Demand for raw materials in New Zealand

A macro view

August 2024

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DATA LOGIC ACTION

1. Measuring raw material use

1.1. Purpose

This report presents estimates of New Zealanders' demand for resources in terms of tonnes of raw materials embodied in goods and services.

This provides a perspective on the sustainability of production and consumption in New Zealand, beyond domestic environmental footprints which are only one part of the picture.

Our estimates illustrate New Zealanders' reliance on global resource extraction. In 2020 New Zealanders demanded 107 million tonnes of raw materials. Of that, 60% was imported.

The main purpose of this report is to explain how we came up with this estimate and what it is made up of.

1.2. Methods

The numbers we present rely heavily on international analyses of resource flows. In particular, the results of a project called GLORIA led by a team from the University of Sydney.

Our contribution has been to use local knowledge to adapt international estimates to better reflect New Zealand data.

Our results should be easier for New Zealanders to use, compared to international sources, because our results are made to match New Zealand statistics on industrial structure and trade.[1]

Our estimates of New Zealand's raw material footprint are smaller than comparable international estimates from the Global Material Footprint Database (GMFD).[2] This is, in the main, because our estimates of domestic extraction of raw materials are smaller than the ones in the GMFD. We prefer our estimates over those in the GMFD because the GMFD uses assumptions about e.g. livestock biomass requirements that are not supported by local evidence.

1.3. Scope and terminology

Raw materials[3]

For our purposes, raw materials mean resources that have been extracted from the environment for use in the economy, in as close to their natural state or point of extraction as possible. This includes:

[1] Stats NZ's most recent, March year 2020, input-output tables.
[2] Global Material Flows Database | Resource Panel
[3] The explanation here is a simplified one, for the purposes of an accessible introduction to the concepts used in this report. For technical descriptions about the scope and terminology for environmental-

- biological products (**biomass**) harvested from the natural environment, such as crops, timber and wild-caught fish
- non-biological products, including
  - **fossil fuels** such as coal and oil
  - **metal ores**, such as iron, copper and gold
  - **non-metallic minerals** like sand and gravel.

When we measure raw materials use, we measure the weight of the raw material when it is extracted. This is also referred to as the raw material equivalent or raw material footprint.

Our numbers thus account for the amount of resources originally extracted along the entire length of supply chains, from a mine to a factory, to a wholesaler and on to the final consumer. Raw materials might be used up or discarded along the way. But we count them in their raw state, as if they were not used up. This allows us to connect final use of resources to extraction at its original scale, at least by weight.[4]

One resource missing from our numbers is bulk extraction of water. It is generally accepted practice in environmental-economic accounting to account for water use separately from other materials.

Final demand

There are two general approaches to measuring resource use. One is the destination (demand) approach and the other is the origin (extraction) approach.

Our focus is on measuring resource use by destination i.e. raw materials used to meet final demand for goods and services in New Zealand. Final demand means end use or last use.[5] It includes consumption and investment. It excludes exports.

An origin measure of resource use would stop at domestic extraction of raw materials within New Zealand, regardless of how those raw materials are used.

Neither the origin approach nor the destination approach is strictly more useful or accurate than the other. They are two blades of the same scissors, each cutting from a different direction. Although origin measures are probably more useful when thinking about regulatory control of environmental effects and destination measures are more useful when thinking about notions of ultimate responsibility or benefits from extraction.

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economic accounting and material flow analysis see e.g. UN et al (2014) System of Environmental-Economic Accounting 2012 - Central Framework; Eurostat (2018) Economy-wide material flow accounts handbook; Stats NZ (2019) Environmental-economic accounts: sources and methods.

[4] Admittedly weight of raw materials is not a good measure of environmental impacts. It is but one indicator of interaction between the environment and the economy.

[5] The final demand numbers are a flow measure, including changes in inventories. Accordingly, a few products have a negative final demand footprint because the main contributor to final demand is a reduction in inventories.

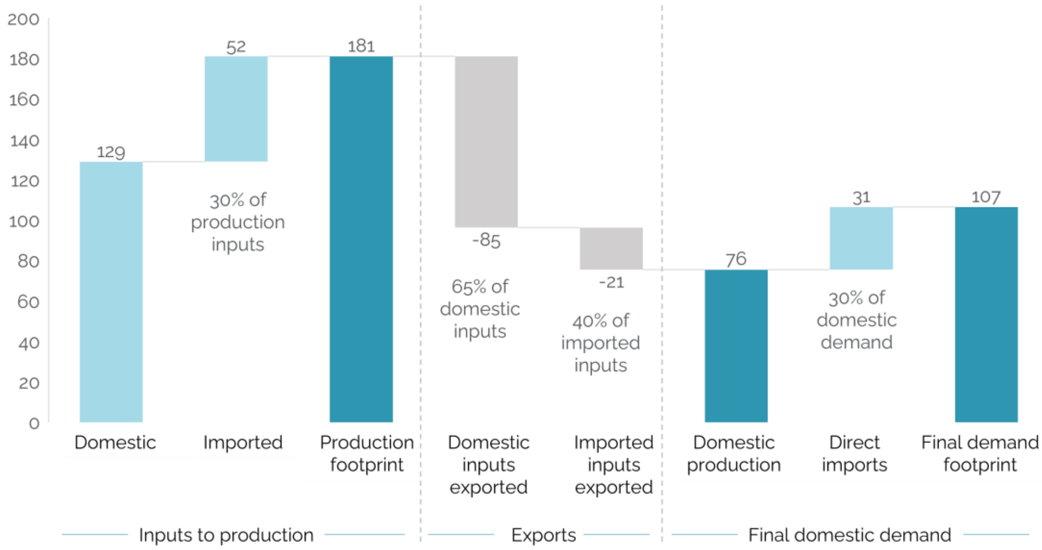
Figure 1 and the summary results in the next section illustrates the relationship between these two approaches.

1.4. Summary results

NZ extracted 129 million tonnes of raw materials domestically

We estimate that New Zealand industry extracted 129 million tonnes of raw materials in 2020. That extraction is directly subject to New Zealand regulation about resource use, and it is what would be counted in New Zealand accounts using an origin measure of resource extraction.

FIGURE 1: MATERIAL FOOTPRINT OF PRODUCTION AND CONSUMPTION
Raw material equivalent megatonnes, March year 2020



NZ industry imported an additional 52 million tonnes as inputs to production

Domestic production in New Zealand used an additional 52 million tonnes of imported raw materials in 2020, for a total domestic production footprint of 181 million tonnes of raw materials.

We could account for imported production inputs as part of New Zealand's use of raw materials. But that would lead to double counting, from an international perspective, because those materials also belong to other countries' production footprints.

If we want to account for use, we need to shift focus from an origin measure of extraction to a destination measure – for logical consistency.

NZ exported 105 million tonnes of raw materials

This means subtracting the amount of raw materials in exports. We estimate 84.8 million tonnes of domestically extracted resources are exported and 20.7 million tonnes of imported production inputs are re-exported; for a total of 105.5 million tonnes of raw materials exported.

The raw material footprint of domestic production for final domestic use is 76 million tonnes. Raw materials extracted domestically make up 44 million tonnes of that (57%) and imported inputs make up 31 million tonnes (43%).

NZ final import demand footprint is 62 million tonnes

To arrive at a total final demand footprint, we add raw materials embodied in goods and services that are imported directly to meet final demand e.g. cars or movies. These add 31 million tonnes. And, in total, New Zealand has a final import demand footprint of 62 million tonnes of raw materials, inclusive of imports imported to make products consumed in New Zealand.

NZ final demand footprint is 107 million tonnes, 60% is imported

All told, New Zealand's final demand footprint is 107 million tonnes. Most of that is imported (60%).

A majority of New Zealand's domestically extracted raw materials end up being used by people outside New Zealand (66%).[6] And, in net, our raw material trade balance is 22 million tonnes (net exports).

New Zealand's import footprint doubled between 1999 and 2019

New Zealand's reliance on raw material extraction overseas has grown faster than price-adjusted GDP in recent decades, except for a decline around the time of the global financial crisis (see Figure 2).

