Measuring dependencies on critical raw materials (CRMs) in the supply chain

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Outline

1. Why analyze dependencies on Critical Raw Materials?
2. How does the Netherlands rank as an importer of CRMs?
3. Adding detail to the national IOT: how are CRMs that are ***directly imported*** used and where do they originate?
4. Measuring ***indirect dependencies***: combining MRIOs, SUTs, and detailed trade data to quantify indirect CRM imports
5. Identifying top suppliers of products that ***contain*** CRMs (relevant for future research related to #4)

Why analyze dependencies on CRMs?

Concerns about supply chain security and price stability

- Geopolitical instability (War in Ukraine, Gaza Strip and global repercussions)
- Reflects interwovenness in internationally fragmented production chains

Concerns about achieving climate goals, circularity and the digital transition

- Exponential increase of demand for CRMs expected in coming years
- High dependence on China for critical technologies necessary for energy transition and chip-making

Concerns about over-dependencies on a single third country

- Countries with a high market dominance can (mis)use this power

Concerns about unsustainable mining and processing/refining

- Current situation bad for climate and for the environment

EU policy response

- **Critical Raw Materials Act (2023)**
- Provisionally agreed upon by the European Parliament and Council of the EU on Nov. 13.
- Adopted by the EU Parliament on Dec. 12.
- European Commission identified **32 *critical* and 2 *strategic*** (copper and nickel) **materials** that imply "*significant economic value*" and "*potential supply chain risk*"
- **This presentation**: analysis considers all 34; combines scandium, HREMs and LREMs

EU and Dutch policy response

- **EU guidelines and aims by 2030:**

≥ 10% extraction within the EU of annual consumption CRMs

≥ 40% processing/refining in EU of annual consumption CRMs

≥ 15% of annual EU consumption CRMs through recycling

≤ 65% supply of CRMs in each relevant production stage sourced from a single country

- **Dutch government publishes own national CRM strategy**

- Focus on circularity, innovation, sustainability, and self-sufficiency via diversification of supply chains

Global perspective (Source: U.S. Geological Survey, 2022)

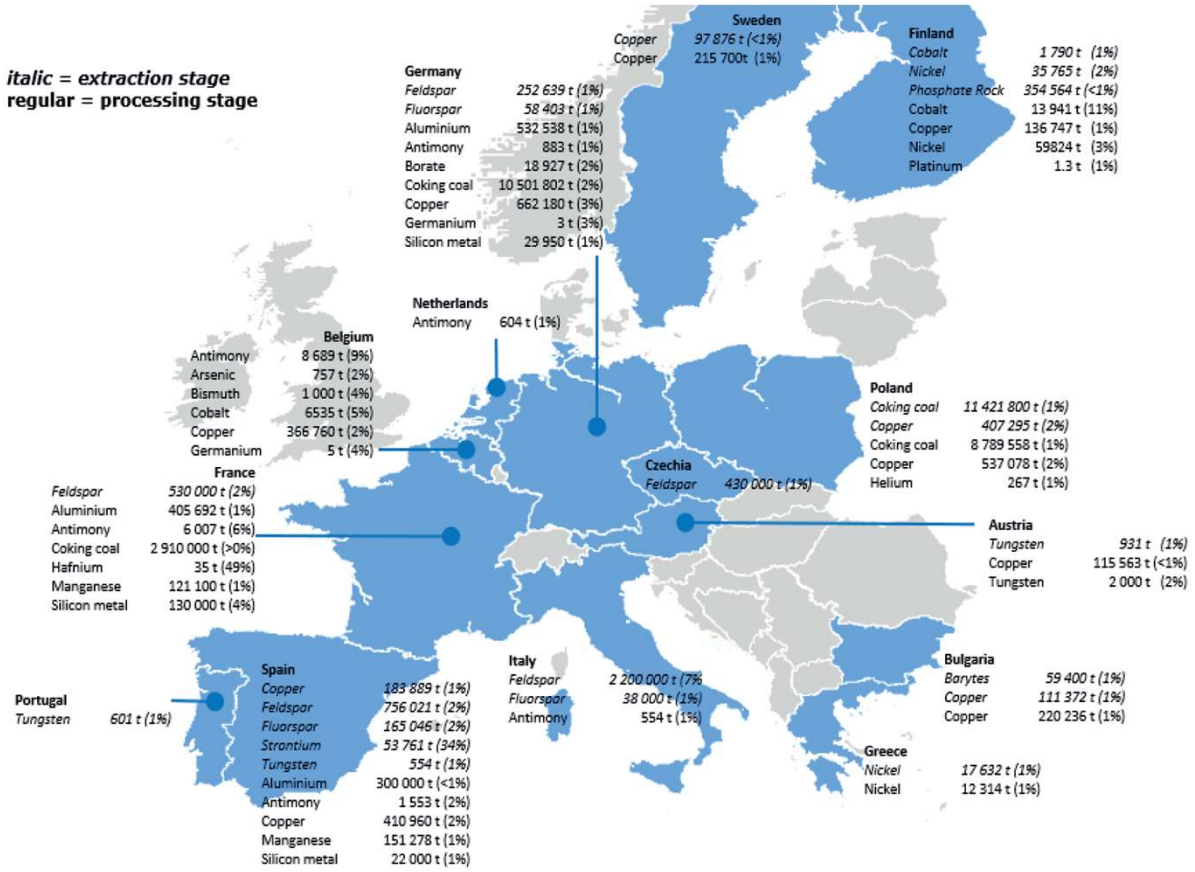
	Extraction (in tons)	Largest producer (% share)		Share of China (%)	China rank
Antimoon	110 000	China	55	55	1
Arseen (trioxide)	61 000	Peru	46	39	2
Bariet	7 900 000	India	33	24	2
Bauxiet	380 000 000	Australië	26	24	2
Beryllium	280	VS	64	25	2
Bismut (refined)	20 000	China	80	80	1
Boraat (boor)	n.b.	Turkije	n.b.	n.b.	2
Fosforiet	220 000 000	China	39	39	1
Gallium	550	China	98	98	1
Germanium (verwerkt, '21)	140	China	68	68	1
Grafiet	1 300 000	China	65	65	1
Helium (mln m^3 gas)	160	VS	47	1	8
Kobalt	190 000	Congo	68	1	12
Koper (mijn)	22 000 000	Chili	24	9	4
Koper (refined)	26 000 000	China	42	42	1
Lithium	130 000	Australië	47	15	3
Magnesium (smelt)	1 000 000	China	90	90	1
Mangaan	20 000 000	Zuid-Afrika	37	7	4
Nikkel	3 300 000	Indonesië	48	3	7
Niobium	790 000	Brazilie	90	nihil	n.b.
Palladium	210	Rusland	42	nihil	n.b.
Platina	190	Zuid-Afrika	74	nihil	n.b.
Silicium	8 800 000	China	68	68	1
Strontium	340 000	Spanje	38	24	3
Tantaal	2 000	Congo	43	4	5
Titanium	8 900.000	China	38	38	1
Vanadium	100 000	China	70	70	1
Veldspaat	28 000 000	India	24	9	3
Vloeispaat	8 300 000	China	69	69	1
Wolfraam	84 000	China	85	85	1
Zeldzame aardmetalen	300 000	China	70	70	1

