Glass Performance Days 2025

10 – 12 JUNE 2025 | NOKIA ARENA - TAMPERE, FINLAND

GLASS PERFORMANCE DAYS 2025

THE LIFE CYCLE EMBODIED ENERGY OF A VACUUM INSULATED GLASS

Quantifying the Life Cycle Trade-offs of Vacuum Insulated Glass: An Embodied Energy Perspective

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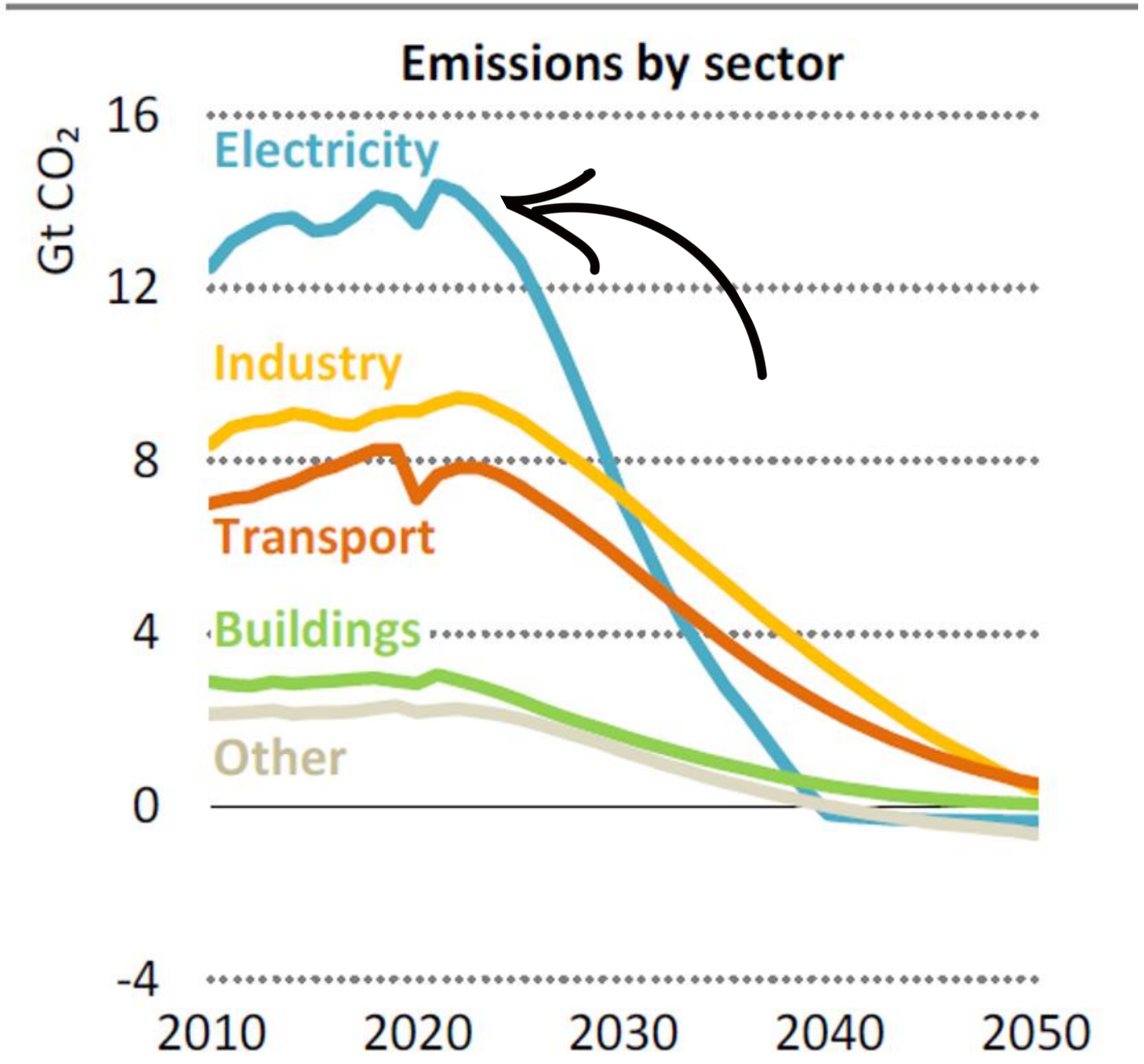
WHY THE TOPIC MATTERS?

