices about how to measure natural resource use can result in very different conclusions about resource productivity and resource decoupling (see Box 2.1).

Two main accounting frameworks – termed production-based and consumption-based accounting – are available at the national level. This chapter provides a brief summary of both. Interested readers should refer to the United Nations manual on economy-wide material flow accounting for more detail.[5]

Production-based or 'territorial' accounting focuses on estimating the total weight of natural resources that enter the domestic economic system. Direct material input (DMI) and domestic material consumption (DMC) are the main metrics used to describe production-based resource use, and are calculated as follows:

(1) DMI = DE + IMP

(2) DMC = DE + IMP – EXP

Where domestic extraction (DE) is the weight of natural resources extracted in the country of interest, direct physical imports (IMP) is the weight of natural resources, semi-finished and finished products imported from abroad, and direct physical exports (EXP) is the weight of natural resources and semi-finished and finished products exported to other countries.[6]

A widely recognised problem with production-based estimates of resource use is that they do not account for the upstream natural resources embodied in manufactured imports or exports. This means that countries (like New Zealand) that have small domestic manufacturing sectors, and therefore import a large proportion of finished goods, will appear to perform well in terms of economy-wide resource efficiency. It also means that countries (again like New Zealand) that have seen manufacturing activity shift abroad over time will appear to have become more resource efficient.

The second approach to measuring natural resource use at the national level – termed consumption-based accounting – offers a solution to both those issues. It focuses on estimating the total weight of natural resources mobilised by the final demand of a country (both in terms of consumption and investment expenditure). In theory, at least, it captures natural resource use across the millions of individual supply chains that feed into any particular economy.

In practice, the raw material consumption (RMC) or material footprint (MF) metrics are used to describe consumption-based resource use. Both are calculated as follows:[7]

(3) RMC (or MF) = DE + rme(IMP) – rme(EXP)

Where the raw material equivalent (rme) of imports and exports represents the natural resources embodied within all traded goods. The raw material equivalent of imported cement, for example, would include all of the non-metallic minerals extracted for feedstock, and all of the fossil fuels used in the extraction and manufacturing process.

5 UNEP, 2021b.

6 UNEP, 2021b, p.13. The manual is explicit that direct physical imports and exports extend to "goods at all stages of processing from basic commodities to highly processed products". That said, establishing the weight of every single import or export consignment is impractical. Furthermore, for complex products like vehicles or electronics, it can be unclear which resource category(s) the associated weight is most appropriately assigned to. As such, in practice, assessments of direct physical trade flows tend to be restricted to bulk commodities (e.g. metal concentrates and products, refined fuels, and timber) and important finished products (e.g. fertilisers and cement).

7 UNEP, 2021b, p.5.

Box 2.1: Different measures of resource use lead to different conclusions about decoupling

There is widespread interest in whether economic activity is decoupling from natural resource use and the generation of polluting waste products. For proponents of green growth, evidence of decoupling is often used to make the case that continued economic growth does not have to be at the expense of the life-supporting capacity of the planet. In contrast, those who argue for degrowth often point to slow (or non-existent) decoupling as a reason why continued economic growth ought to be curtailed.

There is now a considerable body of empirical work on this subject.

At the global level, the evidence seems reasonably clear. Over the last half-century, natural resource extraction and use has increased persistently, albeit at a slower rate than global economic output.[8,9] This relative decoupling is more prominent for some resources than others. For example, there has been significant relative decoupling between fossil fuel extraction and global economic output, but relatively little when it comes to non-metallic minerals.[10]

But that global picture obscures a more nuanced picture at the national level. For many years, the dominant narrative was that high-income countries were successfully decoupling economic output from resource inputs, perhaps even in absolute terms.[11] The thinking went that if all countries could follow that development pathway, then continued growth on a finite planet was possible.

Unfortunately, this conclusion was drawn largely on the basis of production-based measures of resource use (e.g. domestic material consumption). When recently developed consumption-based measures are considered, such as raw material consumption or material footprint, there is much less evidence for decoupling (of even the relative variety) in high-income countries.[12] As discussed further below in chapter four, that certainly appears to be the case for New Zealand.

The likely explanation is that the resource intensity of economic production in high-income countries has decreased as extractive and manufacturing activities have shifted abroad, but that has been at least partially offset by increases in the quantity of resources embedded in imported manufactures.

8 OECD, 2015, Figure 4.3; UNEP, 2024.
9 There is evidence that decoupling between global resource extraction and economic output stalled – or even reversed – between around 2000 and 2015. According to Schandl et al. (2018) this was driven by rapid industrialisation and infrastructure development in parts of the developing world – mostly Asia. More recent datasets (e.g. UNEP, 2024) suggest a continuation of global decoupling from around 2015.
10 OECD, 2015, Figure 4.3; UNEP, 2024.
11 OECD, 2015, Figure 5.12.
12 Wiedmann et al., 2015; Pothen and Welsch, 2019.

Historically, most research on resource use at the national level has focused on production-based accounting. That reflects the fact that the informational requirements of this approach are much less onerous than for consumption-based accounting. Most countries have quite good information about the quantity of natural resources that are extracted domestically each year. Furthermore, because trade data are a key component of the national accounts, most countries also have reasonable information on the quantity of (unprocessed or partially processed) natural resources and products that cross national borders.

Consumption-based accounting, on the other hand, is much more demanding. The need to account for the natural resources 'embedded' in international supply chains means that it is not something that can be systematically measured. Rather, estimating consumption-based resource use at the level of a national economy requires modelling and estimation, and the assembly of large cross-country datasets on resource extraction to inform it.

03

Updates since the literature review

An updated estimate of production-based resource use

The literature review published by PCE last year included an analysis of New Zealand's production-based resource use in 2019.

To get a sense of how the resource intensity of the New Zealand economy has changed through time, PCE staff have repeated the analysis for 1990, 2000 and 2010. In the same way as for 2019, this meant compiling historical data on resource extraction and trade from a range of sources.[13] It also meant updating the 2019 estimate to take account of data revisions and an updated understanding of resource accounting conventions.[14]

Figure 3.1 summarises the results. In 2019, 150 million tonnes of natural resources (direct material input) were fed into the New Zealand economy – 45% more than in 1990.[15] The New Zealand economy more than doubled in size in real terms during the same period, suggesting that domestic production has become more resource efficient over time.[16]

This sort of relative decoupling is widely observed internationally. Data from the Global Material Flows Database (GMFD) indicate that it occurred in almost all Organisation for Economic Co-operation and Development (OECD) member countries over the last three decades.[17] That probably reflects some combination of technological improvements (i.e. enabling less wastage in industrial processes) and structural change (e.g. economy-wide shifts from goods to services).

It also reflects the limitations of production-based measures of resource use. As discussed in chapter two, indicators such as domestic extraction, direct material input and domestic material consumption focus on the natural resources entering an economy – mostly in raw or relatively unprocessed forms. They do not account for the resources 'embedded' in more complex products and therefore do not reflect the total quantity of resources required to meet overall demand in any given year. This probably means that some of the decoupling observed in New Zealand (and other advanced economies) has been achieved by importing resource-intensive products from abroad. As discussed in chapter four (key finding #4), this phenomenon appears to have played a role in the New Zealand context.

13 Data on domestic extraction of fossil fuels, metallic ores and non-metallic minerals are from New Zealand Petroleum and Minerals (2024). Data on domestic extraction of biomass are from MPI, 2025a, 2025b, 2025c, Stats NZ (no date-a) and the FAO, 2025. Data on trade in resources are from Stats NZ (2024a).

14 The most significant change relates to wood. Forestry production is typically reported in volumetric terms (cubic metres) – a density factor is required to convert that into weight. The resource use estimate presented in PCE, 2024, used a density factor representative of 'green' or live *Pinus radiata* (1 tonne per cubic metre). That is inconsistent with international resource accounting conventions (see Table 2.7 in UNEP, 2021b, for example), which use density factors consistent with lower moisture contents. A factor of 0.52 was used for the estimate presented in this report.

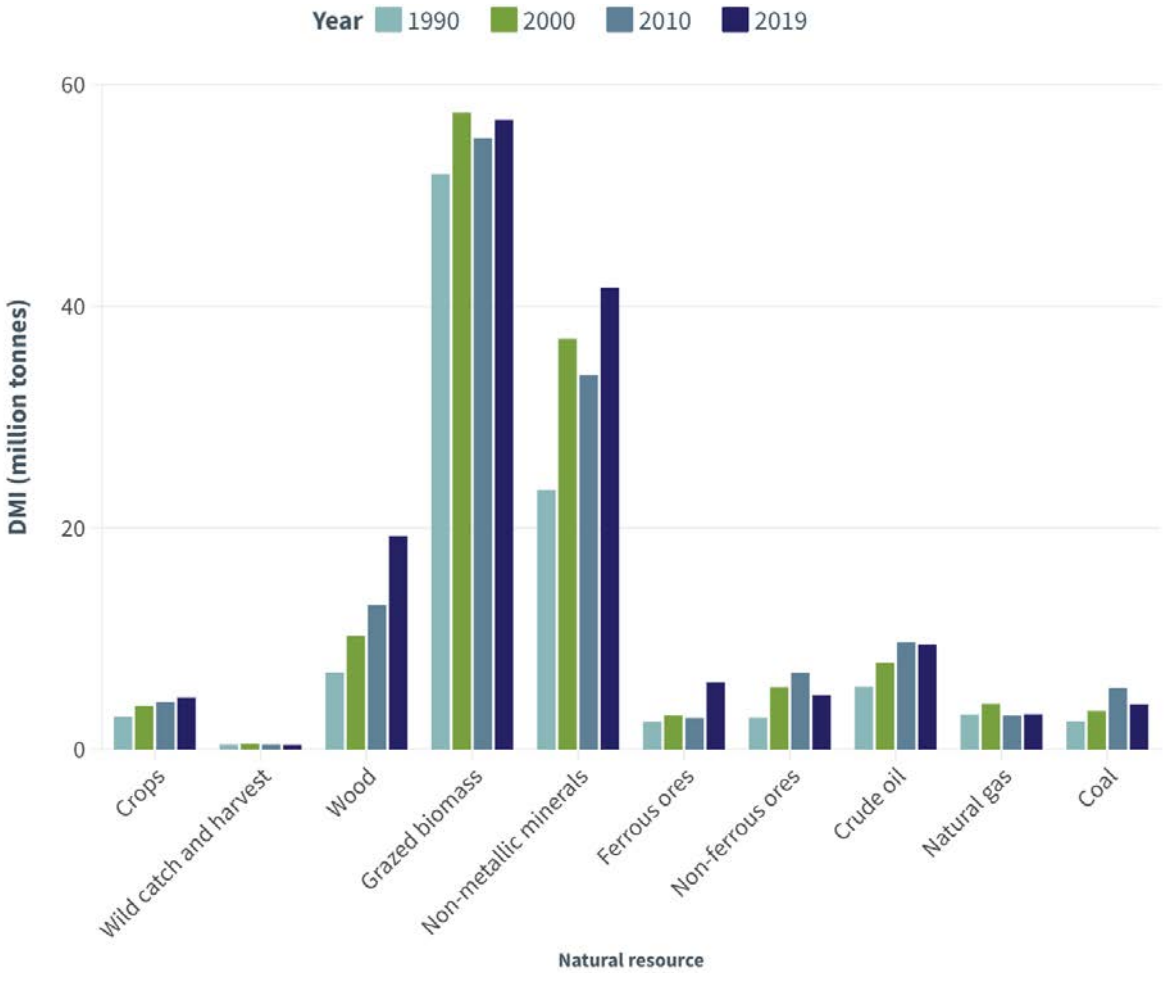
15 These estimates are considerably lower than those reported in the Global Material Flows Database (GMFD) and used by Goddin and Moraga (2024). That is largely due to differing estimates of grazed biomass production. The estimate of grazed biomass presented in this report is based on New Zealand-specific assumptions of dry matter intake developed for the purposes of calculating biogenic methane emissions (for the New Zealand Greenhouse Gas Inventory). We prefer these assumptions to the North America/Oceania-specific assumptions used in the Global Material Flows Database (see CSIRO, 2024, Table 5).

16 Stats NZ, no date-b.

17 UNEP, 2024. Based on the direct material input (DMI) indicator, the only exceptions are Sweden, Australia, Turkey, Luxembourg and Chile. Based on the domestic material consumption (DMC) indicator, the only exceptions are Turkey, Chile and Luxembourg.

These high-level observations on resource decoupling mask important differences at the level of individual natural resources. Inputs of wood to the New Zealand economy tripled between 1990 and 2019, even accounting for the large increase in log exports that took place during that period. Inputs of crude oil (and its derivative products) and non-metallic minerals more than doubled.[18] In each of these cases, there is little evidence to suggest that any decoupling has taken place – even of the relative variety.

At the other end of the spectrum, inputs of fish and other wild catch shrank slightly. It is unclear in what proportion this reflects changes in quota management system as opposed to a dwindling of wild fish stocks – the two are closely interrelated.



Source: PCE data compilation

Figure 3.1: Production-based resource use (direct material input (DMI)): 1990, 2000, 2010 and 2019.

18 Ferrous ore inputs appear to have also increased significantly, particularly between 2010 and 2019. However, that probably partly reflects inconsistencies in the underlying data. New Zealand Petroleum and Minerals has not published data on domestic iron sand extraction since 2016. As such, our estimate for 2019 relies on information published by New Zealand Steel (see New Zealand Steel, 2024). We are uncertain how comparable the metric used by New Zealand Steel is to that previously published by New Zealand Petroleum and Minerals.