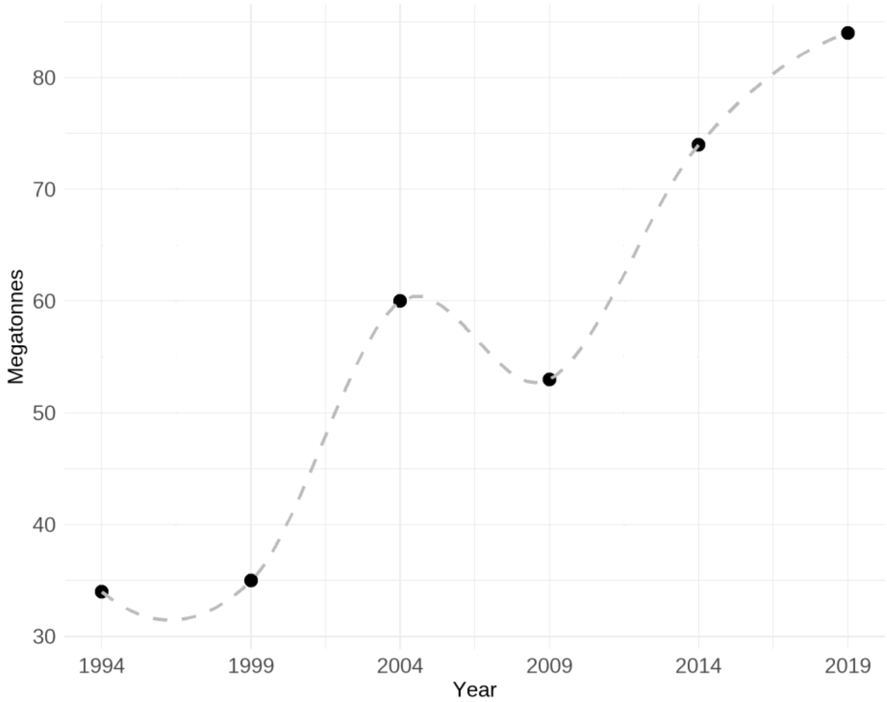
Between 1999 and 2019, the import footprint grew by 4.5% per year on average, compared to average growth in GDP of 3%. This growth amounted to an approximate doubling of the import footprint.

The import footprint of industry output has increased in all industries, though it has been most pronounced in the construction industry which made up approximately one third of the growth in raw materials imported.

[6] More precisely, these are raw materials used by non-residents. This includes tourists in New Zealand, whose spending counts as exports.

FIGURE 2: GROWTH IN RAW MATERIAL FOOTPRINT OF IMPORTS

Raw material equivalent weight of total imports. 5-yearly estimates for 25 years from 1994 to 2019, joined by a smoothed curve (dashed line).



Domestic extraction has not grown in the past 25 years

There has been a gradual increase in domestic extraction in New Zealand over the past 25 years, with periods of both rise and decline and an average growth rate of 0.9% per year (see Figure 3); slower than GDP or population growth.

There is some uncertainty about the precise scale of the change in domestic extraction in the past 25 years (see section 2.2) but the trend accords with the net effect of: declining production of fossil fuels (-0.7% per year); flat livestock production – intensity of livestock production has been increasing on a per animal basis but there has been a long run trend decline in livestock numbers; growth in forest production and quarrying of materials for construction (3% and 1.7% per year respectively).

New Zealand trending towards being a net-importer of materials

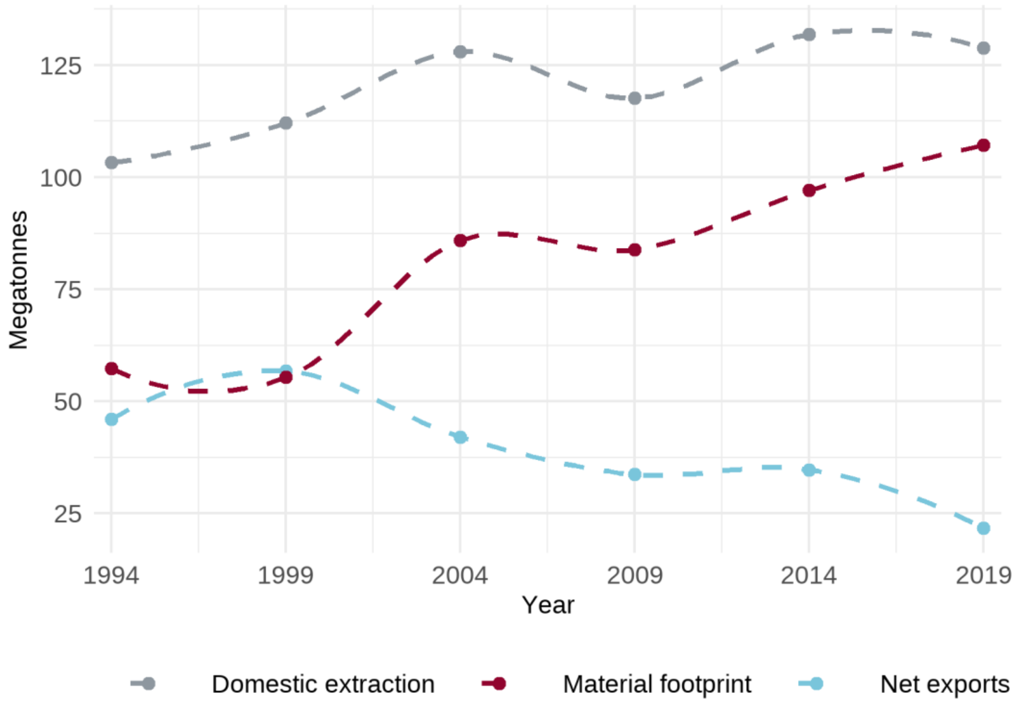
New Zealand has long been a net exporter of raw materials. But this is changing. Indeed, the GMFD reports that New Zealand's raw materials trade balance (net exports) turned negative in 2020 for the first time in the time series of estimates captured by that database (1970-2024). Although, our estimates suggest New Zealand's net exports of raw materials were still positive in 2020 (+16 megatonnes).

Nonetheless, New Zealand's domestic extraction of raw materials has fallen as a share of economic activity. Consequently, New Zealand's exports of raw materials have also fallen. Meanwhile, imports of raw materials have grown and thus, by our estimates, New Zealand's raw materials trade balance has declined rapidly – by 3.8% per annum over the past 25 years (see Figure 3).

The key driver of the increase in import footprint is growth in income and expenditure on imported goods, doubtless influenced by improved purchasing power as many import prices have fallen.

There has also been a gradual trend reduction in the footprint of imports per dollar of spending. But that is small relative to the increase in total import demand and the footprint that comes with that.

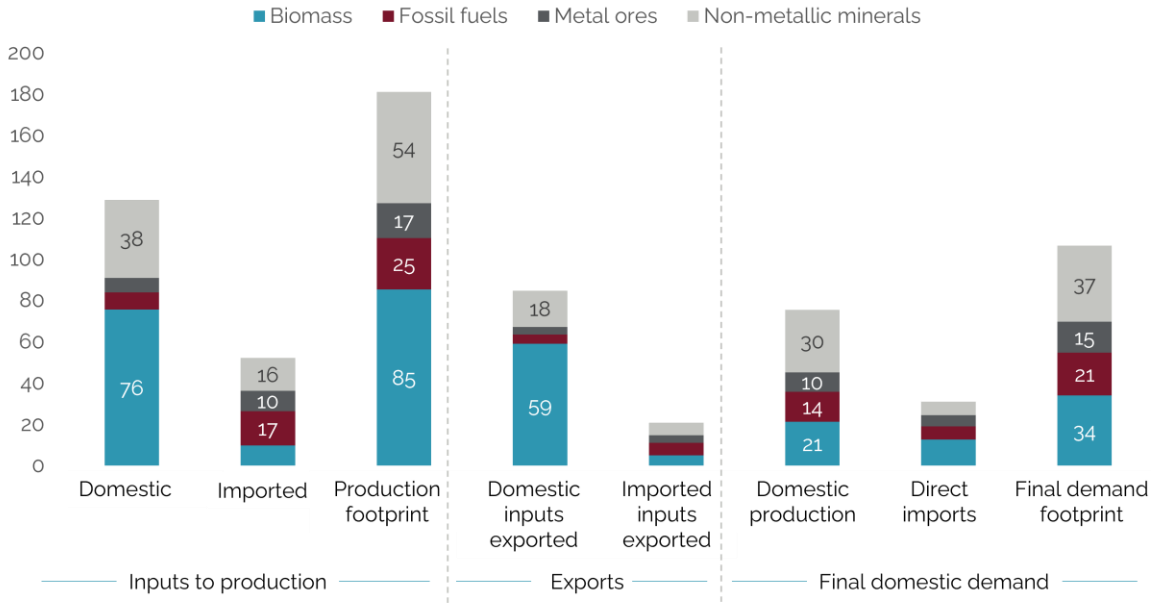
FIGURE 3 TRENDS IN COMPONENTS OF NZ MATERIAL FOOTPRINT
Raw material equivalent weight of total imports. 5-yearly estimates for 25 years from 1994 to 2019, joined by a smoothed curve (dashed line).