Dominance of China in extraction (#1 in ~ half of cases)

Russia frequently in top 10 (21 cases, #1 in palladium)

Single largest producer tends to have a **high share** in worldwide production

EU perspective (Source: European Commission report, 2023)



EU extraction > 1% for only 8 of 34 CRMs (Feldspar in Italy = 7%)

EU processing > 1% for 18 CRMs

Very limited extraction and processing capacity in EU, high extra-EU dependencies

Dutch perspective (rest of presentation)

How does Dutch import value of CRMs rank in a European context (2022)?

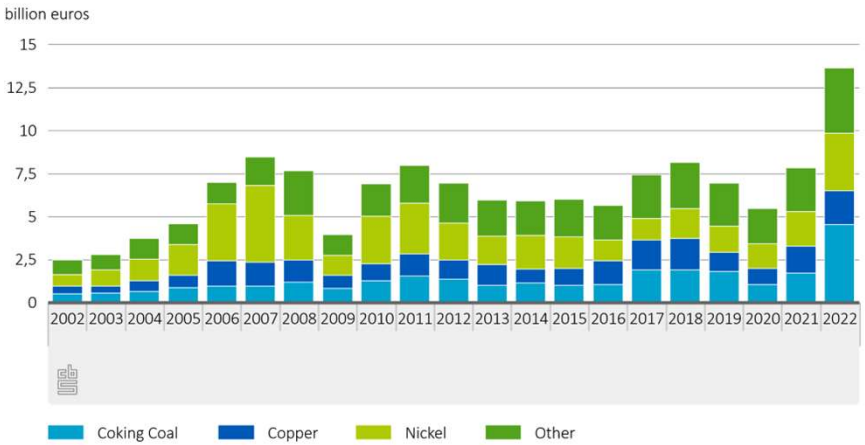
Rank in EU	Frequency	CRMs
1	12	Baryte, Bismuth, Boron, Coking Coal, Gallium, Lithium, Magnesium, Manganese, Nickel, Niobium, Strontium, Tungsten
2	9	Antimony, Arsenic, Cobalt, Fluorspar, Hafnium, Phosphate Rock, Silicon metal, Tantalum, Vanadium
3	2	Germanium, Natural graphite
4	3	Copper, Feldspar, Rare Earth Metals
5	3	Bauxite, Phosphorus, Helium
7	1	Beryllium
9	1	Platinum