A look at the circularity of New Zealand's economy

The economic and environmental opportunities associated with a transition to a more circular economy have received a lot of attention in recent years. Despite that, relatively little effort has been directed towards understanding just how circular New Zealand's economy is (or is not).[19]

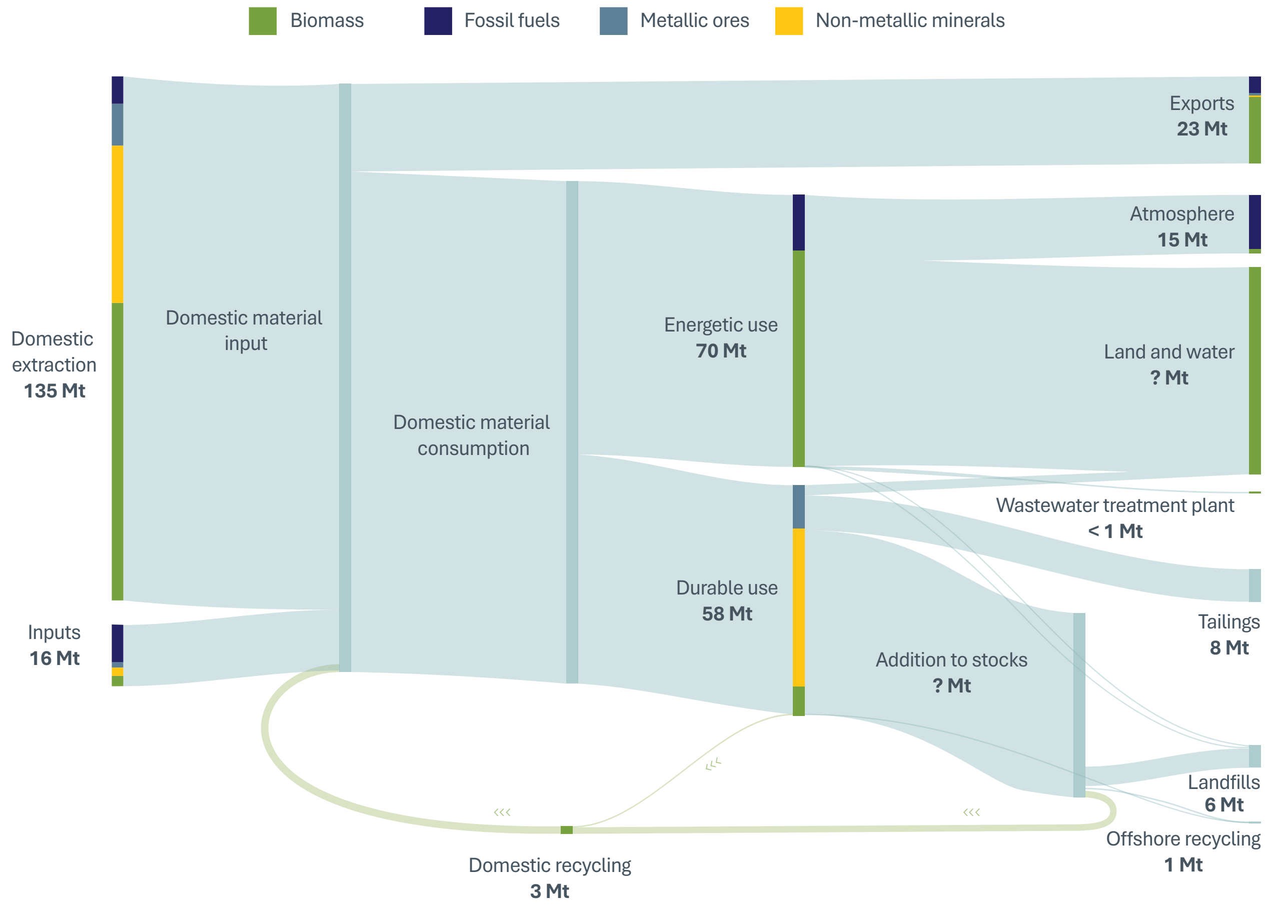
The circularity of a given national economy can be evaluated in different ways.[20] One widely used indicator is the circular material use rate (CMUR), which compares the quantity of secondary materials (those derived from recycled products) with the total quantity of raw materials entering an economy in any given year.[21] Increases in this ratio represent the substitution of secondary materials for their primary equivalents, and reduced demand for natural resource extraction and processing as a result.

It is important to be aware that the CMUR indicator captures just one element of the circular economy – recycling. It largely ignores other circularity pathways – product reuse, repair and remanufacture, for example – that keep products in use for longer and thereby reduce New Zealand's overall demand for natural resources. How widespread those activities are today is unknown, however.

In contrast, the CMUR indicator can be estimated relatively easily, something which has made it popular in international circularity assessments (the Global Circularity Gap Report, for example).[22] In New Zealand's case, it can be estimated by combining official data on waste flows compiled by the Ministry for the Environment – Manatū mō te Taiao (MfE) and others with the data on natural resource inputs (domestic extraction, direct physical imports, direct physical exports) presented above in chapter three.[23]

On this basis, the New Zealand economy remains far from being circular (see Figure 3.2). At least 150 million tonnes of materials were fed into the economy in 2019. Only around 3 million tonnes of these were derived from recycled sources – a circularity rate of perhaps 2%. That is a similar result to one from a recent assessment for Australia (~4%).[24]

19 The only assessment we are aware of is contained in research commissioned by MBIE (see Goddin and Moraga, 2024, Figure 2).
20 See, for example, European Commission, 2023, and Ellen MacArthur Foundation, 2025.
21 Eurostat, 2018a.
22 Circle Economy, 2023.
23 MfE, 2025b; Eunomia, 2021; Stats NZ, 2024a.
24 Miatto et al., 2024.



Source: PCE data compilation

Figure 3.2: Physical material flows (million tonnes (Mt)) through the New Zealand economy in 2019.[25]

25 Note: Mt = million metric tonnes. Data for offshore recycling is from Stats NZ, 2024a. Data for domestic recycling is from Eunomia, 2021, p.95, and MfE, 2025b. Data for landfill disposal is from MfE, 2025b. Data for class 2, 3 and 4 landfills is not available for 2019. As such, data from 2023/2024 has been used in their place.

There are a number of reasons why this estimate of New Zealand's CMUR is probably too low. For example:

- It assumes no role for nutrient cycling. In 2019, more than 50 million tonnes of biomass were fed into the domestic economy as fodder for livestock or food for humans. Some proportion of the nutrients contained in that fodder and food will have been returned to the soil – either via animal excrement and effluent re-application or through composting of food waste and biosolids. Exactly what proportion is unknown. New Zealand's well-documented freshwater quality problem indicates that at least some of these nutrients ultimately make their way into streams and rivers.

- It equates finished metals leaving the economy with metal ores entering it. For most metals, the mass of metal ores entering the economy is at least an order of magnitude larger than that of the finished metals leaving the economy (see chapter four). As such, the circular use rate indicator arguably tends to underestimate the circularity rate for metals.

- It ignores the recycled content of imported materials and products. For example, some imported steel is likely to have been manufactured from recycled feedstock.

- It does not capture all domestic recycling activity. That reflects the limited coverage of domestic waste statistics – something that results from gaps in the underlying monitoring regime. Until recently, only materials diverted for recycling at landfills were required to be reported on.[26] Regulations introduced in 2023 extended those reporting requirements to recyclates collected or processed via council organised or operated waste services.[27] But neither of these regulations captures the materials diverted by purely private recycling operations.[28] Plans to expand the monitoring regime to some of these operations were cancelled by the Government in late 2024.[29]

26 Waste Minimisation (Calculation and Payment of Waste Disposal Levy) Regulations 2009.

27 Waste Minimisation (Information Requirements) Regulations 2021.

28 Consider scrap metal recycling at vehicle wrecking yards, office paper recycling, or the recycling of construction and demolition (by the likes of Green Gorilla), for example.

29 MfE, 2024.

All that said, only a small proportion of the waste generated in New Zealand is currently recycled. Statistics published by MfE indicate that only 10% of solid waste sent to class 1 landfills is diverted to material recovery facilities.[30] The equivalent figure for waste sent to class 2, 3 and 4 landfills (largely construction and demolition waste) is 20–25%.[31] An upcoming report from Eunomia that draws on a variety of unofficial data suggests that actual recycling rates may be significantly higher – potentially in the order of 30–40% depending on the waste streams considered.[32] If so, that would make recycling rates in New Zealand about average by OECD standards.

Importantly though, New Zealand's CMUR would remain low even if these recycling rates approached 100%. That reflects two factors.

The first is that municipal solid waste represents a small fraction of New Zealand's overall waste generation. Many of the volumetrically larger waste streams cannot (currently at least) be captured and recycled. Fossil fuels are (mostly) consumed when they are burned, for example. While the constituent carbon and hydrogen atoms remain (making their way into the atmosphere as carbon dioxide and water), the reality is that no existing technology is capable of economically transforming them back into something useful.

The second is the mismatch between demand for resource inputs and waste supply in a growing economy. In recent decades, direct physical resource inputs into the New Zealand economy have increased by around 1 million tonnes per year on average (see chapter three). While data are unavailable, waste generation is likely to have increased less than this – largely because a significant share of those resource inputs make their way into long-lived 'above ground' resource stocks (infrastructure, buildings, vehicles, etc).

Again, these dynamics highlight the importance of circularity pathways other than recycling – for example, product reuse, repair and remanufacture.

30 MfE, 2025b.
31 MfE, 2025b.
32 Eunomia (unpublished).

Water use

The measurement boundary delineated by formal material flow accounting conventions and principles does not extend to the movement of bulk water from the environment into the economy.[33] However, as a biologically-based economy, water resources are an important component of New Zealand's natural capital base that supports primary sector production and other economic activities. The depletion of freshwater resources can compromise a raft of instream values, including various ecological and recreational benefits. Accordingly, any assessment of material and resource flows needs to consider the extent to which freshwater resources are appropriated by the economy.

The appropriation of freshwater resources can come in the form of inputs derived from either water abstraction or rainfall. For many primary sector activities, rainfall represents an important source of water that underpins crop and pasture growth. Research has attempted to also directly estimate the amount of rainfall used in the production of biomass – for example, through the concept of the green water footprint.[34] There are some regional case studies across New Zealand that quantify the green water footprint of various segments of the primary sector.[35] For example, one study has found that the New Zealand dairy sector uses 12.1 billion cubic metres of water a year, of which 2.46 billion cubic metres stem from surface and groundwater (blue water footprint) and 9.63 billion cubic metres stem from rainfall.[36] However, as far as we can tell, there is no study on the green water footprint of the New Zealand primary sector as a whole.

The assessment of water use in PCE's earlier literature review presented information on total consented water allocation. Research undertaken by the National Institute of Water and Atmospheric Research – Taihoro Nukurangi (NIWA) for national environmental reporting found that, for the 2017/18 year, consented water takes amounted to approximately 13 billion tonnes.[37]

Unlike other resource and material flows presented in our published inventory, estimates derived from water take consents were not based on data measuring direct extraction. The previous estimate was based on consented water take data, which provide an indication of the potential maximum volume of water abstraction.[38] Consents to take water are often not fully utilised; many consents include conditions that restrict taking of water under specified circumstances, and water can be used without a consent when activities are permitted under regional plans. Accordingly, there is potential for significant discrepancies between consented volumes during a given period compared to actual water taken from the natural environment.

The lack of information regarding actual water takes has been identified as a key deficiency in New Zealand's environmental information base. Regulations relating to the measurement of

33 Flows of bulk water are excluded from material flow accounts because of the potential for double counting of moisture content already captured in biomass flows. In addition, the relative magnitude of water flows relative to other resource flows can have a distorting impact on the measurement of other resource categories (Eurostat, 2018b).

34 Mekonnen and Hoekstra, 2011.

35 For example, see Zonderland-Thomassen and Ledgard, 2012, Herath et al., 2013, and Higham et al., 2024.

36 Cameron and Peer, 2025.

37 See Booker and Henderson, 2019. This figure relates to consumptive non-hydropower consents. It is important to note that this single figure masks important spatial variability in the relationship between water resource availability, water allocated for use, water demand and actual water use.

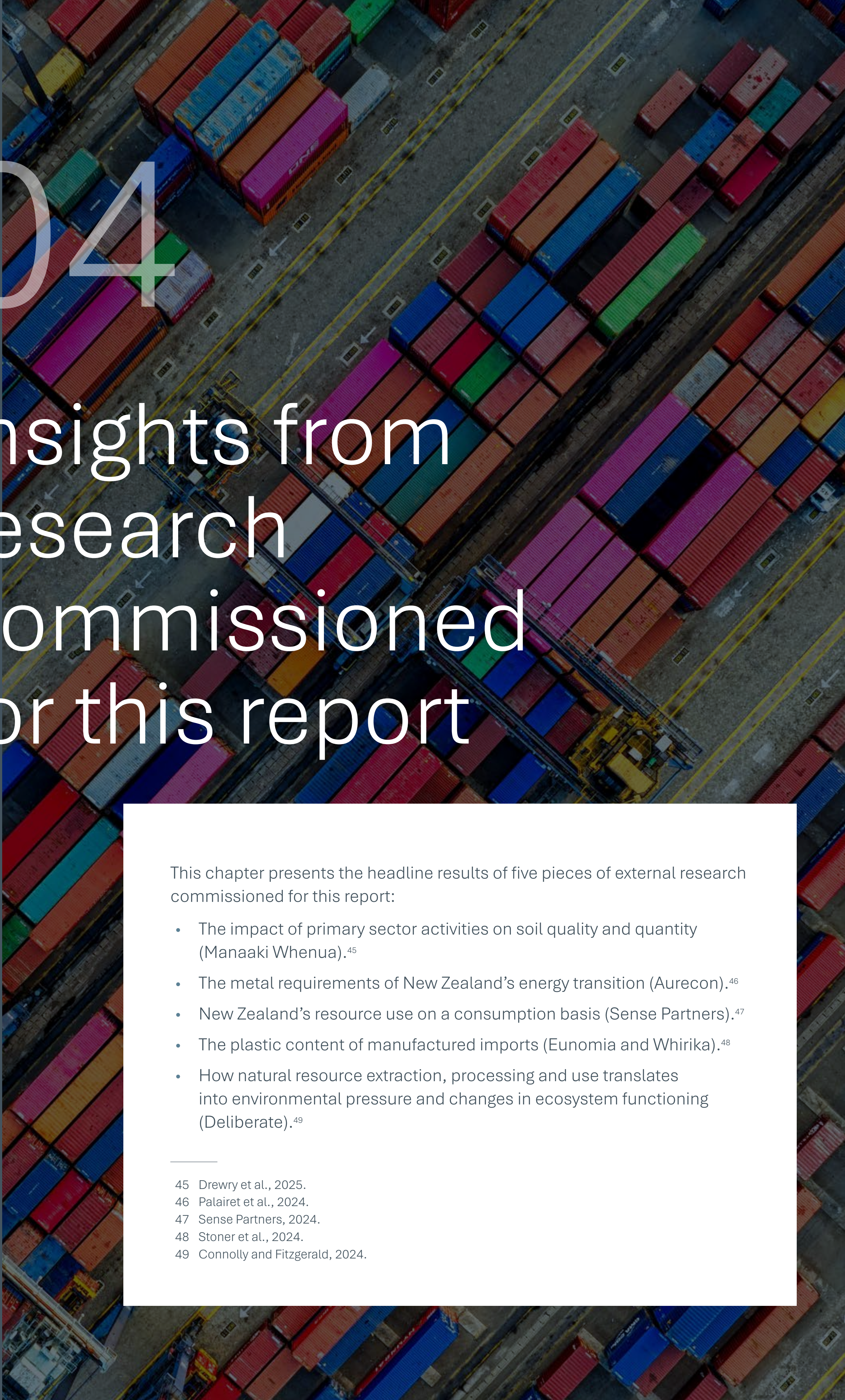
38 Responsibility for the management of freshwater resources falls to regional councils and unitary authorities with consents issued for water abstraction.

water takes have been in existence in some form since 2010, with requirements to progressively expand measurement coverage of takes over time.[39] In their original form, these regulations lacked specificity about how data on water use was to be collected, managed and reported. This resulted in inconsistent practices across water take data providers, which (in turn) has hindered the compilation of a nationally consistent measure of water takes for New Zealand based on data compiled by regional councils.[40] These regulations were amended in 2020 to be more prescriptive, with the changes taking effect between September 2022 and September 2026.[41]

Recent work commissioned by MfE and undertaken by NIWA specifically assessed the state of databases, data conventions and data exchange processes to conduct water quantity accounting in New Zealand.[42] The scope of the work included the collection and analysis of water quantity and use data from selected regional councils. Analysis was then carried out to determine differences between consented amounts and actual takes for those consents with metered water take data. Results showed that actual water takes were generally much lower than the overall consented maximum allowable instantaneous rate of take for the selected case study regions. The discrepancy between consented and metered water volumes suggests that our previously reported estimate derived from consented water take data would be expected to exceed actual water abstraction by a large magnitude.[43]

In addition, one of the key overall findings of the NIWA report was that it is currently not possible to compile a nationally coherent or consistent account of actual water use for New Zealand.[44] Key barriers identified include inconsistencies between regions relating to the definition of technical and measurement concepts, and general data quality issues. Accordingly, the inability to compile a national picture of water use stems not from a lack of environmental monitoring but from deficiencies in the underpinning data and information systems.