- Building sector accounts for 30% of the global energy use.
- 6 $GtCO_2$ indirect emissions — mostly electricity from heating and cooling.

	2010	2021
Buildings 50%	9 637	12 594
Industry	7 450	10 166
Transport	295	441
Hydrogen production	-	2
Global electricity demand	**18 548**	**24 700**



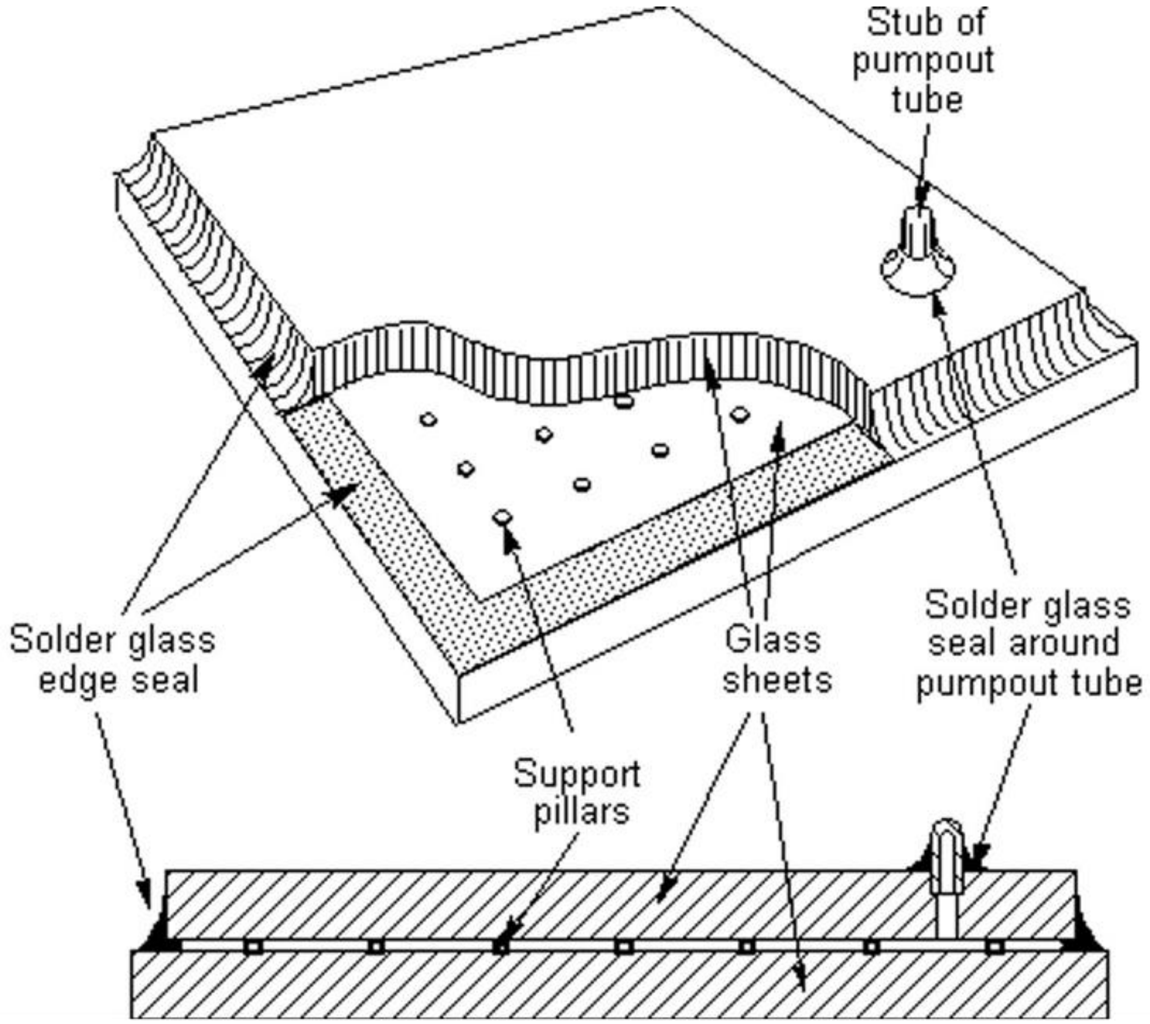
WHY THE TOPIC MATTERS?