Source: **Easy Comext** database from Eurostat

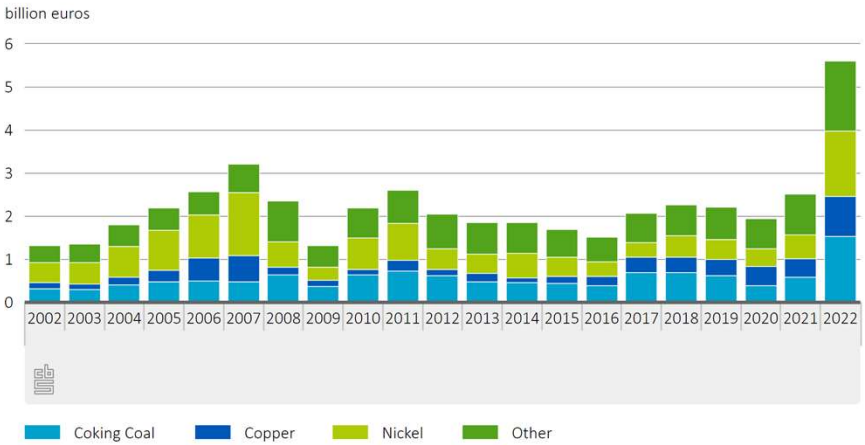
* Includes quasi-transit trade and imports for re-exports

Time-series of imports (Source: ITGS from Statistics Netherlands)

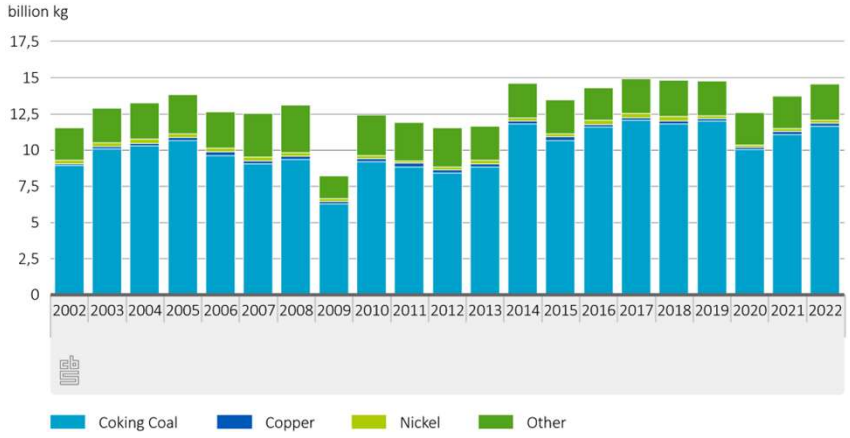
Dutch import of CRMs (in values)



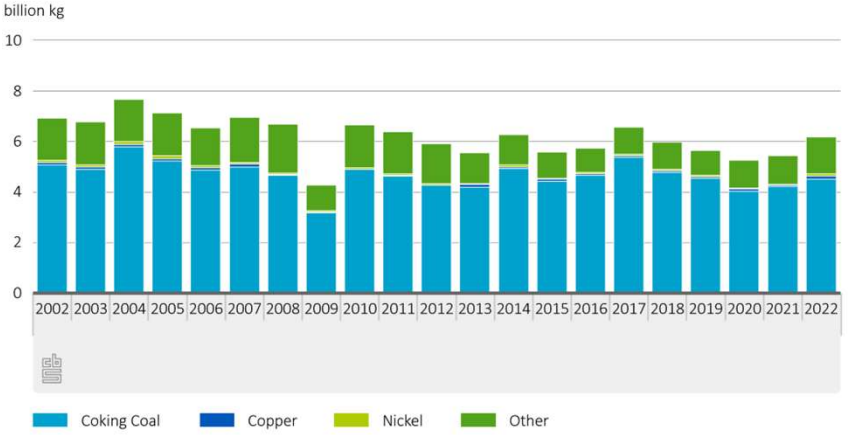
Dutch import of CRMs (in values), excluding quasi-transit trade



Dutch import of CRMs (in weights)



Dutch import of CRMs (in weights), excluding quasi-transit trade



Use and origin of *directly* imported CRMs

		Dutch industries		Domestic FD	Exports (country x product)	
		1	2	Cons; Inv	C1, Product B	C2, Product B
Dutch industries	1	Domestic intermediary deliveries		Dom. FD	0	50
	2				50	0
Imports (country x product)	C1, Product A	50	0	Dom. FD	Re-exports (based on Lemmers & Wong, 2019; no from country to country dim.)	
	C2, Product A	0	50			
		Value added				
		Total output				