39 MfE, 2021.
40 See MfE, 2020, p.307.
41 Resource Management (Measurement and Reporting of Water Takes) Amendment Regulations 2020.
42 See Booker et al., 2024. In the context of NIWA's report, water accounting refers to the process of collation, analyses and presentation of water quantity data.
43 Caution is warranted with respect to the interpretation of these findings due to the limited number of case study regions and their non-random selection. In addition, analysis of actual rates relative to consented takes was based on limited temporal coverage.
44 Booker et al., 2024.



04

Insights from research commissioned for this report

This chapter presents the headline results of five pieces of external research commissioned for this report:

- The impact of primary sector activities on soil quality and quantity (Manaaki Whenua).[45]
- The metal requirements of New Zealand's energy transition (Aurecon).[46]
- New Zealand's resource use on a consumption basis (Sense Partners).[47]
- The plastic content of manufactured imports (Eunomia and Whirika).[48]
- How natural resource extraction, processing and use translates into environmental pressure and changes in ecosystem functioning (Deliberate).[49]

45 Drewry et al., 2025.
46 Palairet et al., 2024.
47 Sense Partners, 2024.
48 Stoner et al., 2024.
49 Connolly and Fitzgerald, 2024.

The impact of primary sector activities on soil quality and quantity

Our updated inventory of resource flows in Aotearoa New Zealand showed that in 2019, about 78 million tonnes of biomass was extracted domestically. This resource category was dominated by grazed biomass and fodder crops, forestry, and agricultural and horticultural crops. This production was entirely dependent on the existence of New Zealand's underlying soil resource.

Material flow accounting principles and conventions measure biomass in terms of tonnes of production. The measurement boundary does not extend to the resources underpinning production. Accordingly, neither soil quality nor quantity is directly accounted for in our inventory of material flows.

New Zealand soil resources can be conceptualised as a stock of natural capital that yields a flow of provisioning services in the form of biomass generation. For a biologically based economy, consideration needs to be given to the impact of economic activity on this natural capital asset underpinning the production of these flows.

Soil resources underpin primary sector production by providing a physical substrate that supplies nutrients and water to plants. However, primary sector activities can have a range of detrimental impacts on soil resources. This degradation has the potential to undermine the productive capacity of New Zealand's soil resources and biomass production. This could compromise the ability of New Zealand's primary industries to produce products for both domestic and export markets.

To supplement the findings of our inventory, Manaaki Whenua – Landcare Research was commissioned to review the impact of primary sector activities on New Zealand's soil resources.

This review focused on synthesising available evidence to summarise these impacts, the extent to which they are reversible and implications for ongoing productive capacity.

Data and evidence were drawn from a range of sources, including environmental reporting (both national and regional), published research and grey literature, and experts from Manaaki Whenua. In addition, the strength of the underpinning evidence base was also assessed, and an overview of key knowledge gaps provided. The data and evidence were largely drawn from New Zealand studies as a comprehensive survey of the international literature was beyond the scope of the review. However, this would constitute a natural extension of this work to address gaps that were identified in the underpinning evidence base.

The scope of the review encompasses a range of primary sector land use activities, including dairy and dry-stock farming, horticulture, cropping and exotic forestry. The review assessed the impact of each activity on the various dimensions of soil quality, including chemical, biological and physical ones.[50] The impact of primary sector land use activities on soil quantity (in the form of erosion) was also assessed.

50 This included soil biota, contaminants, soil carbon, nutrients, pH and physical structure.

It should be acknowledged that while certain land management practices can positively affect soil quality and productive capacity, the review centred on the degradation and depletion of soil resources. Furthermore, wider environmental impacts in the form of greenhouse gas emissions and freshwater quality issues were not considered. These exclusions are consistent with a focus on the environmental risks posed to New Zealand's soil resources from the extraction of biomass.

It is important to note that the evidence base underpinning this assessment draws on research conducted in a specific set of circumstances. Accordingly, the findings described here will not account for the heterogeneity of production systems or land management practices across New Zealand. Furthermore, soil orders have different properties that influence the resilience of the receiving land environment and the impact of primary sector activities.

To account for some of this uncertainty, the review includes an assessment of the character and magnitude of the impact using the Intergovernmental Panel on Climate Change (IPCC) uncertainty framework.[51] This provides an indication of the level of confidence underpinning statements regarding the impact of land use activities on soil properties and implications for the productive capacity of New Zealand's soils.

51 IPCC, 2010, p.3. The IPCC framework assesses uncertainty according to the degree of agreement and an evaluation of the evidence base according to type, amount, quality and consistency.

Key finding #1:
Different primary sector land uses have different impacts on soil quality and quantity.

The Manaaki Whenua – Landcare Research review found that different land uses have different impacts on soil quality and quantity.[52] These impacts depend on the nature of the activity and the intensity of land management practices. The following examples highlight where there is at least reasonable evidence and agreement regarding the impacts of land uses on soil properties.

- Dairy farming often results in compaction and pugging, particularly during wet conditions. Similar impacts are observed in more intensive sheep and beef grazing systems on flat and rolling hill country. Compaction and pugging limit root penetration, water drainage and air movement through soils. Dairy farming is also associated with the accumulation of contaminants, including cadmium and zinc. The accumulation of cadmium is largely the result of the legacy application of phosphate fertilisers, whereas the accumulation of zinc results from the treatment of facial eczema. The use of irrigation as part of more intensive farming operations is shown to decrease soil carbon in most studies.

- The predominant impacts associated with dry-stock hill and high-country farming arise from soil loss from erosion. Land under hill and high-country farming has often been subject to historical clearing and is erosion prone, with the greatest soil loss arising from shallow landslide processes.

- Arable cropping and short-rotation horticulture can result in soil compaction from cultivation and the movement of heavy machinery. In addition, the constant removal of biomass and various land management practices often results in lower soil carbon.

- Perennial horticulture can result in elevated copper levels in some soils due to the application of copper-based fungicides, although the spatial extent of elevated values is unknown.

- Exotic forestry has some impacts on soil properties related to both loss and structure. Exotic forestry is often situated on erosion-prone land, with shallow landslide processes responsible for soil loss. Harvesting practices can exacerbate this risk through the loss of canopy cover and root structure. In addition, localised soil compaction generally results from vehicle movements, particularly during harvesting operations.

52 Drewry et al., 2025.

Key finding #2:
Some of these impacts are reversible. Some are not.

A key consideration with respect to the impact of different land uses relates to the extent to which these impacts are reversible on any reasonable human timescale. The findings of this review indicated that different impacts demonstrate variable levels of reversibility. Some impacts are reversible through land management practices or remedial actions while other impacts are largely irreversible. However, gaps in the underpinning evidence base ensure that it is not possible to assess the reversibility of all soil impacts. The following summarises what is currently known about the reversibility of such impacts.

- Any impact of land use activities on soil nutrient depletion and pH is largely reversible through the application of fertilisers and other inputs, such as lime and composts, to ensure optimal growing conditions.
- The accumulation of trace element contaminants is largely irreversible. This accumulation results from the application of various agrichemicals, such as copper from fungicides and zinc from the treatment of facial eczema, as well as impurities (e.g. cadmium) in some fertiliser products.
- Soil compaction is reversible but requires changes in land management practices, including remedial practices. Evidence suggests that compaction associated with shallow soil depths is more easily reversible but that impacts become harder to reverse as degradation extends further below the top layer of soil. However, there is limited information regarding the reversibility of these impacts for deeper soil layers.
- Depletion of soil carbon can be reversed through the direct input of organic materials or through plant growth. However, in practice it can be difficult to reverse the loss of soil carbon due to the complex nature of the processes that influence soil carbon.
- Soil erosion and loss of soil to waterways is irreversible on any relevant human timescale. Soil erosion leading to the redistribution of soils within production landscapes is somewhat reversible.
- There is currently a lack of evidence regarding the extent to which the impact of different land use activities on soil biota and biological communities is reversible. Some evidence suggests that changing land use can result in irreversible changes to the structural composition of soil biota. However, the underpinning evidence base is limited.

Key finding #3:
Important gaps remain in our understanding of how New Zealand's soil resource is changing.

The Manaaki Whenua Landcare Research review found the evidence base describing links between land use activities and impact on soil properties was reasonable.[53] Despite some deficiencies, the review was able to draw on numerous sources that described the general impact of land uses on soil quality and quantity. However, the review also highlighted several knowledge gaps relating to soil properties, productive capacity and other information needed to enable the more effective management of New Zealand's soil resource. These are outlined below.

- The impact of land use on soil microbes and invertebrates and their role in supporting soil productive capacity was identified as a consistent information deficiency. This extended from basic information regarding the distribution and health of these communities through to their various functions and contribution to soil quality.
- Knowledge gaps relating to the extent and impact of contamination were also identified. For example, information regarding concentrations of copper and zinc, which are suggested to be the primary contaminants of concern in horticultural and pastoral land uses, respectively, was largely limited to regional council state of the environment reporting. The review suggested that a greater level of surveillance of copper and zinc concentrations in key land uses is warranted and additional data from other sources could provide a more comprehensive assessment of the extent of these contaminants. In addition, there is also a dearth of information relating to the extent, impact and reversibility of pesticide residues and microplastics in New Zealand soils.
- Another key gap relates to the lack of quantitative data on soil erosion control. While our general understanding of erosion and its control is reasonable, we lack quantitative data to ensure erosion control is targeted.
- The review also identified knowledge gaps relating to both the effectiveness and adoption of remedial and mitigating land management practices to address known issues (e.g. pugging and compaction).

Much of the available evidence base was limited to research and monitoring that measured and described the impact of various primary sector land uses on soil properties as described in the first key finding. Often, the evidence base did not extend to exploring how these impacts influence the ongoing productive capacity of soils.

53 Drewry et al., 2025.

Accordingly, the review could only make a limited set of definitive statements regarding the extent to which primary sector activities were undermining the productive capacity of New Zealand's soils. The following provides an overview of what is known about the relationship between the impact of various land uses and implications for soil productive capacity.

- Compaction and pugging associated with dairy farming and other intensive grazing systems were identified as having a detrimental impact on primary production, at least over the short term. The resulting changes to soil structure have reduced pasture yields. This relationship between impact on soil properties and subsequent implications for productive capacity was characterised by both robust evidence and high agreement. The evidence base was less certain regarding the impacts on pasture over the longer term and for deeper soil layers.

- Exotic forestry and hill-country farming on eroded land leads to reduced tree growth and pasture production from the loss of topsoil. However, while there was strong evidence regarding the occurrence of erosion in steepland forests, the assessment linking erosion to reduced productive capacity had high agreement but was deemed to be less robust given limited overall evidence.

- Trace element contamination in the form of copper in horticultural systems and zinc in pastoral systems was identified as the greatest risk to the future productive capacity of soils. These impacts are largely irreversible, and elevated concentrations can have adverse impacts on yield and soil functioning. With respect to copper, there is medium agreement and evidence that copper has accumulated to concentrations that may cause negative impacts in some areas, although the spatial extent of elevated values is unknown. There is limited evidence and high agreement that while zinc concentrations in soil subject to dairy farming are elevated, these concentrations do not currently pose a concern in relation to productive capacity.

- The presence of cadmium in soil can result in non-compliance of food crops with food standards, effectively limiting the productive capacity of the soil. There was medium evidence and high agreement that a small number of food crops are either breaching or nearly breaching these standards.

- A key knowledge gap relates to the impact of changing soil carbon content on productive capacity. The review found that while there is a substantial body of evidence on the impact of land uses on soil carbon, there is limited evidence regarding implications for soil productive capacity.

Metal requirements of New Zealand's energy transition

The mineral and metal requirements of a renewable energy transition have received considerable attention recently.

They are central to the Government's recently published minerals strategy and critical minerals list.[54] Both documents foresee an opportunity for New Zealand to supply a greater share of the metals – for example, vanadium and phosphate – that will be required for the global energy transition.

The metal requirements of a renewable energy transition have also been central to an ongoing debate about the relative merits of green growth and degrowth. There is a view in some quarters that a renewable energy transition – a form of green growth – is neither possible nor desirable.[55] Not possible for a range of reasons, but in significant part because the metal requirements of solar photovoltaic (PV) panels, wind turbines and batteries will exceed our ability to supply them.[56] Not desirable because of the environmental burden that large-scale mineral mining and processing tends to leave behind. In the eyes of degrowth advocates, the better solution to climate change and the other environmental challenges we face is a reduction in overall societal consumption.

Despite all of this, there has been little analysis of what the metal requirements of New Zealand's energy transition might actually be. [57,58] Which metals might be required? In what quantities? How much waste might result?

PCE commissioned Aurecon to consider these questions. The modelling approach that was developed is described in full in an accompanying report available on PCE's website.[59] In short, projections of New Zealand's metal demand to 2050 were generated by integrating three types of information:

- **Life cycle analysis data** describing the (current) metal contents of four headline renewable technologies – solar PV, wind turbines, battery storage and vehicles (electric and plug-in hybrid) – and the electricity transmission and distribution networks that support their uptake. This extended to sub-variants of each main technology type (crystalline silicon vs thin film solar cells, for example).
- **Projections** of how the market share of each sub-technology might evolve to 2050, taken mostly from academic research. This matters because different sub-technologies have very different metal requirements (consider lithium-iron-phosphate vs nickel-manganese-cobalt batteries, for example).
- **Projections of renewable technology adoption in New Zealand** from He Pou a Rangi – Climate Change Commission (CCC) and Boston Consulting Group (for grid-scale battery storage). The CCC's demonstration path, which describes a pathway to net zero by 2050, was the central scenario analysed.[60]

As with all modelling, the projections that result are only as good as the assumptions that go into them. The results presented below should be read with that in mind.