New Zealand remains a large net exporter of biomass

New Zealand is a large net exporter of biomass. We estimate that in March year 2020 New Zealand extracted 76 million tonnes of biomass (see Figure 4) – mainly grazed biomass for livestock (51 million tonnes) and wood (18.7 million tonnes). Of those 76 million tonnes extracted, 59 million tonnes was exported (78%).

FIGURE 4: MATERIAL FOOTPRINT OF PRODUCTION AND CONSUMPTION, BY MATERIAL
Raw material equivalent tonnes by raw material group, March year 2020



New Zealand trades biomass for non-renewable resources

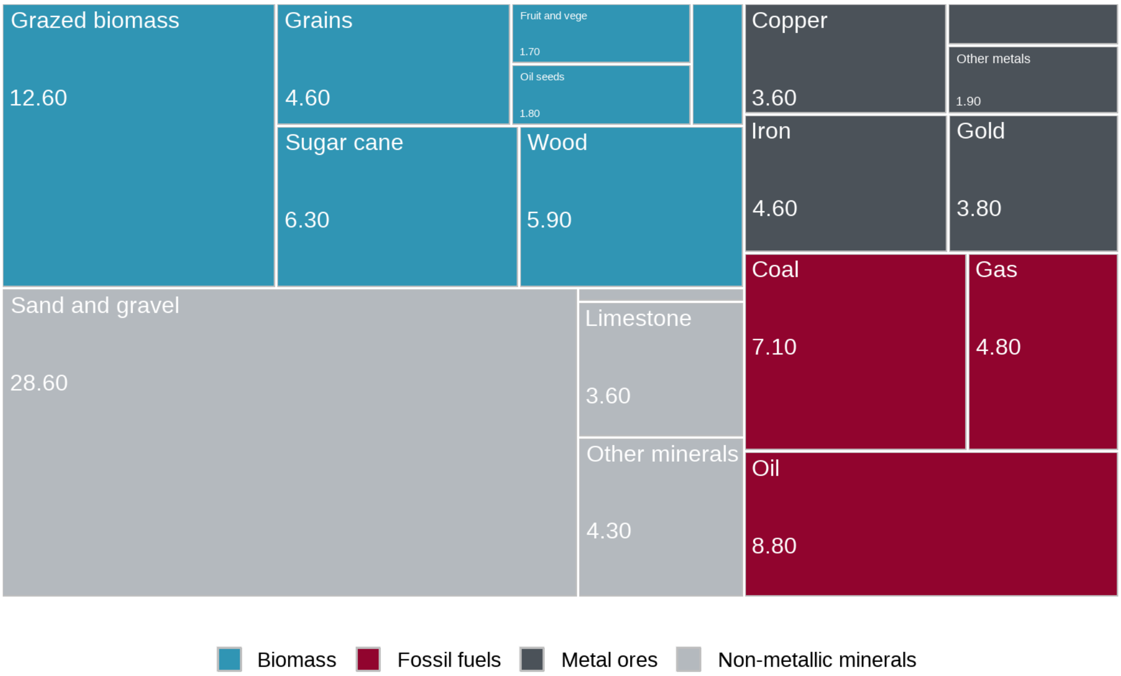
New Zealand's final domestic demand footprint is 60% imported. Within that import footprint, non-renewable resources dominate: 45 million tonnes made up of 17 million tonnes of fossil fuels, 11.6 million tonnes of metal ores and 16.6 million tonnes of non-metallic minerals. As a share of final demand: 82% of New Zealand's fossil fuel footprint is imported, 77% of the metal ore footprint is imported, and 45% of the non-metallic minerals footprint is imported.

Sugar is a notable share of New Zealand's import footprint

Sugar cane stands out as a notable part of New Zealand's consumption footprint and a biomass that is exclusively sourced by imports.

Sugar cane contributes around 6% of New Zealand's final demand footprint and 10% of New Zealand's import footprint (total 6.3 million tonnes, see Figure 5).

FIGURE 5: COMPONENTS OF NEW ZEALAND FINAL DEMAND FOOTPRINT
Numbers are millions of tonnes of raw material equivalents, March year 2020



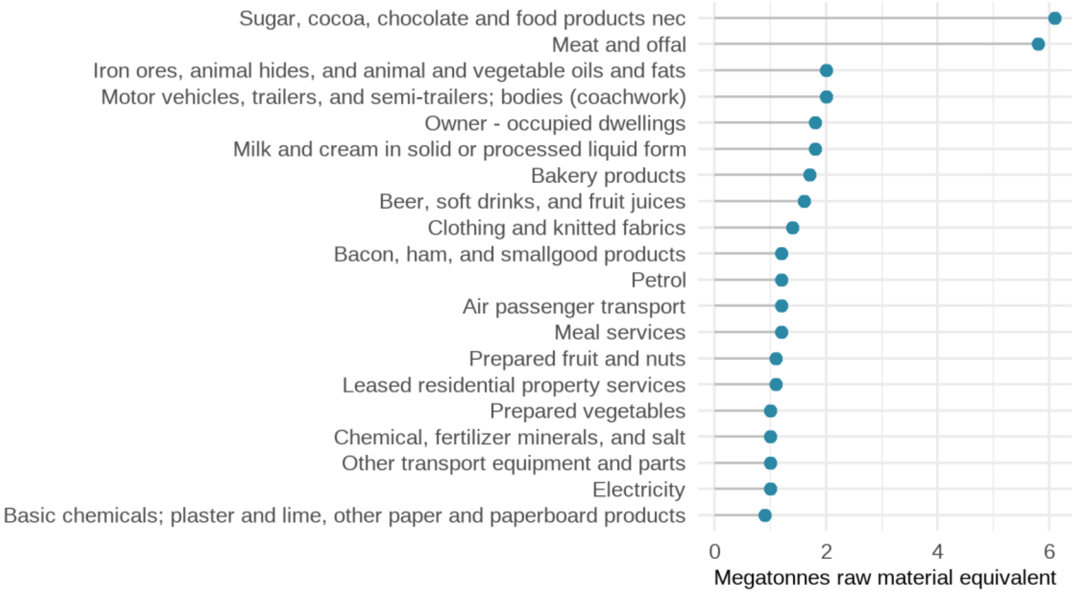
Most of that sugar cane footprint is in food products consumed by households. We estimate that sugar and food products containing sugar are the single largest part of household consumption footprints – larger than e.g. motor vehicles (see Figure 6).

This result is somewhat sensitive to how products are classified – for example vehicle use would have a higher footprint if we combined the footprints of petrol and motor vehicles – but the size of the footprint of "Sugar, cocoa, chocolate and other food products nec" is so large compared to other products that this finding is not likely to be overturned by a different product classification.

The total raw material equivalent weight of "Sugar, cocoa, chocolate and other food products nec" reflects an array of raw materials but 74% of that weight is attributed to sugar cane.

FIGURE 6: TOP 20 PRODUCTS IN HOUSEHOLD CONSUMPTION BY SIZE OF FOOTPRINT

Products defined by the national accounts classification in the Stats NZ supply and use tables

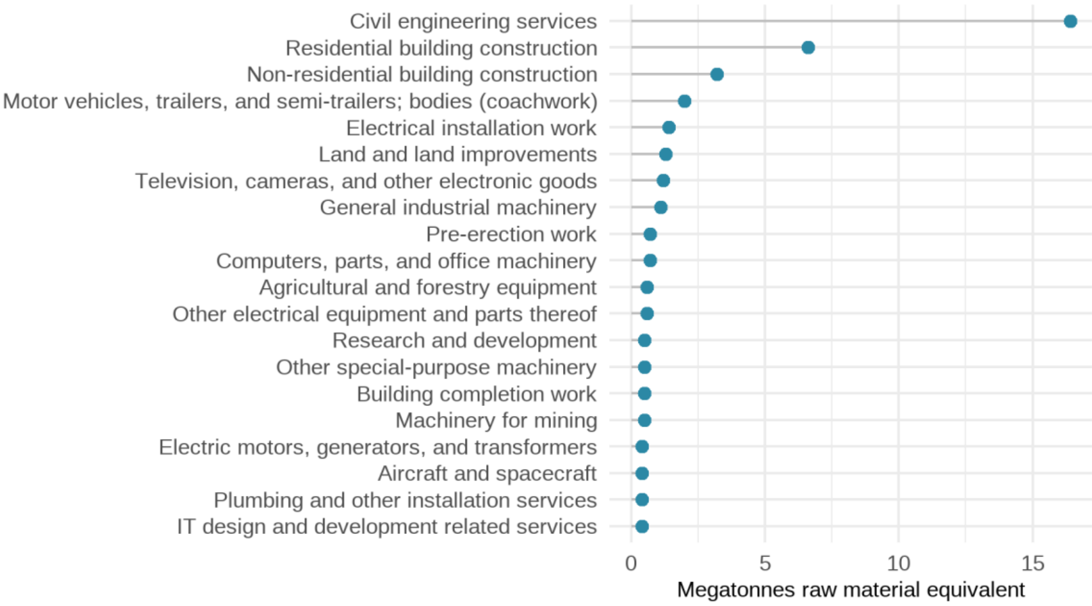


Investment footprint dominated by construction, sand and gravel

Civil engineering services and building construction have the largest investment-related raw material footprint (see Figure 7). Collectively, these construction services have a 29 million tonne material footprint – roughly one-quarter of New Zealand's overall final demand footprint.