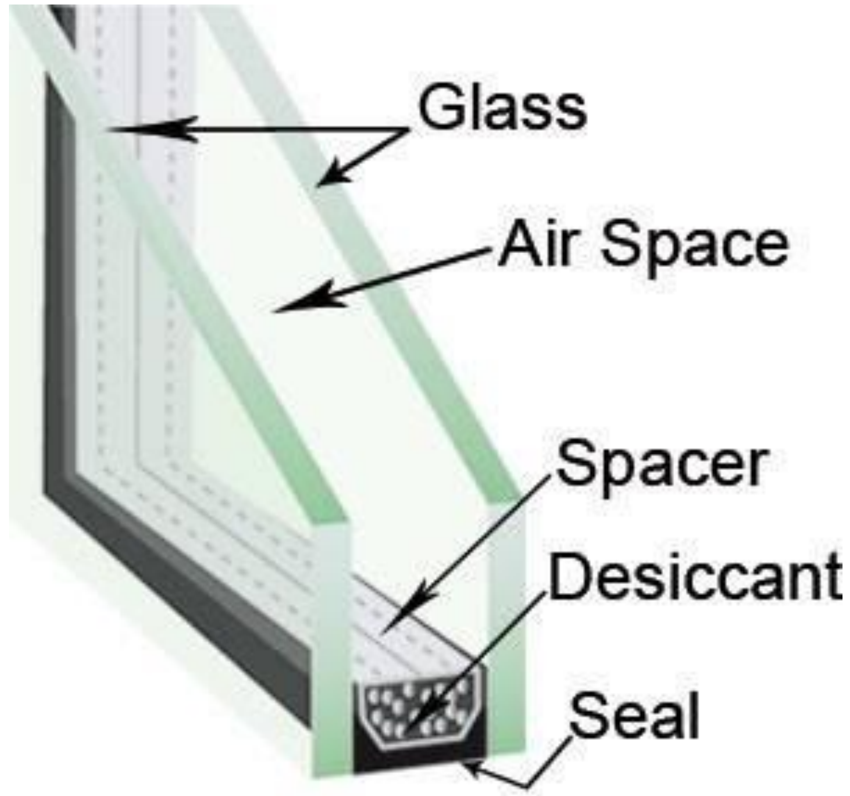
Windows = Major energy loss contributor

- Up to 60% of heat loss from buildings
- Poor insulation, especially in OECD countries
- Cooling demand is growing fastest (IEA 2022)

Energy efficiency vs. embodied emissions

- Efficient designs = lower ops energy, but higher embodied emissions
- Need full Life Cycle Analysis (LCA) to evaluate trade-offs
- VIG = promising technology — but what's the real impact?