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54 MBIE, 2025.

55 Seibert and Rees, 2021; Joy, 2023.

56 Other widely cited issues include (i) the relatively low energy density of batteries and their resulting inability to replace liquid fuels in a number of transport applications (e.g. shipping and aviation), and (ii) the inability of renewable technologies to produce the level of process heat that is required in some manufacturing applications.

57 A recent report by Rewiring Aotearoa (Hall et al., 2024) does include an estimate of the metal requirements associated with the uptake of electric vehicles in New Zealand.

58 Several such analyses have been undertaken at the global level, however. For example, modelling by the International Energy Agency (2024) projects that the uptake of renewable technologies will drive a twofold to fourfold increase in mineral demand relative to today.

59 Palairet et al., 2024.

60 As presented in draft advice provided by the CCC for emissions budget 4 (CCC, 2024).

Key finding #1:
The metal demand associated with New Zealand's renewable energy transition is projected to increase five-fold between 2023 and 2050.

In 2023, domestic investment in a set of core renewable technologies – solar PV, wind generation, battery storage, and electric and plug-in hybrid vehicles – required the mobilisation of around 56,000 tonnes of finished metal. That is projected to increase to 300,000 tonnes by 2050 if new investment in renewable technologies follows something resembling the CCC's demonstration pathway.

As highlighted in Table 4.1, demand for some metals is projected to increase more than for others. Bulk metals – iron, aluminium and copper – see the largest increases in absolute terms. For example, aluminium demand increases from around 8,000 tonnes per year in 2023 to almost 50,000 tonnes per year in 2050.

In relative terms though, the largest increases are projected to come from a set of less common metals. Demand for lithium, graphite and phosphorus – all of which are key ingredients in battery technology – is cumulatively projected to increase almost nine-fold, from 1,700 tonnes per year in 2023 to 14,500 tonnes per year in 2050.

Table 4.1: Projected metal demand (kilotonnes) associated with the adoption of key renewable energy technologies: solar PV, wind generation, battery storage, and electric and plug-in hybrid vehicles.

	2023 (kt)	2050 (kt)	Projected demand growth factor 2023–2050
Iron	40.16	202.86	5
Aluminium	7.94	49.23	6
Copper	3.51	25.07	7
Graphite	1.30	10.72	8
Silicon	0.71	3.69	5
Phosphorus	0.27	2.78	10
Manganese	0.50	2.42	5
Chromium	0.52	2.08	4
Nickel	0.52	2.02	4
Lead	0.25	1.45	6
Lithium	0.13	1.00	8
Cobalt	0.12	0.50	4
Molybdenum	0.07	0.40	6
Rare earth elements	0.04	0.31	8
Magnesium	0.03	0.21	7
Tin	0.02	0.13	6
Zinc	0.02	0.11	6
Vanadium	0.02	0.05	3
Titanium	0.0051	0.0244	5
Boron	0.0013	0.0100	8
Sodium	0.0063	0.0070	1
Antimony	0.0005	0.0034	6
Gold, silver & PGMs[61]	0.0016	0.0033	2
Cadmium	0.0002	0.0015	7
Indium	0.0001	0.0004	7
Zirconium	0.0003	0.0003	1
Gallium	0.0000	0.0002	7

61 Note: PGMs = platinum group metals.

Cumulatively, an energy transition akin to the CCC's demonstration pathway would require around 7.5 million tonnes of finished metal between 2023 and 2050.[62] The quantity of ore required to produce that metal would be many times larger. Copper provides an example. At present, copper makes up around 0.6% of a typical copper ore – the remainder is waste rock, which mostly ends up in tailings dams and associated storage facilities.[63] As such, the 560,000 tonnes of cumulative copper demand projected by the modelling undertaken for this report would ultimately require the extraction and processing of something closer to 100 million tonnes of copper ore (assuming all of it was furnished from virgin ores).[64] The differential for metals like silver and the rare earth elements (whose concentrations in ore are typically measured in parts per million) are much larger again.

These numbers are large, and some context is useful for making sense of them.

One point of comparison is with projections of metal demand in other countries. Recent modelling undertaken for the United States, for example, suggests that a net-zero transition would require 1.5 million tonnes of copper, 1 million tonnes of graphite, and 100,000 tonnes of lithium annually by 2035.[65] Those quantities are in the order of 50 to 100 times larger than those suggested for New Zealand in Table 4.1. That seems broadly reasonable given that the population of the United States is around 70 times larger than in New Zealand.

Another point of comparison is with the fossil resources that are required by New Zealand's existing energy system. In 2023, 4 million tonnes of petrol and diesel was used in domestic road transport.[66] A significant proportion of that fuel will no longer be required as New Zealand's vehicle fleet becomes increasingly electric. If the CCC's demonstration pathway comes to pass, New Zealand will be importing ~190,000 electric and ~20,000 plug-in hybrid vehicles annually in 2040. Based on the analysis undertaken for this report, together with some basic assumptions about the metal contents of different ores, the batteries contained in those vehicles will require perhaps 1.3 million tonnes of metal ore to manufacture.

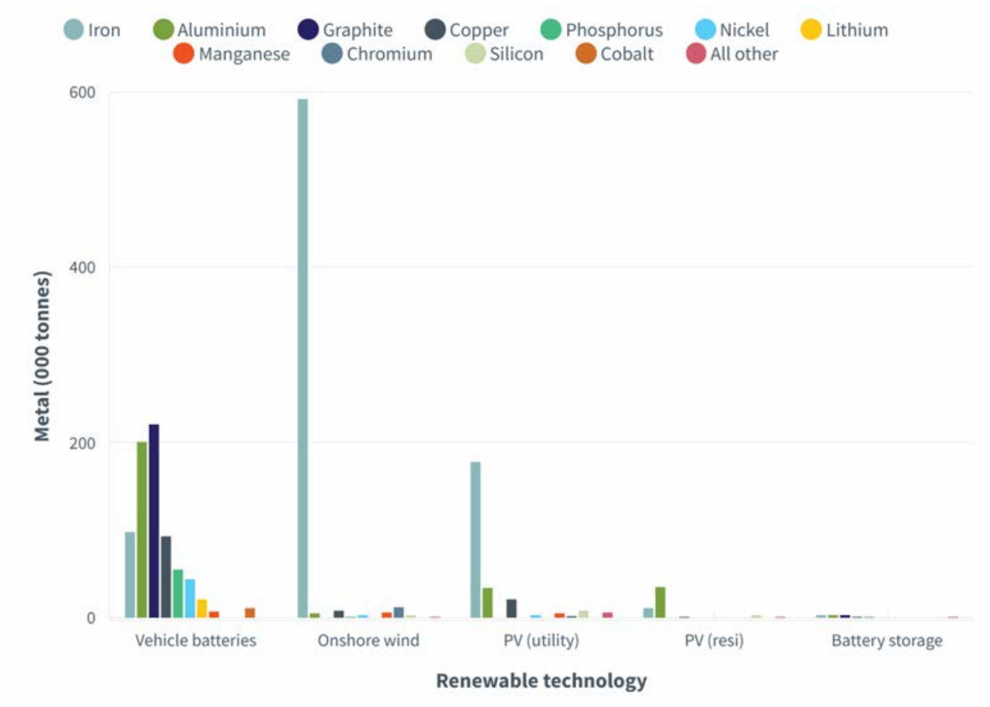
62 1.7 million tonnes if vehicle chassis are excluded.
63 Northey et al., 2014; World Copper Ltd, 2023, p.10.
64 In reality, a significant proportion of global copper supply comes from recycling copper scrap. Data from the International Copper Association suggests secondary supply between 2009 and 2018 was in the order of 30% (International Copper Association, 2022).
65 Wang et al., 2024.
66 MBIE, 2024b.

Key finding #2:
Electric vehicles require considerably more metal ore to be extracted than internal combustion vehicles.

Imported electric and plug-in hybrid vehicles are projected to require 6.5 million tonnes of finished metal between 2023 and 2050 – around 85% of all of the metal demand associated with New Zealand's energy transition.

Most of that metal (perhaps 85%) is the iron and aluminium contained in vehicle chassis and bodies. Electric and plug-in hybrid vehicles have similar requirements to traditional internal combustion vehicles in that respect. As such, much of this metal would be mobilised regardless of how quickly New Zealanders adopt them.

Electric and plug-in hybrid vehicles also contain large batteries. These are projected to require 750,000 tonnes of finished metal between 2023 and 2050, making them the largest driver of metal demand for the technologies assessed in this report (Figure 4.1). Graphite and lithium are both essential ingredients in the lithium-ion batteries that dominate present day electric vehicle markets. Depending on the exact chemistry involved, these batteries also require significant quantities of cobalt, copper, manganese, nickel and phosphorus. Many of these metals are produced from ores characterised by relatively low grades (i.e. below 10% metal content), which is a key reason why electric vehicles require considerably more metal ore to be extracted and processed than traditional internal combustion vehicles.



Source: Based on analysis by Aurecon (Palairet et al., 2024)

Figure 4.1: Cumulative metal requirements by renewable technology 2023–2050

One of the key sources of uncertainty in the projections of future metal demand presented in this report relates to stationary battery storage (whether residential-scale or utility-scale). As shown in Figure 4.1, this is projected to drive very little metal demand over the coming decades. For residential-scale storage, that reflects projections of residential solar PV installation from the CCC coupled with assumptions about the share of those installations that are accompanied by a battery.[67] For utility-scale storage, it reflects projections of battery adoption taken from recent Boston Consulting Group modelling.[68]

It remains to be seen how accurate those underlying projections and assumptions are. That said, there are reasons to believe they may err on the low side, particularly if the sort of electricity system decentralisation envisaged by the likes of Rewiring Aotearoa plays out.[69] Were that to happen, the metal demand associated with stationary storage could be considerably higher. At the same time, some of that additional demand would probably be offset by other factors. Reduced investment in transmission and distribution infrastructure is potentially one example. The cascading use of vehicle batteries in stationary storage applications is another.

Key finding #3:
End-of-life solar PV panels, wind turbines and batteries will begin to generate large quantities of waste in the coming decades.

The renewable technologies assessed in this report have finite lifespans. At present, the effective use life of batteries used in electric vehicles and for residential electricity storage is around 10 years, although this depends significantly on how they are used, and how much performance loss consumers are prepared to tolerate. The use life of solar PV panels and wind turbines is longer – typically around 20 years.

While there are opportunities to extend their use life, every PV panel, wind turbine and battery used to power New Zealand's energy transition will ultimately enter the waste management system. Renewable technologies are by no means unique in that respect. Fossil-fuelled technologies also become waste at their end of life.

Figure 4.2 shows how waste generation resulting from the disposal of PV panels, wind turbines and batteries (residential and vehicle) might evolve if New Zealand's energy transition follows something resembling the CCC's demonstration pathway.[70] By 2040, the arrival of these technologies at their end of life is projected to result in around 30,000 tonnes of metal (and silicon and phosphorus) waste generation each year. By 2050, that figure is projected to increase to around 130,000 tonnes.

67 These assumptions are that (i) 10% of current rooftop solar installations are accompanied by a 10 kWh battery, (ii) this share increases by 2% per year and (iii) battery sizes increase by 2.5% every year.

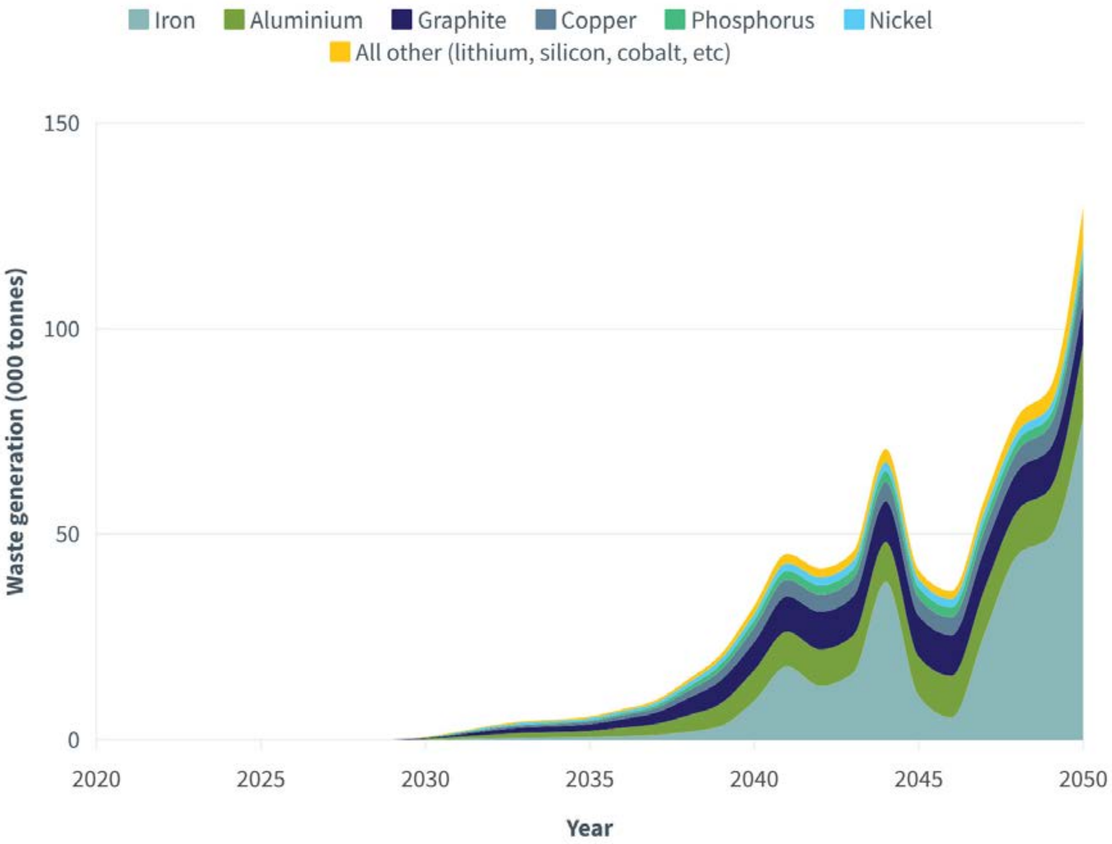
68 Boston Consulting Group, 2022.

69 CCC modelling suggests that New Zealand will have 1,650 MW of rooftop solar capacity by 2050 (CCC, 2024). At an average panel size of 7 kW, that only amounts to around one in ten (currently existing) dwellings having rooftop solar. It is also worth noting that recent modelling from Transpower includes projections in which distributed solar capacity reaches 4,900 MW by 2050 (Transpower, 2020).

70 Only investment in renewable technologies that took place after 2020 is considered – hence the absence of waste generation during the 2020s. The fall in projected waste generation in the mid-2040s shown in the figure results largely from CCC projections which suggest that little or no new onshore wind generation will be commissioned in 2025 and 2026.