Exports of ind. 1

Exports of ind. 2

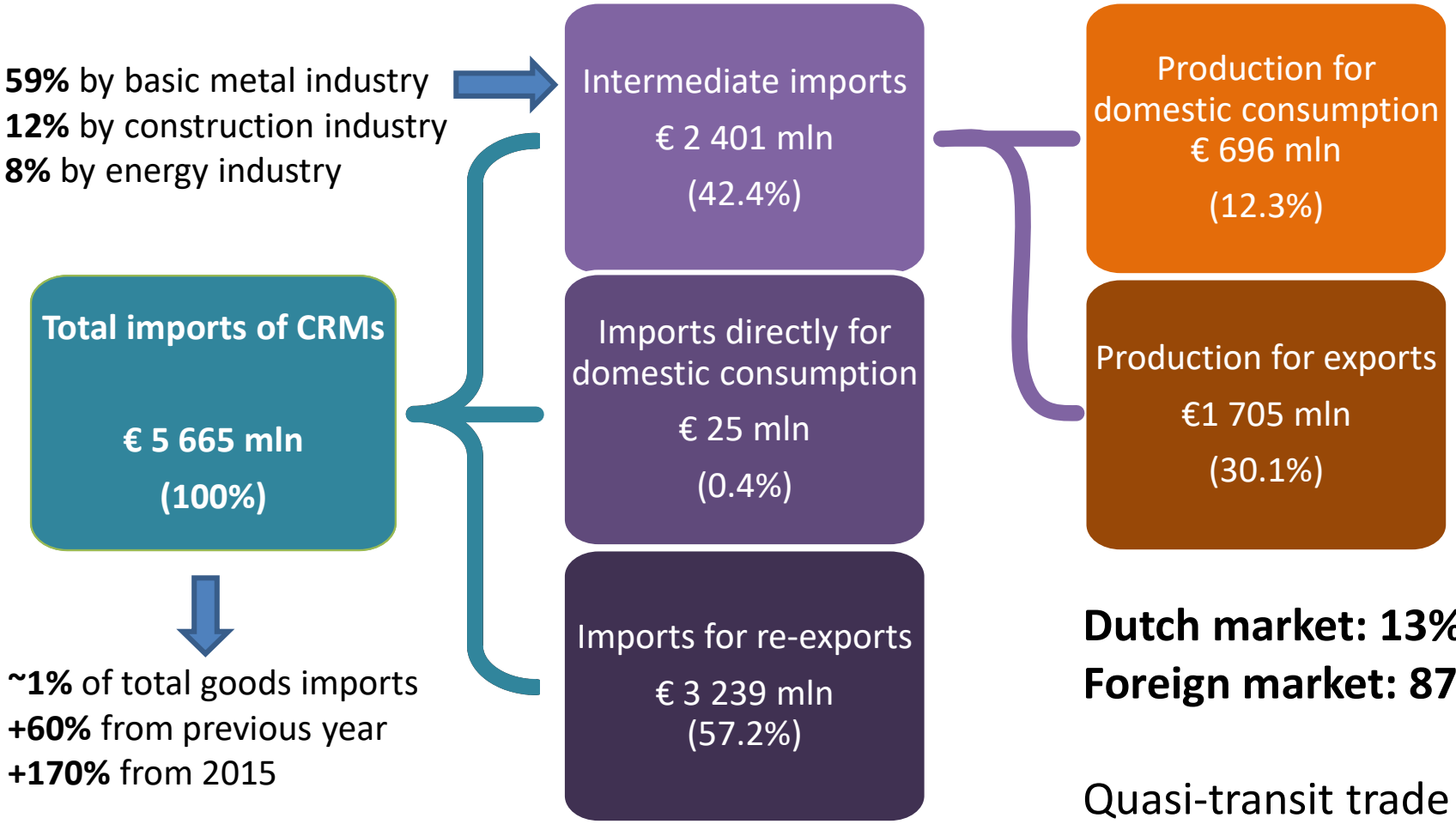
Imports of ind. 1

Imports of ind. 2

Strategy: link micro trade data to national IO table

- Look at trader level who is importing what from where
- Remove imports for re-exports (Lemmers & Wong, 2019)
- Put it in a National Accounts framework (Aerts et al., 2022)

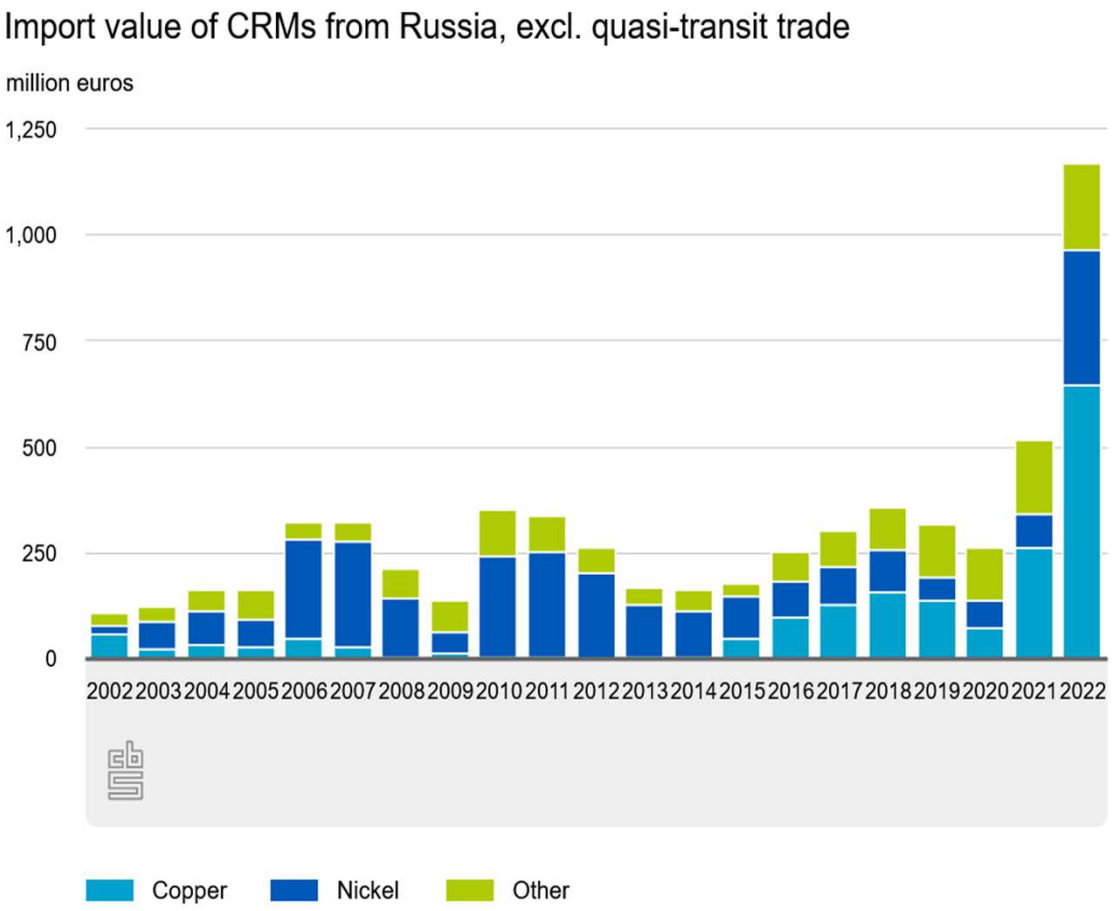
Use of *directly* imported CRMs (2022)