FIGURE 7 TOP 20 INVESTMENT PRODUCTS BY SIZE OF FOOTPRINT

Products defined by the national accounts classification in the Stats NZ supply and use tables



2. Method and data

2.1. Summary of approach

Combining international and local data sources

Our estimates of New Zealand's demand for raw materials, in raw material equivalents, are built from three main components:

- estimates of tonnes of raw materials extracted domestically, from a range of mainly local data sources
- estimates of raw material equivalent intensity of goods and services imported into New Zealand, from the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2022), constructed in the Global MRIO Lab (Lenzen et al. 2017)[7]
- March year 2020 benchmarks for inter-industry transactions, the value of imports and final demand from the Stats NZ March year 2020 input output tables.

Inter-industry transactions used to connect extraction to demand

Data on inter-industry transactions are used to trace the path of raw materials through supply chains and to final demands.

The methods used to track those pathways are not novel.[8] They involve making simplifying assumptions about what inputs are required for production and what products are produced with those inputs.

For example, say we observe the amount (tonnes) of sand and gravel extracted by the mining and quarrying industry. To connect that to demand for final goods and services, we go one step down the supply chain and look at purchases of mining and quarrying industry products by customers such as companies in the construction and glass manufacturing industry. Those buyers of sand and gravel then use it to make products that are either used in products for final customers, e.g. building roads, or products sold to other companies who use them to deliver a product for final use, e.g. selling window glass to construction companies building houses.

Tracking these transactions across the entire economy, for many different products and industries, is complex. However, inter-industry transaction data, from input-output tables, provides a short cut.

[7] We use version 59 of the database.

[8] Interested readers are referred to: Lenzen, et al (2022) for a specific example of measuring raw material equivalents; Blair and Miller (2022) for a foundational description of input-output modelling; and UN (2018) for a comprehensive treatment of how to construct and extend national input output models.

If we assume that sand and gravel make up a constant share of the glass industry's purchases and glass makes up a constant amount[9] of the building industry's purchases, we can estimate in a single calculation the total amount of sand and gravel that needs to be extracted to meet an extra dollar of final demand e.g. for housing.[10] Indeed, we can do that calculation for all industries and all raw materials in a single step, taking account of all the direct and indirect demands for raw materials.[11]

TABLE 1: MATERIAL FOOTPRINTS FROM IMPORTED INPUTS, TOP RANKED INDUSTRIES
Ranked by raw material equivalent footprint from imported inputs.[12]

Footprint rank	Imported	Domestic and export demand	Domestic final demand
1	Petroleum and coal product manufacturing	Dairy product manufacturing	Residential building construction
2	Primary metal and metal product manufacturing	Residential building construction	Heavy and civil engineering construction
3	Construction services	Petroleum and coal product manufacturing	Petroleum and coal product manufacturing
4	Dairy cattle farming	Meat and meat product manufacturing	Construction services
5	Fruit, oil, cereal, and other food product manufacturing	Heavy and civil engineering construction	Non-residential building construction
6	Heavy and civil engineering construction	Fruit, oil, cereal, and other food product manufacturing	Fruit, oil, cereal, and other food product manufacturing
7	Fertiliser and pesticide manufacturing	Construction services	Food and beverage services
8	Non-metallic mineral product manufacturing	Non-residential building construction	Hospitals
9	Sheep, beef cattle, and grain farming	Primary metal and metal product manufacturing	Owner-occupied property operation
10	Residential building construction	Food and beverage services	Meat and meat product manufacturing

Table 1 gives a practical illustration of how measures of raw material footprints change, as we trace material use from production to final demand. It shows the top 10 industries for raw material footprints from imported inputs.[13] The first column is the footprint measured at point

[9] To be more precise, the main assumptions of this sort of input-output analysis are constant returns to scale production technologies and no substitution between inputs.
[10] The conventional formulae for doing this are presented in an appendix to this report.
[11] The calculations required to do this preserve the original amount of raw material extracted i.e. the measured amount of tonnes extracted are neither increased nor decreased as the footprint is tracked along the supply chain, only the attribution – to a demand from an industry or product – changes.
[12] Excludes direct imports to final demand and domestic extraction.
[13] A note of caution: these rankings are illustrative only. Industry classification is not a sound basis for analytical comparison across economic activities, even if it is often used that way, because it is sensitive to decisions by Stats NZ (and other statistical agencies) about which activities to group together and those decisions are not made with raw material footprints in mind. Industry classifications are not commensurable.

of import. Petroleum production and metal production are the industries with the largest footprints. However, the output of those industries is mainly used by other industries.

In the second column of Table 1, ranking the footprints of industries serving domestic and export demand, dairy product manufacturing and residential construction take first and second spot with the largest footprints. Petroleum production falls from first ranked to third ranked and metal production falls from 2nd ranked to ninth.

If we focus on domestic demand – New Zealanders raw material consumption footprint stemming from imported raw materials – Dairy product manufacturing falls out of the ranking altogether because 95% of its products are exported. Metal manufacturing also falls out of the ranking because much of its output supports exporting industries. The industries with the largest footprints from imported inputs reflect a cross-section of domestic industries, from residential building construction in first place, through to hospitality (food and beverage services, 7th placed) and hospitals (8th place). This illustrates the interconnections between producers and consumers across the economy and their reliance on materials extracted abroad.

The footprint measures are high-level indicators

The assumptions required to make these calculations are not realistic or useful for some purposes[14] but they are reasonable for describing or summarising observed economic relationships and measuring the use of products that are indispensable to production in the short term – such as the use of sand in glass.

A potentially problematic aspect of the methodology, in terms of accuracy, is that for practical purposes data on diverse economic activities must be aggregated into a discrete set of categories. For example, in New Zealand's inter-industry transaction tables, glass manufacturing is considered part of the "Non-metallic mineral product manufacturing" industry which produces both glass and cement.[15] That being so, care must be taken in interpreting the footprints.[16]

It is important to acknowledge the considerable variation in activities and footprints included in an industry. And it should be remembered that the numbers are averages, so they will understate the footprint of more resource intensive firms and overstate the footprints of less resource intensive firms.

Similarly, different types of raw materials are aggregated such as gravel and sand or different types of wood. This introduces errors in estimates of material flows when we use purchases as a proxy for material demand. If gravel is more expensive per tonne than sand, industries that

[14] For example, they don't take account of the ability to substitute between wood and steel for construction if one product becomes more expensive than the other. Consequently input-output models are not a good basis for predicting/modelling changes in the economy.
[15] One of the strengths of the GLORIA database – discussed immediately below – and methods is that it is based on an extremely detailed classification system allowing for logically consistent aggregations over different data sets and industry and product classifications.
[16] Aggregation and averaging reduce information and introduces numerical errors that are not trivial, and cause footprint estimates to increase or decrease by e.g. +/- 20% (EC, 2021).

buy most gravel will be attributed a disproportionate share of the sand and gravel footprint. That said, most raw materials we measure are reasonably[17] uniform, so this is not a significant problem.

Given all these simplifications the results of these methods should be interpreted as indicators, not precise measurements. It is also why we refer to the estimates in this report as a macro view of raw material demand.

GLORIA's global multi-regional input-output tables

The GLORIA database contains harmonised measures of inter-industry trade, production and final demand within and between almost every country in the world – 160 countries explicitly and 4 regional aggregates.