That waste represents both an opportunity and a challenge. An opportunity in the sense that there are significant amounts of economic value embedded in it. At current metal prices and exchange rates (February 2025), the cumulative value of the aluminium, copper and nickel contained in this waste stream is in the order of perhaps $5 billion. That is to say nothing of the iron, graphite, lithium and other metals it contains.

The challenge, of course, is whether those metals are economically recoverable and, if they are not, how to dispose of them in an environmentally responsible way. Perhaps the biggest barrier in this respect is the complexity of the components and alloys that are used in many renewable technologies. Separating the higher value materials in this waste stream from the surrounding steel and plastic is far from straightforward and typically requires large amounts of labour (for disassembly) and capital (for metal recovery). Extended producer responsibility schemes can play an important role here, both by providing a source of funding for collection and material recovery, and by incentivising the design of products that are more easily recycled. New Zealand has been in the process of designing such a scheme for large batteries since 2021.[71] Whether this comes to fruition remains to be seen.



Source: Based on analysis by Aurecon (Palairet et al., 2024)

Figure 4.2: Projected waste generation resulting from the disposal of end-of-life solar PV panels, wind turbines and batteries.

71 MfE, 2025a.

New Zealand’s resource use on a consumption basis

The vast array of goods and services consumed in modern societies require natural resource inputs in their production. Quantifying the footprint of an individual product – or country in aggregate – is far from straightforward. The complexity of many products and the global reach of supply chains tends to make simple ‘tallying up’ exercises impractical.

The emergence of environmentally extended multi-regional input-output (EEMRIO) databases offers a way forward. By linking country-specific data on resource extraction (in tonnes) and economic flows and trade (both in dollars), it is possible to estimate the natural resource footprints of goods and services consumed in any given country.

The Global Resource Input-Output Assessment (GLORIA) database – built by Manfred Lenzen and colleagues at the University of Sydney with funding from the United Nations International Resource Panel – is (arguably) the best EEMRIO database currently available. As discussed in PCE’s earlier literature review, GLORIA was specifically designed with resource accounting in mind and includes New Zealand as a standalone country.[72]

Interrogating the GLORIA database is not straightforward. Doing so requires expertise in input-output analysis as well as a lot of computing power. PCE commissioned Sense Partners to help with this. Sense Partners developed a hybrid methodology that combines official statistics on domestic resource extraction and economic flows with estimates of the resource content of New Zealand’s imports from GLORIA.

Relative to a GLORIA-only approach, this hybrid methodology has two advantages. The first is that it allows domestic statistics on resource extraction to be used in place of those contained in international databases. There are significant discrepancies between these datasets – our belief is that the domestic statistics are likely to be more accurate. The second advantage is the additional sectoral detail contained in domestic input-output data.[73] This allows, for example, a distinction to be made between dairy and other cattle farming, something which is important in the New Zealand context.

The full details of the analysis are presented in a report available on PCE’s website.[74] The analysis required a significant number of simplifications and assumptions, and the results presented below should be viewed as indicators rather than precise measurements.

72 PCE, 2024.
73 GLORIA distinguishes between 120 individual industries. The input-output tables published by Stats NZ distinguish between 109 industries and 197 product groups.
74 Sense Partners, 2024.

Key finding #1:
The goods and services consumed by New Zealanders in 2019 required the mobilisation of 107 million tonnes of natural resources.

In 2019, 107 million tonnes of natural resources were mobilised in the production of the goods and services consumed by New Zealanders.[75] For reasons discussed in chapter three, that estimate does not include water. It would be considerably higher if it did.

Around 54 million tonnes of this resource use resulted from the day-to-day spending decisions of households (Figure 4.3). On a per-capita basis, that amounts to 10 tonnes of natural resources per person per year. Half of that footprint is biomass (largely in the form of food). Fossil fuels (~20%), non-metallic minerals (~20%) and metallic ores (~10%) make up the remainder.

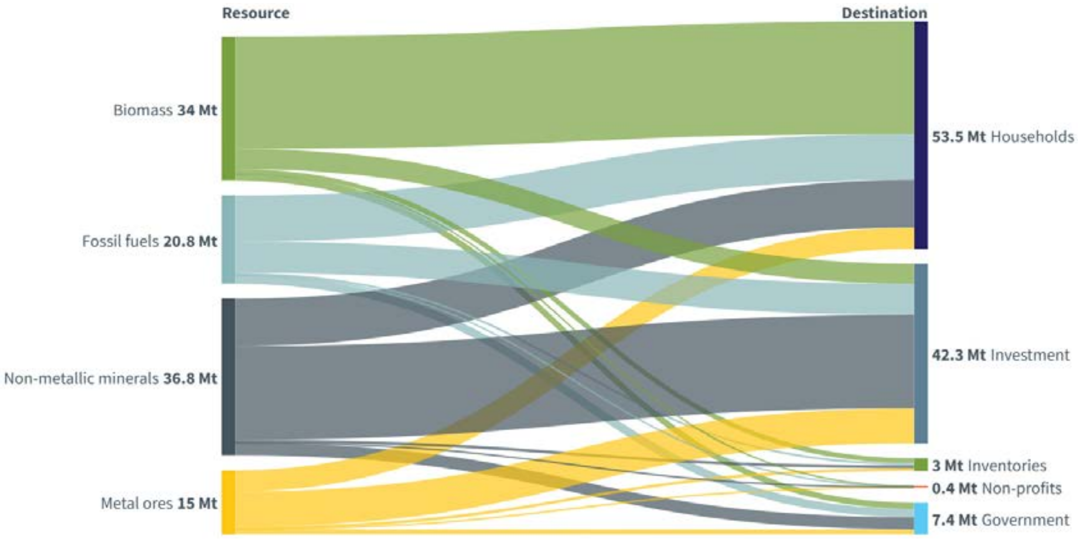
The other big driver of New Zealand's overall natural resource footprint is investment spending – by households, firms and businesses.[76] This accounted for around 42 million tonnes of natural resources in 2019. Non-metallic minerals are the largest contributor, largely in the form of the rock, gravel and sand that are key inputs in construction and infrastructure development.

On a per-capita basis, New Zealand's overall natural resource footprint (~20 tonnes per capita per year) is about average by OECD standards.[77] At the same time, that OECD average is roughly twice as large as the average per-capita resource footprint of developing countries.

75 Or, more precisely, the year ended March 2020.

76 Investment – or 'gross fixed capital formation' – is defined in the national accounts as spending on durable goods (those with usable lifetimes of one year or more). Household spending on new dwellings is included, but household spending on other durable goods (e.g. motor vehicles) is not. See Stats NZ, 2014, p.23.

77 UNEP, 2024. There is some uncertainty here, however. The Global Material Flows Database estimate of 30 tonnes per capita, per year places New Zealand well above the OECD average on a per-capita basis. Assumptions about the biomass requirements of livestock are the main reason for the discrepancy between the Global Material Flows Database estimate of New Zealand's material footprint and the estimate presented here. This is discussed further in the report by Sense Partners, 2024.



Source: Based on analysis by Sense Partners, 2024

Figure 4.3: New Zealand resource use (material footprint – million tonnes) by final demand in 2019.

Key finding #2:
A small number of basics account for the bulk of New Zealand's resource footprint.

Building on work by Miatto et al. (2024), the resources required to produce the goods and services consumed by New Zealanders have been broken down using a 'systems of provision' classification.[78] This involved apportioning the resource footprints of 197 individual products to one of nine 'production systems', each of which delivers goods and services that support material wellbeing. The approach is far from perfect, but does provide a digestible representation of the aspects of daily life that drive New Zealand's demand for resources.[79]

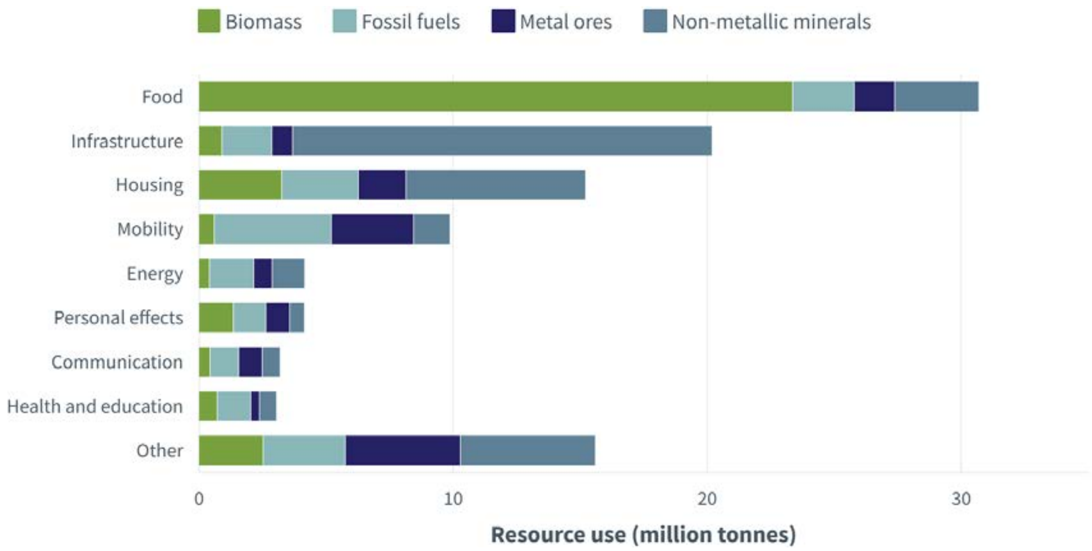
The results are unsurprising (Figure 4.4). A set of core basics – food, housing, infrastructure and mobility – account for 72% of New Zealand's natural resource consumption.[80] A vast range of other items – everything from clothing and personal electronics to education and healthcare – account for the rest.

These results naturally raise questions about where the opportunities to reduce New Zealand's resource footprint might lie. In that respect, it is worth remembering that each of the 'provisioning systems' shown in Figure 4.4 is far from homogenous. A particular service can be provided in a range of ways, and some of those ways are less resource intensive than others.

78 Miatto et al., 2024.
79 See Sense Partners, 2024, p.26–28.
80 The headline figure is similar to that reported for high-income countries as a whole in IRP (2024, Figure 2.20). However, food appears to account for a relatively large share of New Zealand's resource footprint, while the share accounted for by mobility appears relatively low. This may simply reflect differences in the classification systems used in the two studies.

Mobility provides one example. Hatchbacks, station wagons and utility vehicles (SUVs and utes) are all widely used for day-to-day commuting in New Zealand. In some ways, each body type provides a similar service to its owner. But they also come with quite different material requirements. The average weight of hatchbacks imported to New Zealand during the first half of 2024 was around 1.2 tonnes, for example.[81] The equivalent figures for station wagons and utility vehicles were 1.66 and 2.15 tonnes, respectively. Those weight differentials largely reflect differences in the amount of steel and aluminium required for each body type. The differentials would be greater again if the iron ore, coal and bauxite required to produce that metal was taken into account.

Housing provides another example. In 1991, standalone dwellings accounted for 70% of all new builds and had an average floor area of 149 square metres.[82] Apartments, townhouses and units accounted for the remaining 30% of new builds and had an average floor area of 105 square metres. By 2019, the relative share of standalone dwellings had decreased slightly (to 67% of all new builds), with a small but equivalent increase for apartments, townhouses and dwellings. The average floor area of both build types increased, presumably while still providing the same basic accommodation services to their owners.[83] While the material requirements of those larger dwellings are difficult to quantify, all else equal they will be larger than those for smaller ones.



Source: Based on analysis by Sense Partners, 2024

Figure 4.4: Natural resources in New Zealand final demand by system of provision.

81 Ministry of Transport, 2024.
82 Stats NZ, no date-c.
83 By 30% in the case of standalone dwellings, and 5% in the case of apartments, townhouses and units.

As noted above, the analysis also estimated the resource footprints of the 197 product groups contained in the Stats NZ – Tatauranga Aotearoa input-output tables.[84] At that level of granularity, the following hotspots emerge.

- Residential construction required the mobilisation of 7 million tonnes of natural resources, around a third of which was sand and gravel and a quarter of which was wood. Another 3.5 million tonnes were required for non-residential construction.
- Sugar, cocoa and chocolate required the mobilisation of 6 million tonnes of natural resources, 75% of which was sugar cane. Spending on meat required another 4 million tonnes of resources, mostly grazed biomass.
- Motor vehicles required the mobilisation of 4 million tonnes of natural resources. Another 4 million tonnes of petrol and diesel were required to power them.[85]

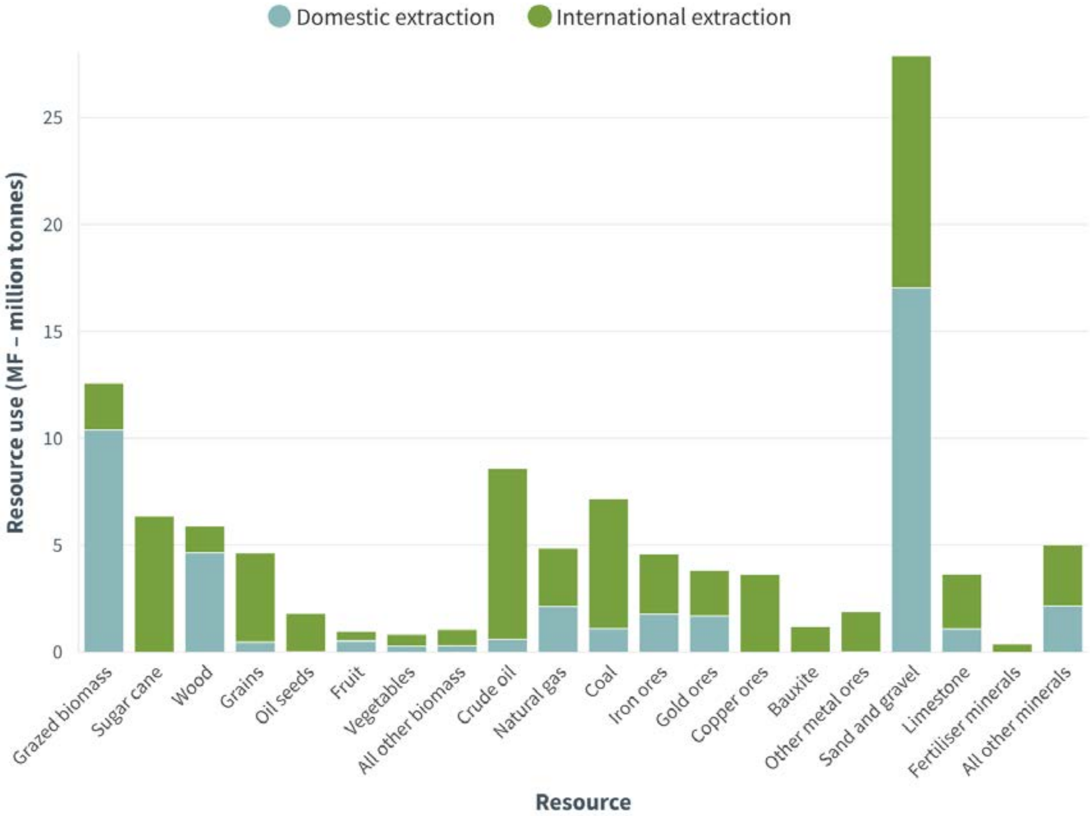
Key finding #3: Consumption in New Zealand relies heavily – and in some cases entirely – on resources extracted in other countries.