Dutch market: 13%
Foreign market: 87%

Quasi-transit trade excluded!

Origin and type of *directly* imported CRMs



Origin: #1 Russia *(~20%, but mainly re-exports)*, #2 Australia and #3 US; just 8% from EU-26

Type: #1 Coking coal *(mainly by Dutch firms)*, #2 Nickel *(mainly re-exports)*, #3 Silicon metal

More details on cross-country heterogeneity (import/use of individual CRMs from which country by which industries) **in full CBS report**

Quantifying *indirectly* imported CRMs in 3 steps

Relates to **Lemmers et al. (2023)** on products in supply chain and **Walker et al. (2023)** on replacing SNAC with SAMCA

- Match (detailed) Dutch imports to foreign industries in OECD ICIO

How much does each foreign industry × country export to the Netherlands?

Step 1

IO-calculations

- How much does a foreign industry export to another foreign industry **within the Dutch** supply chain?

Step 2

- Construct **"Global" export-import tables** (HS-6) fully aligned with OECD ICIO to add product detail in output of 2

FIGARO supply tables, BACI HS-6 trade data, Dutch use tables, BEC classification

Step 3

Quantifying *indirectly* imported CRMs

Supplying country	Region/continent of use					
	America	Asia	EU-27	Óther Europe	Other	Total
Australia	3,8 (3%) (4%)	84,3 (69%) (15%)	31,6 (26%) (3%)	1,0 (1%) (1%)	1,9 (2%) (4%)	122,6 (100%) (6%)
Belgium	1,8 (4%) (2%)	2,2 (4%) (0%)	46,3 (91%) (4%)	0,2 (0%) (0%)	0,5 (1%) (1%)	51,1 (100%) (3%)
Brazil	3,1 (8%) (3%)	11,3 (28%) (2%)	23,9 (59%) (2%)	1,3 (3%) (2%)	0,7 (2%) (1%)	40,2 (100%) (2%)
Canada	6,7 (8%) (7%)	24,0 (28%) (4%)	35,0 (41%) (3%)	19,5 (23%) (24%)	0,3 (0%) (1%)	85,4 (100%) (4%)
Chile	4,0 (4%) (4%)	64,8 (68%) (12%)	18,7 (20%) (2%)	0,4 (0%) (1%)	7,6 (8%) (14%)	95,6 (100%) (5%)
China	5,7 (8%) (6%)	35,5 (49%) (6%)	24,8 (34%) (2%)	3,1 (4%) (4%)	3,3 (5%) (6%)	72,3 (100%) (4%)
Germany	5,7 (5%) (6%)	11,3 (10%) (2%)	87,9 (81%) (7%)	3,0 (3%) (4%)	0,9 (1%) (2%)	108,7 (100%) (5%)
Italy	2,3 (4%) (2%)	1,3 (2%) (0%)	55,0 (89%) (4%)	1,3 (2%) (2%)	1,8 (3%) (3%)	61,5 (100%) (3%)
Kazakhstan	0,1 (0%) (0%)	5,3 (11%) (1%)	38,0 (80%) (3%)	2,1 (4%) (3%)	2,2 (5%) (4%)	47,8 (100%) (2%)
Norway	1,8 (6%) (2%)	2,2 (8%) (0%)	24,9 (85%) (2%)	0,3 (1%) (0%)	0,2 (1%) (0%)	29,3 (100%) (1%)
Peru	3,5 (7%) (4%)	33,1 (70%) (6%)	8,4 (18%) (1%)	0,4 (1%) (1%)	1,7 (4%) (3%)	47,1 (100%) (2%)
Poland	0,1 (0%) (0%)	2,3 (3%) (0%)	67,0 (94%) (5%)	1,6 (2%) (2%)	0,5 (1%) (1%)	71,5 (100%) (4%)
Rusland	5,8 (2%) (6%)	42,3 (14%) (8%)	228,7 (78%) (19%)	14,0 (5%) (17%)	3,2 (1%) (6%)	294,0 (100%) (15%)
South Africa	2,4 (6%) (3%)	16,7 (38%) (3%)	19,8 (45%) (2%)	1,5 (3%) (2%)	3,4 (8%) (6%)	43,9 (100%) (2%)
UK	0,8 (2%) (1%)	8,3 (23%) (2%)	25,0 (68%) (2%)	1,4 (4%) (2%)	1,2 (3%) (2%)	36,8 (100%) (2%)
US	18,5 (13%) (20%)	23,8 (16%) 4%)	90,5 (63%) (7%)	8,3 (6%) (10%)	2,9 (2%) (5%)	144,0 (100%) (7%)
Other EU-27	2,8 (2%) (3%)	9,7 (5%) (2%)	163,0 (89%) (13%)	4,7 (3%) (6%)	3,6 (2%) (7%)	183,8 (100%) (9%)
Other non-EU-27	25,1 (5%) (27%)	171,0 (37%) (31%)	236,0 (51%) (19%)	15,8 (3%) (20%)	17,6 (4%) (33%)	465,4 (100%) (23%)
Total	93,8 (5%) (100%)	549,1 (27%) (100%)	1 224,5 (61%) (100%)	79,8 (4%) (100%)	53,7 (3%) (100%)	2 001,0 (100%) (100%)