The database traces the supply and use of 120 different goods and services and measures the extraction of 367 types of raw materials alongside as other indicators of environmental and social impact such as greenhouse gas emissions.[18]

GLORIA is used to produce the UN Global Material Flows Database (GMFD) which contains international estimates of raw material footprints – measures that are equivalent to the ones presented in this report, albeit with slightly different dimensions and data sources.

We use the GLORIA classification as our classification for raw materials and we use GLORIA to estimate tonnes of raw materials imported, per dollar of product imported.[19]

2.2. Domestic extraction

We use a range of sources to obtain estimates of tonnes of raw materials extracted domestically. Our approach for selecting amongst sometimes competing estimates are to prioritise sources in the following order:

- official or quasi-official statistics from New Zealand government sources such as Statistics New Zealand, or the Ministry for Business Innovation Employment (MBIE)
- local industry reports or media statements
- estimates by international organisations
- values in the GLORIA database.

In the main, local estimates and international estimates are the same because the international estimates are drawn from local estimates.

[17] It is hard to think of any raw materials that are homogeneous. Even basic metal ores or crude oils have substantial variations in usefulness or value per unit weight depending on purity or chemical composition.
[18] See the Appendix 2 for a sample of results from GLORIA for New Zealand's consumption-based emissions footprint.
[19] USD import values are converted to NZD values using the average, by year, of monthly exchange rates published by the RBNZ e.g. 0.6593 for calendar year 2019.

The value of seeking out a range of sources is to:

- check the accuracy of international estimates, including those from GLORIA
- obtain estimates for small(er) industries that are missing from international estimates or official sources e.g. because data is deemed confidential.

In a handful of cases, we have used estimates from international sources because local estimates do not exist.

In principle, there is potential for small disagreements between sources due to different year end dates. Our estimates are for transactions in the year ended March 2020.[20]

Below we discuss the data we have collected and notable departures from the sources and estimates used in GLORIA.

Grazed biomass

The single largest difference between our estimates of domestic extraction and those in GLORIA is in grazed biomass.

We estimate 51 million tonnes of grazed biomass were extracted domestically in New Zealand March year 2020. The comparable GLORIA estimate is 76.2 million tonnes, 49% larger.

GLORIA and the GMFD use a set of standardised and highly aggregated coefficients for estimating animal feed requirements. The numbers are very different than what we observe in New Zealand. This is shown in Table 2. The biggest difference is in the estimated raw material requirement for non-dairy cattle, where the GLORIA coefficient is 86% higher than the equivalent estimate from New Zealand modelling.

TABLE 2: DIFFERENCES BETWEEN ESTIMATED GRAZING REQUIREMENTS
Average tonnes of dry matter per animal per year, main animal types

Livestock type	Coefficient from NZ modelling	GLORIA coefficient[21]	% difference
Dairy cattle	4.2	5.9	39%
Non-dairy cattle	3.2	5.9	86%
Sheep	0.4	0.6	56%

[20] Where source data is annual and has a different year end date, we convert the data to March year end annual by number of months per year e.g. our estimate for March year 2020 is three-quarters of the 2019 calendar year value plus one-quarter of the 2020 year calendar value.

[21] Technical annex for global material flows database (2024) p.15. The GMFD coefficients shown here are ones are for cattle and buffalo and for sheep and goats. The GMFD data does not appear to distinguish the data any further than that. It also uses high level regional aggregates with the coefficients for New Zealand coming from a region labelled "North America and Oceania". The source data for the GMFD estimates is also old.

Our estimates, from New Zealand modelling, are based on numbers in the New Zealand Greenhouse Gas Inventory[22], and those numbers are produced by the Ministry for Primary Industries (MPI) model of greenhouse gas emissions in agriculture.[23]

We calculate average weight of dry matter intake per animal per day using estimated methane emissions per animal in the Greenhouse Gas Inventory. We convert those numbers into average dry matter intake using animal-specific rates of conversion of dry matter into methane, also from the Greenhouse Gas Inventory.[24]

We include supplementary feed in our grazed biomass estimates, but only if the feed is likely grown and used on farm.[25] Excluding feed that is more likely to be purchased off-farm helps us to avoid double-counting, which would otherwise occur if, for example, we included imported supplementary feed alongside estimates of grazed biomass based on daily average requirements for dry matter intake. The estimated rates of supplementary feed use are from the MPI greenhouse gas modelling.[26]

Crops and horticulture

We estimate that biomass embodied in crops and horticulture contributed 5.1 million tonnes to New Zealand's domestic extraction footprint in March year 2020. This is larger than the 4.3 million tonnes recorded in the GLORIA database.

Data on crop yields comes mainly from Stats NZ data on crop yields and land use.[27] This is also the data that is used by the FAO which is, in turn, the source for estimates in the GMFD and GLORIA.

We have, however, undertaken some bespoke estimates of extraction using industry data, where Stats NZ does not publish data and FAO estimates were missing or appeared incorrect. Remarkably, data on horticultural production, by product, is not readily available from

[22] New Zealand's Greenhouse Gas Inventory 1990–2022 | Ministry for the Environment
[23] Detailed methodologies for agricultural greenhouse gas emission calculation (2024).
[24] This is simply the reverse of how emissions are calculated in the MPI model, which begin with estimates of typical daily energy requirements, depending on animal age and size classes, plus estimates of typical energy content of pasture. The conversion factors we use draw directly from comparing emissions with underlying estimates of dry matter intake supplied by MPI.
[25] We assume the following supplements are grown and consumed on-farm: fodder beet, kale, turnips, swedes, baleage.
[26] This is a material but not a significant contributor to the difference between our estimates and those in the GMFD. Without the adjustment for use of supplementary feed, our estimate of grazed biomass would be only 6% (3 million tonnes) higher and still 30% smaller than the GMFD estimate.
[27] Agriculture | Stats NZ.

standard statistical sources, like Statistics New Zealand.[28] We used alternative sources to estimate production of olives[29], hops[30], summer fruit[31], citrus fruit[32] and pipfruit.[33]

Wild caught fish and other aquatic biomass

We estimate aquatic biomass, mainly from fishing, contributed 0.5 million tonnes to New Zealand's domestic extraction footprint in March year 2020. This is larger than the 0.4 million tonnes recorded in the GLORIA database.

Our estimate of raw material extraction in fisheries includes estimates of tonnes of oysters and mussels produced in aquaculture.

By convention, farmed fish are not included in materials accounts. This is because they are a cultivated resource, not a natural system. They involve heavy reliance on external inputs (e.g. feed) and would not exist but for being "in the economy".

We take the view that this logic does not apply to cultivation of mussels and oysters, at least given the way most of the shellfish aquaculture industry in New Zealand operated in 2020.

Key inputs for shellfish aquaculture are sourced directly from natural systems. Spat is typically collected from the wild and the animals grow in and rely on natural systems, even if there is some intervention in terms of providing structures for the animals to attach to.

We take the view that these better represent a transition of materials from the natural environment into the economy than, for e.g., the use of pasture for livestock grazing, at least in the New Zealand context.

Metallic ores

Our data includes estimates for raw material extraction of gold and silver and iron ore.

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[28] We note that MPI does do a lot of market monitoring, however it is export focused, so does not capture total production.

[29] These are missing altogether from the FAO and NZ official data. We estimate olive crop weights using estimates of typical yields per tree per region and estimated numbers of trees per region reported by Olives New Zealand e.g. 2020-Grove-Census-Harvest-Data-Report.pdf (olivesnz.org.nz).

[30] E.g. FAO data on NZ hops production is imputed/estimated, presumably because NZ government does not provide this data perhaps due to the industry involved few growers, which causes confidentiality issues. In any event, NZ industry reports hops production that is around one-third larger than the FAO estimates (New Zealand records record hops harvest (nzhops.co.nz))

[31] Production (tonnes) of cherries, apricots, nectarines, peaches and plums are estimated using data on the value of domestic and export sales and the kg of export sales from Summerfruit NZ and data on hectares planted from Statistics New Zealand. The industry data is used to estimate typical yields per hectare for the 2021-2022 season and we use that figure along with 2020 data on hectares planted to estimate tonnes of biomass in 2020.

[32] Citrus New Zealand

[33] We found very little public data on apple and pear production volumes. Ultimately, we relied upon harvest volumes reported by the USDA (New Zealand fresh deciduous fruit reports), on the assumption that their reports from Wellington would have relied on better market intelligence than we could produce in the time available.