The quantity of natural resources that are mobilised in the production of goods and services consumed in New Zealand (107 million tonnes) is not all that different to the quantity of natural resources extracted in New Zealand. That high-level picture masks important differences for individual resources, however.

As shown in Figure 4.5, a large share of the grazed biomass, wood, and rock, gravel and sand consumed by New Zealanders is sourced domestically. That is not surprising. New Zealand has large and internationally competitive food and forestry sectors, it would be unusual if large quantities of these resource inputs were sourced from abroad. At the same time, the low value-to-weight ratio of rock, gravel and sand means it does not tend to be widely traded internationally.

In contrast, there are other resources for which New Zealand's consumption relies heavily on the rest of the world. Crude oil, metal ores (with the exception of iron and gold ores), fertiliser minerals, sugar cane and oil seeds are all good examples.

84 Stats NZ, 2021.
85 MBIE, 2024b.



Source: Based on analysis by Sense Partners, 2024

Figure 4.5: Natural resources in New Zealand final demand by origin.[86]

There is nothing particularly unusual about New Zealand's reliance on the rest of the world for certain natural resources. Among other things, regional differences in mineral endowments and growing climates mean that all countries rely on international supply chains to a greater or lesser extent. In that context, it is worth remembering that New Zealand's reliance on other countries for some resources is mirrored by our role as a significant exporter of other resources. Based on the analysis undertaken for this report, 65% of the natural resources extracted in New Zealand ultimately end up in exports. Unsurprisingly, the ratio is even higher for certain types of biomass – approaching 80% for grazed biomass and wood.

The deep integration of most national economies within the global economic system makes it easy to lose sight of the impacts that consumption decisions in one country have on the natural environment in others. It is doubtful, for example, if international consumers of food and fibre produced in New Zealand are aware of the impacts that these industries have had on New Zealand's freshwater quality. Likewise, how many New Zealanders are aware of the far afield environmental impacts of metals, sugar cane and oil seeds we source from elsewhere? The latter two have been linked with deforestation and biodiversity loss, while metal extraction – if done poorly – can lead to high levels of toxicity in the vicinity of mine sites and processing facilities.[87]

86 Note: MF = material footprint.
87 For example, see Goldman et al. 2020.

Key finding #4:
The share of New Zealand's resource requirements sourced from the rest of the world has increased over the last three decades.

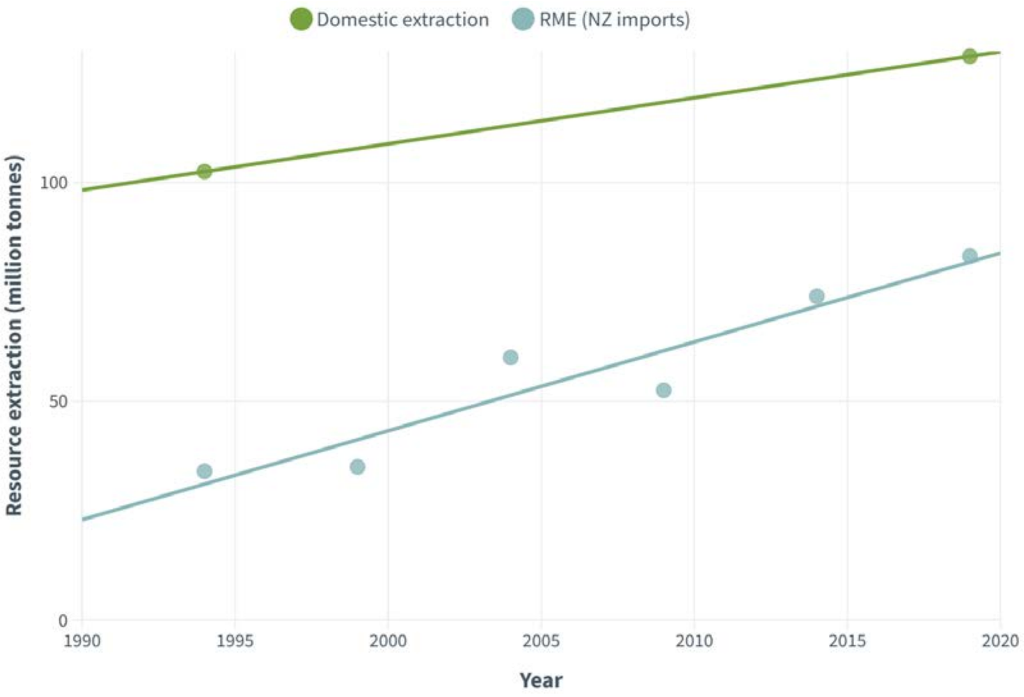
The quantity of natural resources embedded in New Zealand's imports more than doubled between 1994 and 2019 – from 35 million tonnes to 83 million tonnes (Figure 4.6). In contrast, domestic resource extraction increased by only 25% during the same period – from 103 million tonnes to 129 million tonnes.[88] In short, the share of New Zealand's natural resource requirements sourced from the rest of the world appears to have increased significantly over the last three decades.

The key driver of New Zealand's growing claims on the rest of the world was import spending, which more than tripled in nominal terms over this period.[89] The fact that the resource content of imports grew at a slower rate may in part reflect inflation in the price of the goods and services imported to New Zealand. That said, official import price deflators do not suggest that was a major factor between 1994 and 2019.[90]

An alternative explanation is that the resource intensity of New Zealand's imports has fallen in real terms, either because global production systems are using natural resources more efficiently or because the composition of New Zealand's imports has shifted towards less resource-intensive products. A preliminary decomposition analysis undertaken by Sense Partners suggests that the former – a more efficient use of natural resources by global production systems – was more important.

Whatever the case, it seems clear that the improvements in domestic resource efficiency discussed in chapter three have been at least partially offset by an increase in the resource content of imported goods and services. That is consistent with an emerging body of evidence that some of the decoupling documented in high-income countries (using production-based measures of resource use) has been achieved by importing resource-intensive products from abroad.[91]

88 The analysis undertaken by PCE in chapter three suggests a slightly larger increase took place between 1990 and 2019 – from 97 million tonnes to 135 million tonnes.
89 Stats NZ, no date-d.
90 RBNZ, 2024.
91 Wiedmann et al., 2015; Hubacek et al., 2021.



Source: Based on analysis by Sense Partners, 2024

Figure 4.6: Domestic extraction and resource content of imports compared 1994 and 2019.[92]

Key finding #5:
Services have a smaller resource footprint than goods, but are certainly not 'weightless'.

A widely observed phenomenon in developed countries over the last few decades has been an ongoing shift from goods to services. This is visible in economic statistics describing the share of services in domestic output.[93] It is also visible in statistics on the share of services in economic consumption, which suggests that the relocation of some manufacturing to emerging economies has not been the only factor involved.[94]

There is an idea in the sustainability literature that this shift will help to reduce societal resource and waste footprints.[95] The underlying logic is that services are relatively 'weightless' or 'dematerialised' relative to goods. Consider subscriptions to streaming services or a ticket to the movies, for example.

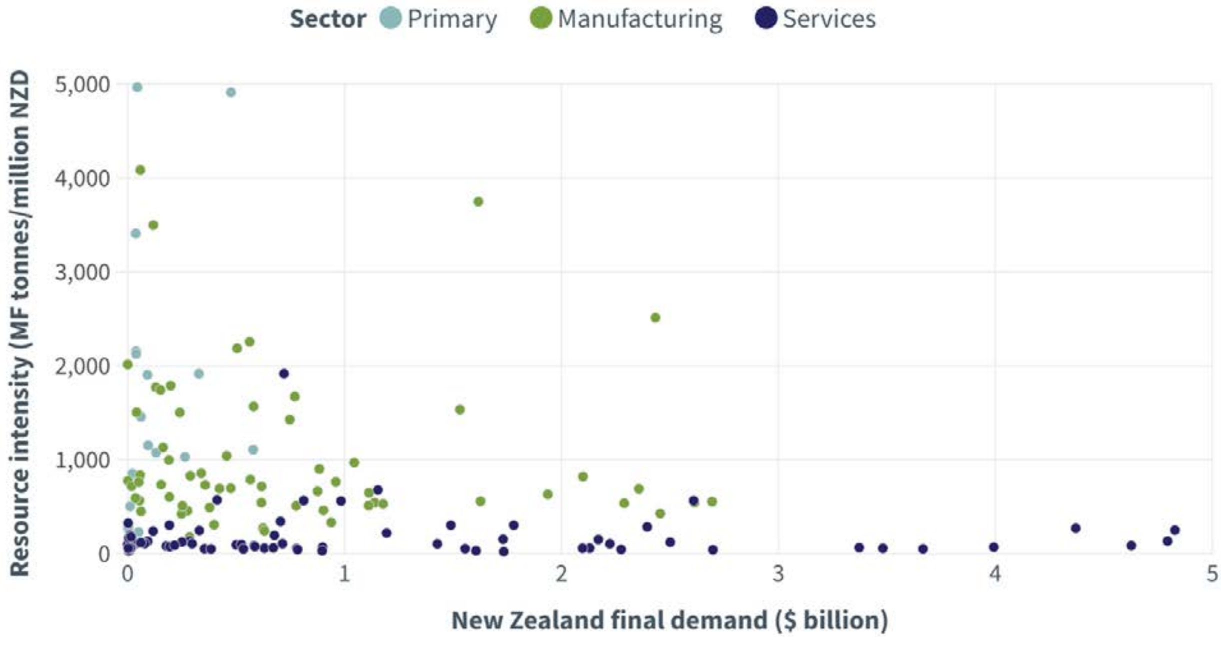
The analysis undertaken by Sense Partners for this report allows the resource intensity of the goods and services consumed by New Zealanders to be compared. Furthermore, because the analysis extends to the supply chains that sit behind individual industries, it accounts for the broad range of inputs that are required in the production of final goods and services.

92 Note: RME = raw material equivalent.
93 World Bank, 2024.
94 In New Zealand, for example, the share of services in household final demand increased from 48% in 1990 to 55% in 2019 (Stats NZ, no date-e).
95 For example, see Fix, 2019.

The resource intensities of the 197 manufactured goods and services contained in the Stats NZ input–output tables are shown in Figure 4.7. On average, one million dollars of manufactured goods consumed by New Zealanders in 2019 required the mobilisation of around 1,100 tonnes of natural resources. The equivalent figure for services was around 200 tonnes. This suggests that services, while not completely weightless, do have a significantly smaller resource footprint per dollar than manufactured goods.

An important caveat to this conclusion is that the analysis does not account for the fact that the provision of services always relies on earlier investments in capital goods. In the case of the streaming services mentioned above, server farms are required to store data and network infrastructure is required to distribute them. In the case of a ticket to the movies, a screen and projector is required, as well as a theatre for customers to sit in. If these capital goods were accounted for, the resource footprint of services would be higher than what is shown in Figure 4.7.

Services are not unique in this respect. Making manufactured goods also requires earlier investment in a range of capital goods – factories, machinery, computers, etc. Whether these requirements are greater or smaller than those for services remains an open question.



Source: Based on analysis by Sense Partners, 2024

Figure 4.7: Resource intensity of goods and services in New Zealand final demand in 2019.[96]

96 Note: MF = material footprint.

New Zealand's hidden plastics problem

Plastics pollution is a rapidly emerging environmental issue. It has resulted from the dramatic increase in plastics use that has occurred over the last three or four decades and the inability of waste management systems to cope with the waste products that inevitably result.

Reducing the flow of plastic waste into the environment in a cost-effective way requires an understanding of (i) the key sources of plastics waste and (ii) the pathways along which it travels. As the Prime Minister's Chief Science Advisor (PMCSA) put it in a recent report on plastics:

> *"Measuring the amount and types of plastic we use and discard is a prerequisite for appropriate management and monitoring – it is a vital step in allowing us to make evidence-informed decisions around where we direct resources to improve our use and management of plastic, and to track their effectiveness.*[97]*"*

In theory, quantifying plastic flows in New Zealand should be reasonably straightforward. Primary resins are not manufactured domestically and, as such, trade data should provide good insights into the quantity of plastics that enter New Zealand's economy each year. PCE undertook such an analysis as part of the literature review published in early 2024 and found that New Zealand imported 460,000 tonnes of plastic in 2019.[98]

That estimate is almost certainly a minimum, however. It extended to imports of primary plastic resins and semi-manufactures, but not to the vast array of more complex plastic-containing products that are ubiquitous in modern societies (vehicles, appliances, paints, furniture, etc).[99] *A priori*, it seems reasonable to think that these 'hidden' plastic flows could account for the bulk of New Zealand's plastics use – and therefore potentially also waste generation.[100]

PCE engaged Eunomia and Whirika to undertake further analysis on this issue. To do so, they developed a bottom-up methodology that combines data on the plastic intensity of individual products with trade data on the quantities imported. Eighty-eight individual products were assessed and ultimately combined into one of twelve headline categories: clothing, electrical equipment, footwear, furniture, instrumentation, machinery, medical, paint, rubber, textiles, toys and recreational equipment, and vehicles.[101]

As far as we are aware, this analysis provides the most complete picture of New Zealand's overall plastics use profile currently available.

It is not perfect, however. The analysis required a number of simplifying assumptions to be made, all of which have the potential to introduce error. The fact that available trade data does not always denominate imports in units of mass was particularly problematic. This necessitated the use of conversion factors to align data on import quantities with data on plastic intensities. The assumption that each of the 88 individual products analysed are homogenous is also likely to have introduced error. A full discussion of these (and other) issues is included in a technical report available on the PCE website.[102]

97 Office of the PMCSA, 2019, p. 202. Or, as research by White and Winchester (2023), has highlighted, the value of focusing policy attention on packaging waste (for example) may be questionable if other products (e.g. clothing and textiles) represent a more important source of plastics waste.

98 PCE, 2024, p.16.

99 'Semi-manufactures' refers to a broad range of simple plastic products: pipes, hoses, films, plates, etc.

100 This nomenclature is from Birkbeck et al. (2023), who distinguish between non-hidden, semi-hidden and hidden plastic flows.

101 Stoner et al., 2024.

102 Stoner et al., 2024.

Key finding #1:
There is far more plastic in complex products than in packaging.

The analysis undertaken by Eunomia and Whirika suggests that New Zealand imported 1.5 million tonnes of plastic in 2022. Around two thirds of that plastic was contained in complex manufactured products, with vehicles and tyres, textiles and clothing, and electrical equipment the largest sources by weight (see 'Key finding #2' below). Imports of primary resin, plastic semi-manufactures and packaging make up the remaining third.