Figure: bilateral trade in CRMs within the Dutch supply chain, mln. euros, 2019 (before entering NLD!)

- All upstream chains
- Excludes indirect Dutch imports for re-exports and transit-trade (not contained in MRIOs)

Quantifying *indirectly* imported CRMs

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Illustration: In the Dutch supply chain of CRMs, **Chile exports €65 million in CRMs to Asia** (2/3 of total Chilean CRM exports in Dutch supply chain)

- Mainly copper to China
- Possible to quantify how much embodied in which directly imported products
- e.g., how much nickel from Russia or lithium from Chile involved in direct Dutch imports of cars from the US

Step 1: match Dutch imports to foreign industries

Necessary ingredients:

- Imports of goods and services
  - CPA
  - Country
  - Import value
- Figaro supply table
  - CPA
  - Country
  - Industry (NACE2)
  - Total (production) value
- MRIO
  - Industries (NACE2)

Approach (basic idea)

Necessary ingredients:

- Imports of goods and services
  - **CPA**
  - Country
  - Import value
- Figaro supply table
  - **CPA**
  - Country
  - **Industry** (NACE2)
  - Total (production) value
- MRIO
  - **Industries** (NACE2)

Make an industry distribution per **CPA** and **country** on basis of the production value

Possible problem #1

- Matching (non-unique) industries in NACE2 (+) from Figaro to industries in a different MRIO, for example:

	ADB	NACE2
1	Textiles and textile products	C13T15
2	Leather, leather products, and footwear	C13T15

- **Consequence**: the textile and leather industries have identical shares; they might become too dominant in a distribution per CPA and country (the production value of C13T15 is duplicated)
- Solution A: allocate manually based on the last CPA digit. E.g.: textile products are only made by the textile industry; shoes by the leather industry
- Solution B: distribute the production value of those sectors for each CPA of a certain land based on the production (of those sectors) in the MRIO; and only then make an industry distribution

➢ **Solution B was chosen** as this is easier to program

Possible problem #2

Figaro and OECD MRIO have different country coverages

- Countries in both Figaro and in the OECD MRIO?
  → Trust ‚'entirely' on Figaro for the country and CPA distributions
- Countries *not* in Figaro, but present in the OECD MRIO? (e.g., Singapore),
  → Make inferences on the distributions.
- Possible solutions:
  - Ideally, we use a different source! But where? National SUTs? Exiobase?
  - Make distributions based only on the FIGARO ROW?
  - Something on developing countries versus non-developing-countries?
  - A combination of FIGARO ROW + FIGARO countries?
    But how do we combine these? Using weights - 50/50, 75/25?

Possible solution: combine distributions

- Chosen solution: **combine FIGARO ROW & FIGARO non-ROW** (mainly due to cross-country heterogeneity)
- Choose weights for ROW and non-ROW such that the **sectoral exports of a certain country to the Netherlands** (according to the MRIO) **aligns well with 'estimations' of these exports on the basis of the Dutch import figures** (from Statistics Netherlands) and FIGARO distributions. Thus, we require totals of Dutch goods imports.
- Good fit = minimal (average) relative sectoral discrepancies (or distance) of a country between the MRIO and a combination of FIGARO + Statistics Netherlands data

$$\widehat{w}_{\text{row}} = \underset{w\epsilon[0,1]}{\arg\min}(1/K)\sum_{i}^{K}\frac{|Import_{i,MRIO} - (w * Import_{i,ROW} + (1-w) * Import_{i,niet-ROW}|}{\max\left(Import_{i,MRIO}, (w * Import_{i,ROW} + (1-w) * Import_{i,niet-ROW}\right)}$$