Tonnes of gold extracted is estimated to be 3.5 million tonnes. This is based on gold production reported by NZ petroleum and minerals, scaled up to reflect the estimated difference between final amounts of gold produced (which is reported) and material extracted. For this scale factor, which in practice is a variable depending on the mine, we use an estimate of 2.2 grams of gold per tonne of ore, reported in a technical study of the Martha mine in Waihi.[34] We deduct from this the amount of silver produced as a co-product, but the amount of silver extracted is trivial and because it is a co-product of gold there no additional adjustment is made to account for the difference between metal produced and ore extracted.

We estimate iron ore extraction of 3.65 million tonnes. This is inferred from NZ Steel's reported use of iron sands mined at its Waikato North Head site[35] plus an estimate of the production of iron sand at Taharoa (2.35 million tonnes), inferred from trade data.[36]

Fossil fuels

We use estimates of fossil fuel extraction published by MBIE.[37] The values used are shown in Table 3, alongside the raw material categories used in the GLORIA database and adopted by us for classifying raw materials.[38]

TABLE 3: FOSSIL FUEL EXTRACTION
March year 2020

Material extracted	Tonnes
Lignite (brown coal)	294,000
Other Sub-Bituminous Coal	1,444,000
Coking Coal	1,301,000
Crude oil	1,125,000
Natural gas	3,967,000
Natural gas liquids	163,000
Total	8,293,000

[34] This is the estimate used in the technical report but is conservative – i.e. at the lower end of a range so apt to overstate extraction. See Waihi Martha Mine Technical report, p. 210.

[35] Energy Resources & Recovery | New Zealand Steel (nzsteel.co.nz) presents a range of 1.2 million to 1.4 million tonnes of iron sand extracted from which we assume 1.3 million tonnes of iron sand is used. While 4 to 7 million tonnes of sand is mined for that amount of iron sand, it is returned to the natural environment which, by convention means that it is not counted in raw material extraction for economic use.

[36] The Taharoa estimate is from UN Comtrade data on iron ores and concentrates (HS 260112) exported from New Zealand as reported by importing countries the product was exported to. This is a guesstimate, however the volume accords with the general magnitude of the production capacity of the Taharoa site, with the last publicly reported value for exports from that site being 3.2 million tonnes, from 2016 when it was owned and operated by Bluescope steel.

[37] Energy statistics | Ministry of Business, Innovation & Employment (mbie.govt.nz)

[38] In the table we exclude materials with zero extraction in New Zealand e.g. oil shale and tar sands.

These numbers for fossil fuel extraction are very similar to those in the GLORIA database, albeit 8% larger in total. The most notable product-specific difference is in natural gas extraction where the figure in Table 3 is 20% larger than the figure in GLORIA.[39]

Non-metallic minerals

The main source of data (by weight) for our estimates of the extraction of non-metallic minerals comes from NZ Petroleum and Minerals (NZP&M) survey reports.[40]

However, we have supplemented that with alternative sources of data to fill in gaps where data is confidential or missing and to convert data from the classifications used by NZP&M and the ones used in the GLORIA database.

In cases where tonnes extracted are small and we have no other sources of data, we have used GLORIA estimates by default, in order not to overlook categories of extraction. This does risk overstating the amount of material extracted because the GLORIA categories include catch-alls such as 'Industrial minerals n.e.c.'. Some of the tonnes in those catch-all categories could be counted in other categories of the NZ data, but we cannot tell.[41]

TABLE 4: NON-METALLIC MINERALS EXTRACTION
March year 2020

Material extracted	Tonnes	Source
Ornamental or building stone	37,000	NZP&M, building stone & decorative pebbles
Dolomite	66,000	USGS + farm survey data on product use
Limestone	2,978,000	NZP&M 2019 data, USGS estimate for 2020
Industrial minerals n.e.c	61,000	GLORIA
Salt	100,000	GLORIA
Gypsum	29,000	GLORIA
Structural clays	176,000	GLORIA
Specialty clays	51,000	NZP&M, clay for pottery and ceramics
Industrial sand and gravel	1,181,000	NZP&M, industrial and silica sand
Sand gravel and crushed rock for construction	31,732,000	NZP&M, rock and sand for: (i) reclamation, (ii) building, (iii) roading, and (iv) fill.
Other non-metallic minerals n.e.c.	2,357,000	NZP&M other plus pumice
Total	38,768,000	

On the other hand, survey data from NZ clearly does not count all non-metallic minerals. For example, it does not include salt. And we take some comfort in the fact that e.g. GLORIA's

[39] We cannot be sure what is behind the difference, but it could be partly due to timing differences i.e. calendar years versus March years.

[40] Minerals statistics - New Zealand Petroleum and Minerals (nzpam.govt.nz)

[41] One downside to using the GLORIA classifications for recording raw materials is that it is not always clear what the GLORIA materials are referring to. 'Industrial minerals n.e.c.' is one example and the technical description of this category in the GLORIA documentation is imprecise. Also, more generally, the GLORIA classification of materials by type of use, such as construction dominant or industrial and agricultural dominant, does not have an obvious one-to-one concordance with NZ classifications by use.

estimate of salt extraction – for which we do not have direct estimates from local sources – does accord with approximations from production information for the salt works at Lake Grassmere.[42]

In addition to using GLORIA estimates, we also make use of estimates from the US geological survey (USGS). That is an input also used in GLORIA.[43]

Our figure for 38.8 million tonnes of non-metallic minerals extracted is 2.5 times the 15.7 million tonnes recorded in GLORIA for New Zealand for 2019, in the version of GLORIA we have used.[44] The source of this difference is in the amount of sand and gravel extracted for construction.

2.3. Imported material footprints

GLORIA estimates of tonnes per dollar of imports

We calculate imported material footprints using estimates of tonnes of raw materials per dollar of product imported based on the GLORIA database.

When solving for material footprints by imported product, we aggregate the regional dimension of the GLORIA database (version 59, year 2019) to 21 regions.[45] We do this because it makes the calculations faster. This is likely to introduce some aggregation error, though size and direction of that error is uncertain.[46]

Concordance to Stats NZ IO imports

The GLORIA database has a different product/sector classification than the one we use. We use the product classification and import values in the Stats NZ IO table, because our goal is to align our footprints with the Stats NZ IO table.

GLORIA uses a bespoke classification, so there is no standard concordance available, and our concordance should be considered imprecise and a potential source of error.

To translate tonnes of raw materials per dollar of imports from the GLORIA classification to the Stats NZ classification, we produced a concordance based on comparing the names of

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[42] Salt production at Lake Grassmere.

[43] USGS estimates are used where NZ data is missing and that does mean they are approximations at best, but we use them where the tonnes involved are relatively small, where we could not find local data source and on the assumption that the estimates will be better than we can do.

[44] The GMFD shows 36.8 million tonnes for 2019, indicating that the data has been updated this year.

[45] Our labels for these are based on regional groupings used by the World Bank: Australia, New Zealand, Caribbean, Central America, Central Asia, Eastern Africa, Eastern Asia, Eastern Europe, Melanesia, Middle Africa, Northern Africa, Northern America, Northern Europe, South America, South-eastern Asia, Southern Africa, Southern Asia, Southern Europe, Western Africa, Western Asia, Western Europe.

[46] Our geographical aggregation is a simple approach to aggregation. We did consider alternative analytical aggregations and while they promise the possibility of reducing aggregation error it appears that no single approach is known to work best (Lenzen, 2019), so we adopted a simple approach and one that would allow for reporting using groupings that are more easily explained – as compared to aggregating over regions based on e.g. similar production structures.

products contained in the Stats NZ IO (by detailed CPC code) against the names for products[47] in the GLORIA database.

We used a concordance between the 197 IO table products and 300 national accounts products, and a concordance from those NA products to 2,792 Central Product Classification[48] (CPC) products.

GLORIA does have a concordance to high-level ISIC industry groups and Stats NZ's national accounts products can also be concorded to ISIC industries. So, we use ISIC industry groups as an initial grouping method.

We then adopted a two-step process for elaborating the concordance:

1. Matched GLORIA and national accounts products, separately, to a modified group of ISIC Rev 4. industries to filter the set of possible matches.
2. Matched GLORIA products to national accounts products using both the national accounts product description and the descriptions of CPC products linked to those national accounts products.

This produced a chain of concordances which we could follow to complete the match: GLORIA to national accounts and then to IO table products.

We then identified where any GLORIA products were matched to multiple IO products and used import trade data to estimate a split. We then compared the results of these splits, i.e. GLORIA import values split to match IO table categories and made judgement-based adjustments if there were significant differences between trade volumes in the IO table and trade volumes predicted by split.