The analysis sheds light on the different pathways that plastics take through the New Zealand economy (Figure 4.8).

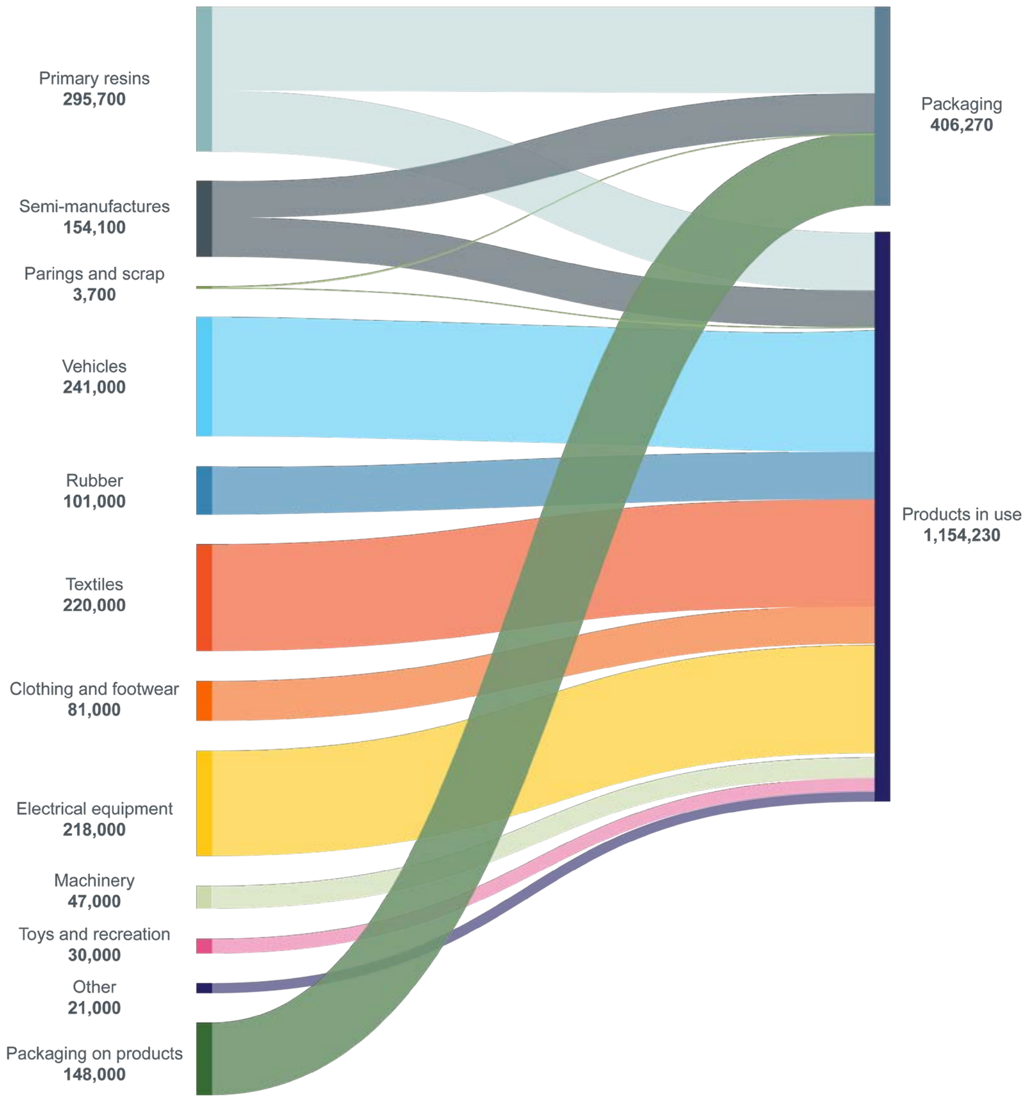
Around 400,000 tonnes ultimately becomes packaging, much of which has a short use life and will be disposed of relatively quickly. Packaging therefore accounted for around 25% of New Zealand's total plastic use in 2022 – a very similar proportion to that calculated in a recent study in Australia.[103]

However, most of the plastics entering the New Zealand economy are contained in products themselves – everything from toys and musical instruments to vehicles and heavy machinery. These products – and the plastics they contain – become part of an 'in-use stock', and will only emerge as waste when owners deem them to be no longer useful. The typical use life of products varies widely – months or years for some clothing and footwear, years or decades for appliances and vehicles.

In the context of plastics, much of New Zealand's recent circular economy and waste policy has focused on packaging (and other single-use plastics). The creation of a mandatory product stewardship scheme for plastic packaging is one example.[104] Product bans affecting plastic bags, food and beverage packaging, straws and labels is another.[105]

There are good reasons for that focus. The likelihood of plastic packaging making its way into the natural environment may well be higher than the plastic contained in end-of-life vehicles or appliances, for example. At the same time though, the analysis undertaken for this report suggests that existing policies only extend to a small proportion of New Zealand's overall plastics use (and associated plastic pollution). That raises a question as to whether there would be value in expanding the policy focus to those products – vehicles, clothing and textiles, and electronics – that account for the bulk of New Zealand's plastic use.

103 O'Farrell et al., 2022, Table 11.
104 Sage, 2020.
105 MfE, 2023a, 2023b.



Source: Based on analysis by Eunomia and Whirika (Stoner et al., 2024)

Figure 4.8: New Zealand's plastic imports (tonnes) by source in 2022.

Key finding #2:
The largest components of New Zealand's plastic use – vehicles and textiles – are also key sources of microplastics.

The analysis undertaken for this report suggests that vehicles and tyres (~340,000 tonnes of plastic), and textiles and clothing (~300,000 tonnes of plastic) rival packaging as the largest components of New Zealand's plastic use.

Internationally at least, both product categories have been identified as key sources of microplastic pollution.[106] In the case of vehicles, this arises from tyre abrasion that occurs during vehicle use. With textiles and clothing, it is due to microfibre shedding that happens when synthetic fabrics are worn, used or washed.

In the New Zealand context, microplastic pollution has been documented in coastal environments, at remote locations in the Southern Alps, in urban streams and air, and in a number of wild fish populations.[107] While the sources of these plastics – and how they make their way into the environment – remains poorly understood, a number of these studies identify microfibres derived from textiles and clothing as a significant component of the overall plastic flux. More research is needed, but it may be that a relatively simple 'end of pipe' solution – either targeting households or wastewater treatment plants – could capture at least some of the fibres derived from textiles and clothing before they enter the environment.

106 OECD, 2021; Thompson et al., 2024.
107 NIWA, 2021; Ghanadi et al., 2024; Aves et al., 2024; WAI Wanaka, 2024; ESR, 2023; Fan et al., 2022; Rotman, 2020; Clere et al., 2022.

From resource use to environmental harm: a system dynamics approach

The insights presented in the previous chapters centre on the quantity of natural resources that make their way through the New Zealand economy each year. While this is crucial information, it tells us little about how these resource flows translate into environmental pressure. Detailed material- and place-specific studies would be needed to assess these environmental impacts quantitatively. However, by recognising that resource use and material flows are part of complex systems, we can explore the resulting environmental pressures through a qualitative lens.

PCE engaged the consultancy Deliberate to better understand the key environmental pressures associated with the extraction, processing, use and disposal of natural resources in Aotearoa. Deliberate used a qualitative system dynamics approach for this work. This was informed by input from 12 experts selected by PCE based on their expertise across different environmental domains: nutrient losses, habitat loss, greenhouse gas emissions, plastic pollution, chemical releases, particulate matter and solid waste.[108]

The work resulted in four causal diagrams that articulate feedback loops between resource use, material flows and the environment. The first causal diagram is an overview diagram that articulates the main feedback pathways influencing environmental pressures and their broader impacts. Three more detailed diagrams explore how resources and material flows lead to environmental pressures within the thematic areas of (1) plastics and the chemicals associated with them, (2) pharmaceutical use in humans and animals, and (3) water availability. Readers can view the diagrams and their detailed description in the consultant report.[109]

The process of conceptualising resource use and material flows using the system dynamics methodology provided valuable insights as an exercise in itself. The system dynamics approach usefully conceptualised how the New Zealand economy relies on natural resource use and how this use exercises pressure on the natural environment through complex feedback loops. We discuss these dynamics more thoroughly below to contextualise the key finding from this report.

How the New Zealand economy uses natural resources and exerts pressure on the environment

New Zealanders use natural resources every day. They are the foundation of what underpins our societal wellbeing and quality of life. Natural resources provide us with food and shelter, heat our homes and move us around, provide recreational spaces and cultural identity, and so much more. However, the extraction, processing and use of these resources also creates an array of wastes and pollutants, many of which put substantial pressure on the environment. The resulting environmental change then has a range of impacts (direct and indirect) on the economy and our wellbeing.

The assimilative capacity of the environment to absorb our society's pollution and waste streams is limited. Once exceeded, it can seriously affect the ability of our renewable resources to regenerate, which is linked to our wellbeing. For example, a reduction in water quality in the marine environment can reduce ecosystem health and affect the ability of fish stocks to regenerate.

108 See Connolly and Fitzgerald (2024) for a detailed description of the methodological approach, including engagement with experts over the three sessions.

109 Connolly and Fitzgerald, 2024.

Importantly, many environmental systems experience delays and lags before the effects of pollution and wastes become apparent. When environmental impacts are finally detected, they may often only be the first indication of larger flow-on effects already underway but yet to fully present. This insight is an important demonstration of the value of conceptualising resource flows and environmental pressures – if we rely only on measurement, it is always retrospective (the impact is already here).

Changes in the environment can also limit human and economic activity, and negatively affect human health. Resource use interacts with wider economic and human activity in complex ways. Environmental pressures are predominantly driven by these socio-economic dynamics, not the environment itself – the problem is us.

Plastics provide a useful example. Rapid growth in plastic demand since the 1950s has led to more plastics in use (e.g. in the built environment or to assist food production). These plastics can leach various chemical additives, negatively affecting human health. Some of these health effects are known – for example, some plastics and/or their additives are carcinogenic, some disrupt the human endocrine function, and others are sources of systemic inflammation.[110] From human use, these plastics and their additives have multiple ways of entering the environment and ultimately putting pressure on it, reducing ecosystem health.

110 See Abril et al., 2020.

Key finding:
New Zealanders use three main strategies to reduce the impact of resource use on the environment – all three are technology-driven and have limitations.

Different ways to address some of the environmental impacts of our resource use have been developed. Three recurring strategies were identified within the three subject areas and the broader discussion among the experts.

- Containment/capture of pollutants and wastes before they enter the natural environment.
- Substitution of one resource with a potentially less polluting one.
- Improved efficiency of existing resource uses.

There are several well-known success stories associated with each strategy. The development of modern wastewater treatment systems has greatly reduced the disposal of untreated human waste into the environment, along with the associated public health burden. Switching from chlorofluorocarbons (CFCs) to hydrofluorocarbons (HCFCs) has meant the ozone hole has started to decrease in size. The vastly improved efficiency of modern internal combustion engines has meant less carbon dioxide in the atmosphere than would otherwise have been the case.

As we discuss further in the case studies below, however, none of these strategies are perfect, with each having the potential to result in complacency, burden shifting or rebound effects.

Containment and capture of pollutants and wastes before or as they enter the environment

The first strategy identified is the containment or capture of pollutants and wastes before or as they enter the environment to minimise their impact. This can include materials at their end of life, such as household waste going to landfill, or carbon capture and storage. This strategy is driven by human innovation and technology and has in many cases been highly successful in minimising contamination and the associated negative environmental and human health implications. The environmental risk arises when the capture or containment is imperfect – for example, leaky landfills – creating new or additional pressures on the natural environment, which need to be managed.

Wastewater treatment plants (WWTPs) are another good example of capture and containment of wastes and pollutants. Again, this is imperfect as even state of the art facilities cannot remove all pollutants from wastewater. This can be illustrated through the example of pharmaceuticals entering the environment. People use pharmaceuticals every day, from contraceptives and basic painkillers, to drugs for managing major infections and diseases. Often, very little thought is given to whether and how pharmaceuticals enter the natural environment and what impacts this may have on natural resources. The reason, perhaps, for this lack of awareness is that we think of pharmaceutical use as contained – contained within our bodies, and if not by them, then contained by WWTPs or landfills. Pharmaceuticals used by people, however, can enter the environment in various ways where they cause environmental harm, e.g. on aquatic life.[111] Pharmaceuticals pass through people, both in unmetabolised and metabolised forms, and are then excreted and enter the wastewater system. WWTPs often do not manage to remove the whole parent compound or its metabolites completely. Thus, some pharmaceuticals flow on into the environment with the treated wastewater. In other cases, people incorrectly dispose of expired or unused pharmaceuticals by flushing them down the sink or toilet. This directly introduces them to the wastewater system, where they are similarly not fully removed before being released into the environment.[112]

While wastewater treatment has become more sophisticated over time, it is imperfect. Even when best practice is followed, there is always potential for certain pollutants or contaminants to leak through filters and treatments, accumulating in the environment and subsequently becoming a source of future environmental pressures in the long term. In New Zealand, many WWTPs are old and may not be able to fully remove pharmaceuticals from wastewater before it is released into the environment. Sludge from WWTP is also often moved to landfill where leakages into the environment may also occur. The containment is imperfect.

An example of imperfect containment is the compound 17α-ethinylestradiol (EE2), which is found in the contraceptive pill, menopausal hormone replacement therapy products, and treatments for various hormonal and gynaecological disorders. It is known as an endocrine-disrupting chemical (EDC). EDCs can disrupt the normal endocrine function of aquatic species at very low exposure levels. New Zealand WWTPs can, at most, remove 80–85% of EDCs.[113] EE2 has been identified in rivers around the world. It is well established that low concentrations of EE2, as they typically occur in aquatic environments, can disrupt the sexual development

111 Kidd et al., 2007.

112 See WHO, 2012. Other paths into the environment exist, of course, e.g. when pharmaceuticals are incorrectly disposed of in household rubbish and are sent to landfill or when they are directly disposed of into the environment. Sludge from WWTP is also often moved to landfill where leakages into the environment may also occur. A lot of pharmaceuticals are also used in farm animals and pets, which have their own pathways into the environment. Some of these additional pathways are described in the Deliberate report, see Connolly and Fitzgerald, 2024.

113 Ho et al., 2020.

and reproductive performance of fish, at least under long-term exposure, and that this can translate into a population collapse, affecting the ability of this resource to renew.[114] In addition, compounds such as EE2 can also interact in unpredictable ways with other compounds when entering the natural environment, creating new compounds that are commonly referred to as novel entities, which may entail unknown and unforeseen risks.