Output Step 1

Now we have exports to the Netherlands per

- Industry in the MRIO
- Country in the MRIO

Next step: compute how much a foreign industry exports to another foreign industry within the **Dutch** supply chain

Step 2 – IO-analysis

Next step: compute how much a *foreign industry* exports *to another foreign industry* within the **Dutch** supply chain

For instance, in the chain of bilateral exports from **DEU basic metals (C24) → FRA fabricated metal products (C25),** the possibilities include:

- DEU C24→ FRA C25→ Exports to NLD; but also:
- DEU C24→ FRA C25 → BEL C29 (auto-industry) → Exports to NLD, or
- CHN B05_06 (mining and quarrying) →DEU C24 → FRA C25 → Export to NLD
- Etc.

Output Step 2 – IO-analysis

Given *i* = exporting industry and *j* = importing industry, mathematically this is approximated by:

$$bilateral\ trade_{i,j} = a_{i,j} * \sum_k l_{j,k} * export_k$$

$$\begin{bmatrix} a_{ii} & a_{ij} & \cdots & a_{ik} \\ a_{ji} & a_{jj} & \cdots & a_{jk} \\ \vdots & \vdots & \ddots & \vdots \\ a_{ki} & a_{kj} & \cdots & a_{kk} \end{bmatrix} \begin{bmatrix} l_{ii} & l_{ij} & \cdots & l_{ik} \\ l_{ji} & l_{jj} & \cdots & l_{jk} \\ \vdots & \vdots & \ddots & \vdots \\ l_{ki} & l_{kj} & \cdots & l_{kk} \end{bmatrix}$$

From Step 1

— With the $a_{i,j}$ $(i,j)^{th}$ element of the input coefficient matrix A that is made on the basis of the MRIO, $l_{j,k}$ is the $(i,k)^{th}$ element in the Leontief inverse and $export_k$ is the export to the Netherlands by foreign industry k from step 1.

— The output is a dataset with bilateral trade data between foreign industries related to the export to Netherlands. We still miss a product dimension!

Step 3 – Construct global export/import tables

a) **Build global export table** on basis of BACI, MRIO & Figaro
   Output: how much of a HS-6 product does each foreign industry in the MRIO export?
b) **Obtain import use distributions** on basis of Dutch use table
   Output: how is each imported HS-6 product used by a foreign country? (i.e., import distribution across industries)
c) **Combine (a) and (b)** proportionally.
d) **Extra steps** (e.g., BEC) to ensure consistency with the MRIO

Output = dataset (a **super detailed OECD ICIO table**) showing **bilateral** industry-to-industry trade with HS-6 level detail between all country*industry combinations in the MRIO

Step 4 – Combine steps 2 and 3

Recap

Output from Step 2: a dataset with bilateral trade flows between foreign industries related to the export to the Netherlands

- We still miss a product dimension!!!

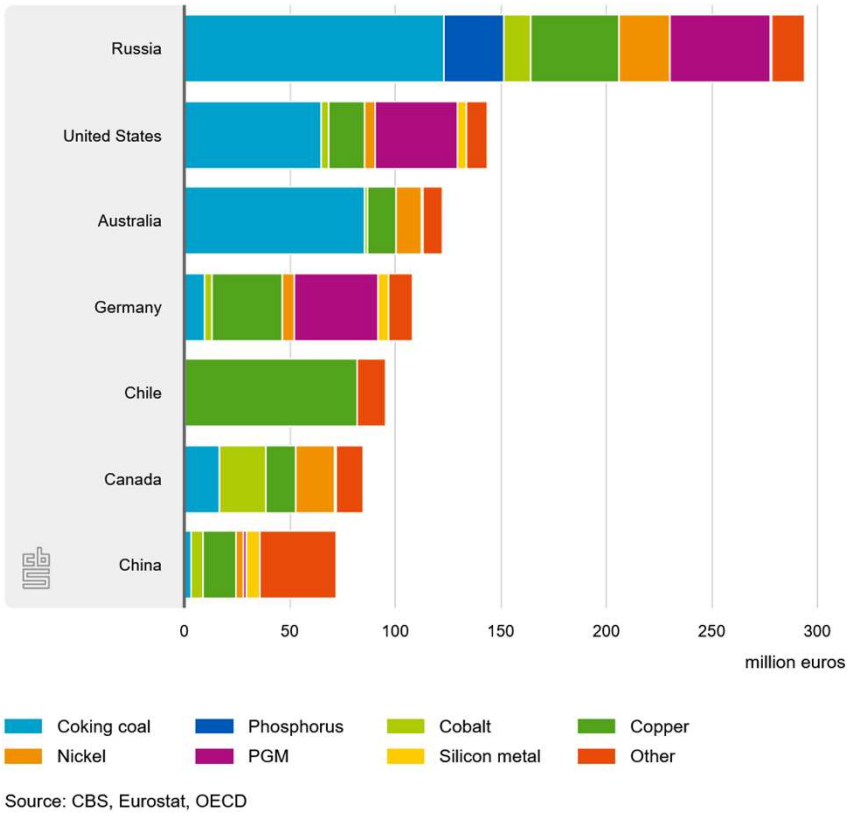
Output from Step 3: a dataset with bilateral trade flows between foreign industries at detailed product level (HS-6)

Last step: combine 2 and 3, i.e., add a product dimension to bilateral flows in Step 2 on the basis of a proportional product distribution in Step 3.