This process was not very systematic. GLORIA's classifications contain elements of both industry (ISIC) classifications and product (CPC, HS) classifications. So, to complete the concordance we had to take account of the details of ISIC (industry) classifications which in some cases are quite different to the classifications used in New Zealand.

Products that needed closest inspection were services industries, where the GLORIA classifications appear to differ most from the New Zealand ones.

Bespoke adjustments to data

We made two adjustments to the GLORIA estimates of the material intensity of imports. One was an addition to the bauxite footprint for imports of basic metals. The total footprint for bauxite in imported intermediates from the GLORIA database was substantially smaller (95% smaller) than what we would expect to be the minimum given the amount of alumina imported for processing at the Tiwai smelter. So, we added an estimate of the bauxite footprint of imported alumina for use at Tiwai using back-of-the envelope estimates of

[47] Note that strictly speaking the GLORIA nomenclature is for sectors that are sufficiently detailed that they typically look more like products than industries.
[48] Version 2.0

300,000 tonnes of aluminium produced and four tonnes of bauxite required per tonne of aluminium produced.

We also reduced to zero the large weight of gas attributed to New Zealand imports of gas extraction services. This was based on our judgement that New Zealand imports of gas extraction services is likely dominated by consultancy or similar technical services that do not have a strong upstream connection to gas extraction. Although the people supplying gas extraction services may be connected to gas extraction in other countries the gas is likely an output of those services rather than an input.

Time series analysis

We have used GLORIA to estimate the material intensity (tonnes per dollar) of imports into New Zealand at 5 yearly intervals between 1994 and 2019. This was the basis for Figure 2 and Figure 3. We have also used GLORIA-based estimates of domestic extraction and exports to produce a time series for overall New Zealand demand for raw materials.

Unlike our March year 2020 estimates, these time series estimates are only partially based on New Zealand data on domestic extraction and are not based on New Zealand data on inter-industry transactions, imports or exports.

We are confident that the GLORIA data is sufficiently like New Zealand data as to be able to provide a robust indication of growth trends. Notably because the GLORIA database is based on international data that is, for the most part, produced from New Zealand data (e.g. UN Comtrade trade data and US geological survey data).

But we do know that the GLORIA data differs materially from New Zealand estimates of domestic extraction in the case of grazed biomass and extraction of sand and gravel. So, we have constructed time series estimates of these series (using the methods described in section 2.2) and adjusted the GLORIA satellite tables for raw material extraction.

We have also rebased the level for the resulting time series for overall material footprint and its main components (domestic extraction, imports, and exports), to remove minor differences between our estimates and those in GLORIA. That is, the GLORIA estimates have been joined to our 2020 March year estimates and we have back-cast the aggregate import, export and domestic extraction footprints using growth in the GLORIA estimates over the 5 yearly intervals.

Appendix 1: Material footprint formulae

This appendix gives a brief overview of the formulae used to calculate material footprints. This provides context for interested readers not familiar with input output models but familiar with matrix and linear algebra.[49] It is not intended to be a general guide to input-output models and national accounting, or a technical guide to performing the calculations. There are numerous other publications better suited to those purposes. Examples are cited above and in the references.

Input-output models

Input-output models represent production of firms (vector of gross output x) as a function of final demand (vector f) and inter-industry transactions. Inter-industry transactions are presented as a matrix of (fixed) technical coefficients (unit of input per unit of output) describing transactions between sellers and buyers (A):

$$\mathrm{x} = (\mathrm{I} - \mathrm{A})^{-1}\mathrm{f}$$

Where I is the identity matrix.

The term $(\mathrm{I} - \mathrm{A})^{-1}$ is usually abbreviated to L for Leontief, after the originator of input-output models, i.e. $\mathrm{x} = \mathrm{Lf}$.

An example of a Leontief can be found in Stats NZ's input output tables.[50] It is constructed from the table of inter-industry transactions (in dollars, Z) by dividing transaction values by the gross output of purchasers.

$$\mathrm{A} = \mathrm{Z}\hat{\mathrm{x}}^{-1}$$

$$\hat{\mathrm{x}}^{-1} = \begin{bmatrix} 1/x_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1/x_n \end{bmatrix}$$

The key thing to know is that the Leontief describes the total requirement, direct and indirect, for inputs from firms/industries to meet an additional unit of demand. If demand for the first element in f increases by one unit, the system can be re-solved to find out what that implies for gross output for all the industries in x.[51]

These models and the transactions they model can be either industry-specific (i.e. industries as buyers and sellers) or product-specific (products sold and bought), but they can't be explicitly both. Industry-specific transactions are most usual because data is typically collected on an industry by industry (firm-by-firm) basis.

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[49] We choose the matrix algebra representations here because they are compact, and we find them easier to interpret. Readers who find summation notation easier to read are referred to e.g. Lenzen et al (2022).
[50] Sheet '5 Total requirements' [National accounts input-output tables: Year ended March 2020 | Stats NZ]
[51] Many texts and articles on input output models provide step-by-step explanations of how this works as well as intuitive explanations based on straight-forward power series approximations e.g. Blair and Millar (2022).

Multi-regional input-output models

Multi-regional input-output models work in the same way as regular input output models, but typically involve more dimensions because buyers and sellers are indexed by both industry and location. Besides that, the mechanics are the same.[52]

Environmental extension to raw materials

The input-output model is extended to measure material footprints (vector m), by the addition of a matrix (q) describing the inputs of raw materials per unit (dollar) of output of firms or industries first using the raw materials e.g.

$$m = \mathrm{q.L.}f$$

In our estimates: m is a 367 by 1 vector of material-specific footprints; q is a 367 materials by 109 industries matrix of material requirements (per dollar of output), L is a 109 industry by 109 industry Leontief matrix and f is a 109 by 1 vector of total final demand by industry.

There are numerous variations on that equation that can be used to either retain information (avoid aggregation) or to isolate material footprints of interest. For example, diagonalising the final demand vector will mean the results retain (sum separately over) each of the different industry final demands. That is, replacing f with:

$$\hat{\mathrm{f}} = \begin{bmatrix} f_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & f_n \end{bmatrix}$$

Our use of the formulae

Our main estimates of domestic extraction footprints by final demand use the equation

$$M = \mathrm{q.L.}\hat{\mathrm{F}}$$

Where the matrix of raw materials per unit of output (q) is the one estimated for this project, the Leontief is from Stats NZ's input-output tables and the final demand matrix is a block diagonal matrix containing final demand by industry and by category of final demand. This yields a final demand footprint matrix (M) that is 367 (materials) by 654 (6 demands x 109 industries).

Our estimate of footprints from imported intermediates uses the same equation but replaces the matrix of domestically extracted raw materials per unit of output with an estimate of raw materials imported per unit of output.

[52] What makes multi-regional models different is the data collection and curation. Data collection is a difficult task even for domestic input-output tables. It is a much harder task for multi-regional models.

Appendix 2: Consumption-based emissions

The GLORIA database provides a useful way to measure emissions embodied in imports into New Zealand and include those in New Zealand's measure of consumption-based (destination) emissions.

Stats NZ produces estimates of emissions embodied in imports[53] but those estimates assume that products from overseas have the same production technology as locally produced products. There is good reason to believe that the emissions intensity of imported products is typically higher than domestic products, due to e.g. the higher rates of use of fossil fuels in stationary energy production.

GLORIA provides a straightforward alternative estimation approach that can take account of differences in the emissions intensity of production overseas.

The table below provides preliminary evidence that the Stats NZ method does indeed understate emissions embodied in imports. This Table is an extract from Table 7 in Stats NZ's latest (year ended 2021) estimate of New Zealand's consumption emissions, with alternative calculations at the bottom using results from GLORIA for emissions embodied in imports.