Substitution of one resource with a potentially less polluting one

The second commonly used strategy is substituting a polluting resource with a potentially less polluting one to minimise the impact of an activity. A good and effective example of this is the replacement of ozone-depleting substances in refrigerants (such as CFCs and HCFCs) with 'greenfreeze', which is neither ozone-depleting nor greenhouse gas emitting, greatly reducing the impact of refrigeration on the environment.[115] However, not all substitution attempts are as successful, and in some cases the substituting resource may prove just as harmful for the environment or exert new and different pressures in the longer term.

Another example of chemical substitution can be observed with chemical additives in plastics. Plastic use in New Zealand has rapidly increased over recent decades, and as a result, plastic waste has become a pressing environmental issue (see also chapter four). To give plastic different types of properties, chemical additives are bound to it. These chemical additives move with plastics through the value chain. In addition to the harmful environmental impacts of plastics, the chemical additives can become separated from the plastic polymers and enter the environment, where they can become a source of harm in their own right.[116] Leaching of chemicals can happen at various stages of the value chain, including while in use, while recycling or while being processed at a waste facility. Similar dynamics to pharmaceutical leaching apply here. This is well documented for certain chemicals, e.g. bisphenol A (BPA).[117]

One way we have tried to address the harmful impacts of plastic use and its chemical additives is by substituting the problematic resource with a different one. BPA is a case in point. BPA is a well-known EDC. It has frequently been used in the production of plastic products. The high production volumes and disposal of these products have led to widespread dispersal of BPA into the environment. BPA can also leach out when plastic containers are used to store hot foods or liquids.[118] BPA has been used so widely that it is not only present in the natural environment but has also been detected in blood, urine, maternal plasma, fetal plasma and placental tissue.[119] Its association with human diseases, such as diabetes and breast cancer, is contested.[120] Today, BPA has been phased out from many plastic products and has been substituted with BPA analogues called BPB, BPS, BPF and BPAF, to achieve similar properties.[121] However, subsequent studies have shown that BPB, BPS, BPF and BPAF show similar toxicities for the environment and humans as BPA and that they just as easily spread into the environment, food and the human body.[122] This is a classic example of how 'today's problems come from yesterday's solutions', which is a risk when we substitute materials.

114 Länge et al., 2001; Kidd et al., 2007; Schäfers et al., 2007.
115 Gschrey et al., 2018.
116 See Hahladakis et al. 2018.
117 For example, see Huang et al. 2020.
118 de Paula and Alves, 2024.
119 Schonfelder et al., 2002; Vanderberg et al., 2010.
120 EFSA 2023; EFSA 2024; FDA 2014; Lambré et al., 2023; Vom Saal and Vandenberg, 2021.
121 Bisphenol B (BPB), bisphenol S (BPS), bisphenol F (BPF) and bisphenol AF (BPAF).
122 Cano-Nicolau et al., 2016; Chen et al., 2016; Huang et al., 2020.

There are thousands of chemical additives that are classified as hazardous or that do not have any hazard data available.[123] We do not know how they interact with the environment or how they interact with each other once they enter the environment or while they are decomposing. There is a real risk that many of these chemicals are highly hazardous to the natural environment and human health. A recent report on planetary boundaries identified this risk from “truly novel anthropogenic introductions to [the] Earth system” as stemming from the lack of safety assessments for many of the chemicals currently in use.[124] So, even when substituting one chemical additive with another one, in the absence of a comprehensive risk assessment, there is a real danger of creating new or cumulative pressures on environmental and human health.

One of the most prominent examples of substitution is the invention of the plastic bag. Swedish engineer Sten Gustaf Thunlin invented the plastic bag, which was patented by the Swedish company Celloplast in 1965. The plastic bag quickly began to replace paper and cloth bags in Europe and then across the world.[125] Anecdotally, Thunlin is said to have invented the plastic bag as a reusable substitute for the largely single-use paper bag, which was associated with deforestation across Europe. In the New Zealand setting, this trend is now being reversed, as single-use plastic bags have been phased out.[126]

Improved efficiency of existing resource use

The third strategy identified is improving the efficiency of an existing activity to minimise its impact. Through research and development, we can find alternative ways of doing the same thing but using less, therefore reducing our resource use and impact on nature.

In the agricultural sector across Aotearoa, the efficiency of irrigation water use is becoming an increasingly important topic. Climate change is shifting weather patterns, New Zealand is set to get hotter, and we are observing both more frequent and more intense droughts.[127] This will put further pressure on water resources for primary production. In New Zealand, like elsewhere, the intensification of agricultural production has led to a greater effort to improve water use efficiency. This has been achieved through technological efficiency gains (e.g. more efficient irrigation equipment) or the introduction of crops and pastures with a lower water use profile (e.g. through cultivar selection or breeding). This, in turn, has led to increased water efficiency gains (a reduction in the water intensity of agricultural production), which has reduced agricultural water use.

However, there are limits to these efficiency gains as additional efforts produce diminishing returns. This is because an activity that uses a resource (e.g. plants needing water) will always need that resource, no matter how efficient it becomes. As such, improvements in efficiency can reduce resource flows, but only to a point. For example, the move from border-dyke irrigation to sprinkler irrigation on many Canterbury dairy farms has drastically improved irrigation efficiency, however, there is a limit to further efficiency gains as pasture in Canterbury relies on irrigation.

In some cases, these efficiency gains may induce a rebound effect and result in more of the resource being used (often referred to as ‘Jevon’s paradox’). Technical efficiency gains often result in changes in social expectations of what is possible from the more efficiently used resource, perversely resulting in more of the resource being used. In the case of water, improvements in terms of water use efficiency may lead to more production or more intensive production. In the case of irrigation, this

123 Wagner et al., 2024.
124 Richardson et al., 2023, p.6.
125 UNEP, 2021a.
126 See MfE, 2023b.
127 Daalder, 2024.

could mean that the efficiency gains made with irrigation equipment allow farmers to sow more pasture and stock more animals. As such, despite the efficiency improvements, no water is 'saved' or returned to the environment, as it is reused within the farming operation.[128]

Another prominent example of a rebound effect relates to energy use. As more energy-efficient technologies become available, their cost reduces and people tend to increase their consumption, which leads to an overall increase in energy use rather than energy conservation. For example, the improvements in the efficiency of air-conditioning have made this technology cheaper to produce and cheaper to run. Consequently, more people are installing air-conditioning units, and more people are running them for longer. As a result, the total amount of electricity to cool buildings has increased, even though individual air-conditioning units use less electricity.[129]

Improving efficiency is crucial to reducing the impact of natural resource use on the environment. However, if we are to decouple wellbeing from resource use, we must pay close attention to the potential rebound effect of efficiency gains.

128 See Grafton et al., 2018.
129 See Owen, 2010.

05

Some final thoughts

A recommendation

This report marks the completion of the first phase of PCE's work programme on natural resource use and waste generation.

Over the course of the last 18 months, we have compiled available data on the impacts of economic activity in New Zealand on the natural world. A range of data and knowledge gaps emerged in the process, and we have commissioned research to try and fill them. Together with research recently published by the Ministry of Business, Innovation and Employment,[130] this has resulted in an improved picture of natural resource flows in New Zealand: where they originate, in what quantities, who consumes them, and how they ultimately emerge as waste. However, that picture remains incomplete on several fronts.

Water is the most important. As discussed in this research note and the earlier literature review, the total quantity of water used in New Zealand's economy remains unknown. There is a lack of information regarding the amount of rainfall taken up directly by plants and pasture to support their growth. This information will become increasingly important in the future as climate change modifies precipitation patterns, potentially requiring more irrigation to support primary sector productivity.

Further, the amount of water abstracted each year in New Zealand is unknown. That is not due to insufficient monitoring – amendments to the Resource Management (Measurement and Reporting of Water Takes) Regulations in 2020 mean that the vast majority of water takes are monitored in considerable detail. Rather, it reflects the difficulty of aggregating the large quantities of information collected by New Zealand's 16 regional and unitary councils to the national level. This limited understanding of water use at the national level represents a major hole in our environmental understanding, one that PCE intends to pursue further in an upcoming report on emerging technologies.

Solid waste is also problematic. As discussed in chapter three, only those waste operations undertaken by (or on behalf of) territorial authorities are required to report on the tonnages of materials being disposed of and recycled. Purely private operations – for example, metal scrap recycling at wreckers yards, office paper recycling, or recycling of construction and demolition waste – are not covered. For as long as that continues, New Zealand's true recycling rates will be difficult to determine with any precision.[131]

These issues aside, official statistics describing a wide range of resource and waste flows in New Zealand are generally of good quality. New Zealand Petroleum and Minerals maintains annual time series data on the quantity of metals, minerals and fossil fuels extracted domestically. The Ministry for Primary Industries does something similar for biomass production. Trade data published by Stats NZ are often denominated in weight as well as value terms. The Ministry for the Environment publishes data on greenhouse emissions and, more recently, on the quantity of solid waste that is sent to (and diverted from) landfill each year.

The estimates of New Zealand's production-based resource use and circular material use rate (CMUR) presented in this report result immediately from the compilation of this information. While both indicators are far from perfect and are currently only snapshots in time (2019/20), they could be easily updated on a regular basis if the underlying data was available in one place.

130 MBIE, 2024a.
131 Plans to expand the monitoring regime to some of these operations were cancelled by the Government in late 2024 (MfE, 2024).

A range of use cases exist for such a platform. One is natural capital adjusted productivity analysis, which is only possible with time series data describing capital, labour and natural resource inputs. Another is circularity analysis, which requires data on resource flows into the economy and waste flows out of it. A third is state of environment reporting, where information about environmental pressures (e.g. waste generation) is arguably just as important as resulting changes in environmental state. Perhaps most importantly though, having a single platform that describes the physical flows from the environment to the economy (and vice versa) would provide a sounder basis for evaluating the overall sustainability of New Zealand's economic system.

With these issues in mind, **there is clear value in New Zealand establishing – and regularly updating – a national material flows platform that brings together information on resource extraction, trade and waste flows in one place**. This need not be an overly onerous or expensive exercise. In its simplest form, such a platform could simply draw together already existing data on domestic resource extraction, physical trade and waste flows. Stats NZ would be well placed to lead such an exercise, particularly given its recent interest in better integrating environmental and economic statistics.[132] However, the various data issues relating to waste and water would need to be addressed for Stats NZ to produce a comprehensive assessment of resource flows.

132 Stats NZ, 2024b.

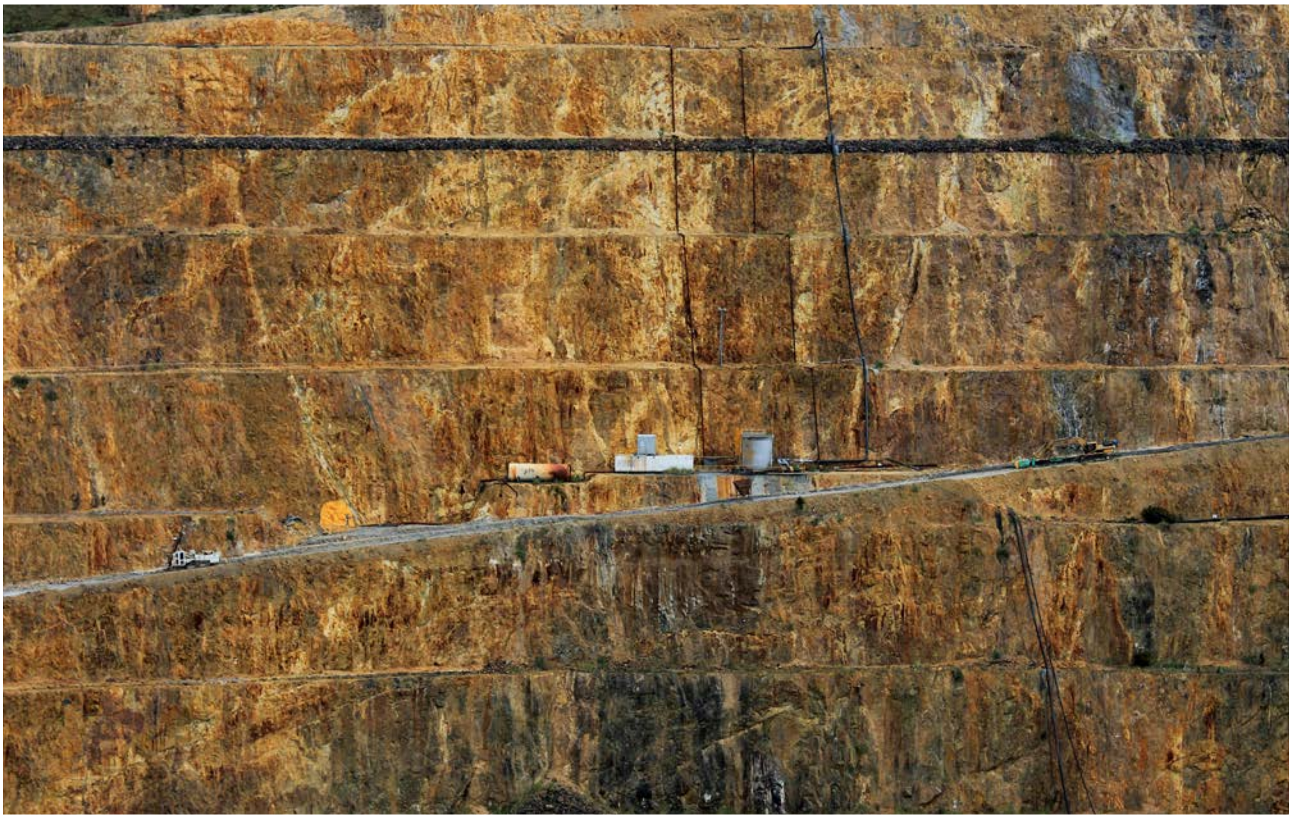
What next?

The focus of PCE's work on resource use and waste generation will now turn to the future. The main objective being to assess how New Zealand's resource use and waste generation might evolve over the next few decades, and what environmental risks might emerge as a result.

The work programme will include two main strands. The first is quantitative and will generate projections of how New Zealand's resource and (to the extent possible) waste footprints are likely to change if mainstream projections of economic growth, demographic trends, technological change and other drivers come to pass. This work will be undertaken within a computerised general equilibrium (CGE) framework similar to that used for the OECD's Global Material Resources Outlook and Global Plastics Outlook, and the International Resource Panel's Global Resources Outlook.

The second strand is qualitative and will use strategic foresight tools to build on the modelling work. Considering the projections generated by the CGE model as well as other data and evidence, this strand will consider how multiple drivers come together to shape a broader range of futures than just the business-as-usual one mentioned above. Qualitatively exploring alternative scenarios will allow us to explore relationships and trends for which we do not have numerical data, including shocks and discontinuities, motivations, values and behaviour.

While this work programme is now well advanced, the Commissioner would welcome any feedback or suggestions on the direction it is taking. The future of resource use and waste generation is inherently uncertain, and hearing from a diverse range of perspectives will help us to make sense of the factors that are likely to be important.



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