Final output: bilateral trade of products (HS-6) between foreign industries that is (indirectly) related to exports to the Netherlands (i.e. to Dutch imports)

New insights and output

Largest indirect suppliers of critical raw materials, 2019



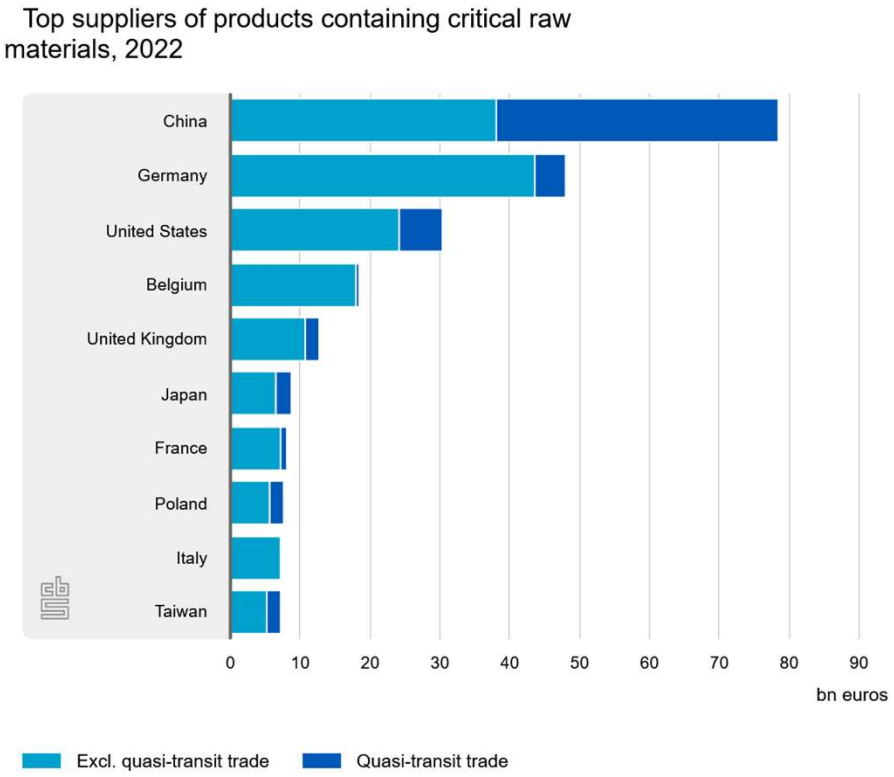
Source: CBS, Eurostat, OECD

Type of new insights:

- Russia top indirect supplier (left)
- Indirect CRM imports 2X larger than direct CRM imports
- Much more in report:

1. Which industries are the top indirect importers of CRMs?
2. Which industries are the most dependent on CRMs for imports?
3. Which industries import more CRMs indirectly, which ones more indirectly?

Top suppliers of products that *contain* CRMs



Resource Scanner lists which products (HS-6) contain which CRMs: https://www.grondstoffenscanner.nl (jointly developed by the Dutch Organization for Applied Scientific Research and Netherlands Enterprise Agency)

- Import value of unique products containing CRMs (e.g., solar panels or electrical cars) =
  > 1/3 total value of Dutch imports
- Importance of China **much** higher than in the direct (or even indirect) import of CRMs themselves

Future research

Limitation of GVC analysis: extraction of CRMs that are processed into (intermediate) products within a country before crossing that same country's border is not captured in approach

- Due to their lack of visibility in trade data
- China produces gallium and creates LEDs for export. Netherlands imports these via Germany in the form of electrical appliances.

Future research:

- Map the indirect imports of (intermediate) products known to embody CRMs instead of CRMs themselves (e.g., map LEDs instead of gallium)
- Look into the CRMs involved in specific import products
- Focus on 'criticality' of individual CRMs and vulnerabilities
- Map shifts in CRM supply chains (e.g., Congo exports directly to EU?)

Conclusion

- Analysis demonstrates the **potential of using detailed data to increase granularity** in national IOTs and publicly available MRIOs
- …allows for in-depth GVC-type analyses and monitoring of CRM dependencies (both direct and indirect), a topic high on the policy agenda

- **The Netherlands is Europe's largest importer of CRMs from outside Europe, *but…***
- 87-95% (excl/incl. transit trade) for foreign market (re-exports or processed into exports)
- Largest flows involve low value (coking coal) or strategic, not 'critical', materials (copper, nickel)

- **Russia is largest supplier (direct / indirect) of CRMs to NLD in gross terms, *but…***
- Role of China is much greater in terms of extraction, dependence on unique CRMs, and in the import of products embodying CRMs

- Much room for further investigation and deeper analyses (refer to previous slide)

Thank you for your attention!

Questions of comments?

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