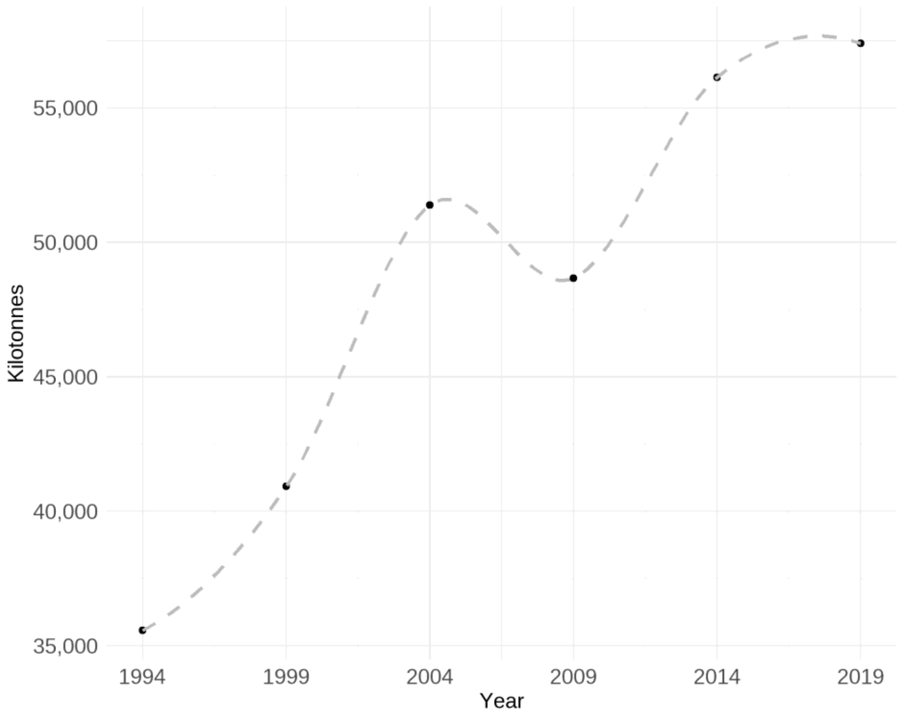
TABLE 5: ALTERNATIVE ESTIMATE OF NZ CONSUMPTION-BASED EMISSIONS

	2014	2019
GHG inventory total - excluding LULUCF	79,209	79,985
plus residents operating overseas	2,439	3,161
less non-residents operating on domestic territory	325	412
Equals SEEA production total	81,323	82,734
plus emissions embodied in imports	29,380	31,395
less emissions embodied in exports	53,131	53,737
Equals consumption-based emissions	**57,571**	**60,393**
Alternative estimate of emissions embodied in imports	32,130	33,418
Percentage difference from Stats NZ estimate	9%	6%
Alternative estimate of consumption-based emissions	**60,321**	**62,416**
Percentage difference from Stats NZ estimate	5%	3%

[53] Greenhouse gas emissions (consumption-based): Year ended 2021 (provisional) | Stats NZ

GLORIA can be used to estimate consumption-based emissions overall (see for example Figure 8), although in principle it is better to use detailed local information for the domestic and export components of the estimates because estimates of emissions are quite sensitive to assumptions about local conditions, as illustrated by the size of revisions to and estimated uncertainty ranges around New Zealand's official greenhouse gas inventories.

FIGURE 8: GLORIA-BASED ESTIMATES OF NZ CONSUMPTION-BASED EMISSIONS



Appendix 3: Systems of provision

Other studies have aggregated final demand footprints into categories referred to as systems of provision. For example (Miatto et al, 2024a, 2004b):

- housing
- mobility
- food
- energy
- communication
- waste management.

We have produced a similar set of summary measures, shown in Figure 9.

Our categories differ to those used in other studies. This is mainly because the system labels used in other studies do not have well-defined classifications, so there are not easily replicable.

We take systems of provision to mean production (economic) systems that deliver services that support material living standards and, to lesser extent, wellbeing of humans.[54] And we use the terms production, economic and systems in the broad sense: including people, social systems, political systems and uses of the natural environment. We do not mean simply markets and money.

On this definition we agree with the use of broad groupings to classify systems such as food provision, energy and housing. These are reasonably well-defined and widely understood systems.[55]

But we find the concept of "mobility" hard to use for measurement/classification. It is unclear whether this ought to include only personal travel or also freight. On its face, we think mobility ought to encompass roading, but it is unclear how best to identify raw material use in roading versus other infrastructure that is produced in, around and under roads by civil engineering or similar construction firms (e.g. wastewater and sewerage).

More broadly, transport[56] is almost always an intermediate goods or service – used to enable some other activity that is a direct source of wellbeing. Transport may be an essential

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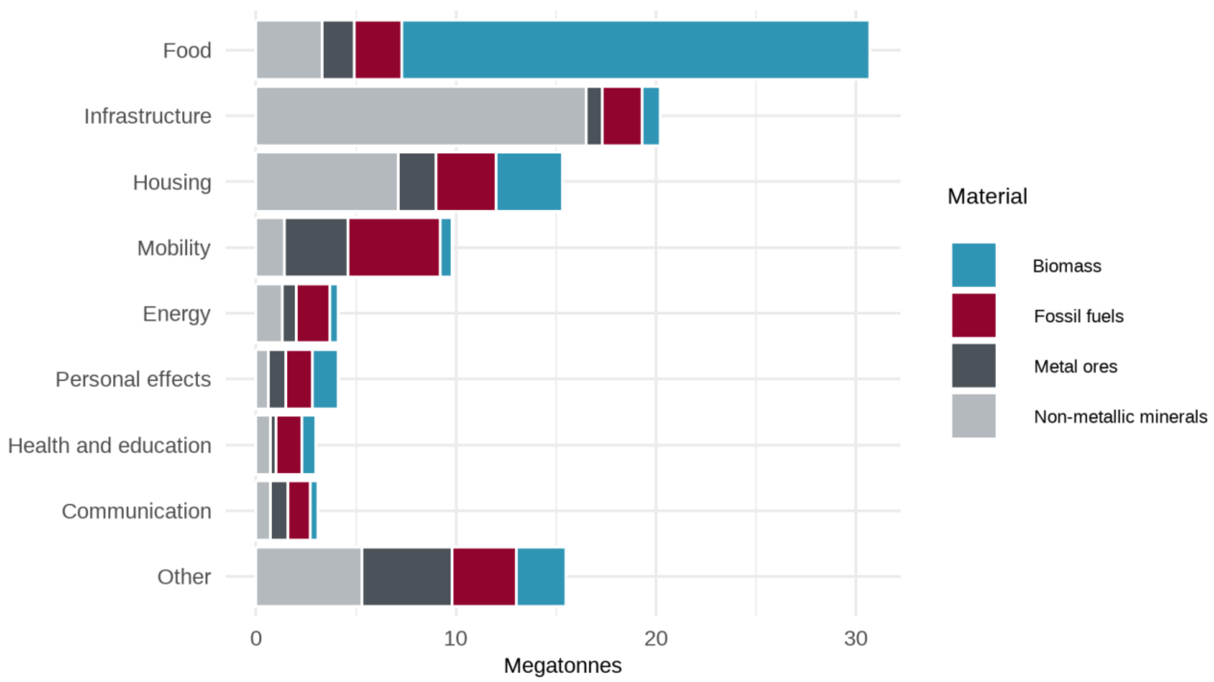
[54] We do not intend to provide a/the definitive interpretation of this concept, only a workable one for our own use. We appreciate that we may not have properly understood the intent behind the concept of systems of provision.
[55] This can be seen in the structure and recording of statistics, with food easily identifiable and energy use captured in well-defined balance tables for most developed and many developing economies. And counts of dwellings and household living arrangements are well defined and residential building activity relatively easy to spot in industry activity measures.
[56] Assuming this is roughly what is meant by mobility. We are not sure.

component of the provision of services in every sector of the economy, yet it does not rank highly in terms of improving wellbeing or satisfying human need. Essential as it may be, it is not any more notable a provisioning system, for human need satisfaction or flourishing, as systems that provide clothing, water, health, education or security and safety services.

Given these considerations, we include categories for:

- personal effects, encompassing clothing and other common household items and appliances
- health and education, including goods heavily used medical services
- infrastructure, including: social infrastructure (government); network services that are not naturally included in energy or mobility or communications; services that do not belong to a single sector or end service such as civil engineering construction.

FIGURE 9 GROUPING FINAL DEMAND FOOTPRINT BY SYSTEMS OF PROVISION



Under the communications category we include all information systems services, print media, and the household use of computers on the assumption that they are mainly used for exchange of information over the internet.

We have not included a waste category, rather we subsumed waste within infrastructure, mainly because on its own it is a very small category empirically.

Our views on the importance of social services and institutions are at least partly reflected in other papers that refer to systems of provision or provisioning factors. Vogel et al (2021) refer to social systems that produce education and healthcare and Tanikawa et al (2021) refer to social service provisioning. However, we cannot use their frameworks for our purposes as

Vogel et al focus on outcomes of economic systems, not systems of production, and Tanikawa et al describes only a limited subset of output or service utilisation measures (floor space).

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