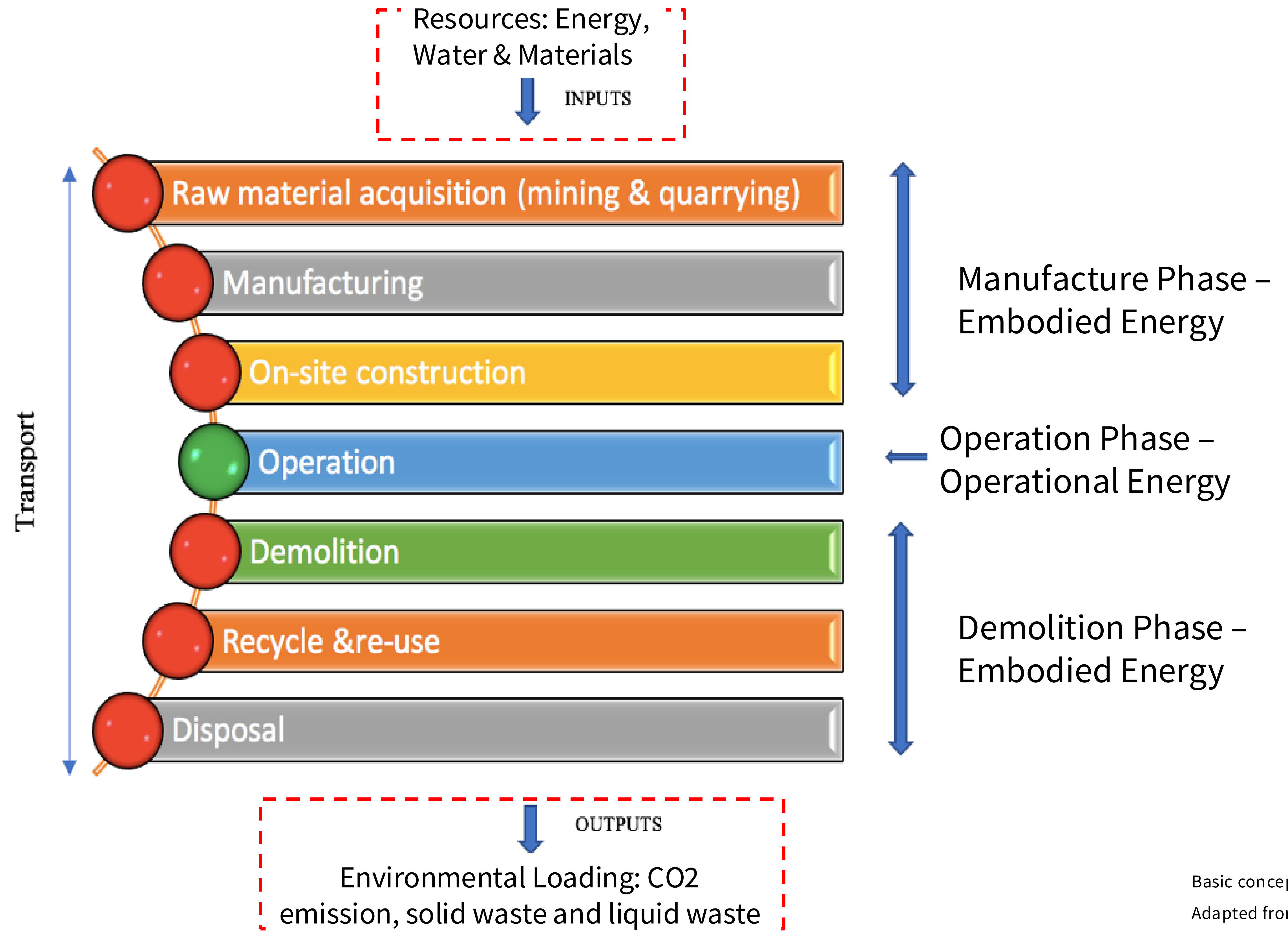




VIG VS IGU

Feature	IGU	VIG
Insulation Method 🌀	Gas-filled gap (Air, Argon, Krypton)	Vacuum gap (~0.2 mm)
Thermal Conductance 🌡️	1.8–3.0 W/m²·K	As low as 0.35 W/m²·K
Glass Thickness 📏	~24–36 mm (double/triple pane)	~6.2 mm (2 × 3 mm panes + vacuum gap)
Spacer Type 🧩	Hollow spacer (aluminum/steel/plastic) on perimeter of glass	Micro-scale pillars, as an array on glass surface, to resist atmospheric pressure
Edge Sealing 🔗	Butyl/Silicone room temp. sealants as a gas barrier	Solder glass frit, formed at high-temp for a hermetic seal
Low-E Coating 🪞 ✨	Single coating on interior pane	Single coating on interior pane
Manufacturing Energy ⚙️ 🔋	Moderate (mainly glass processing + soft sealing)	High (due to edge seal cure, vacuum sealing, precision component work)

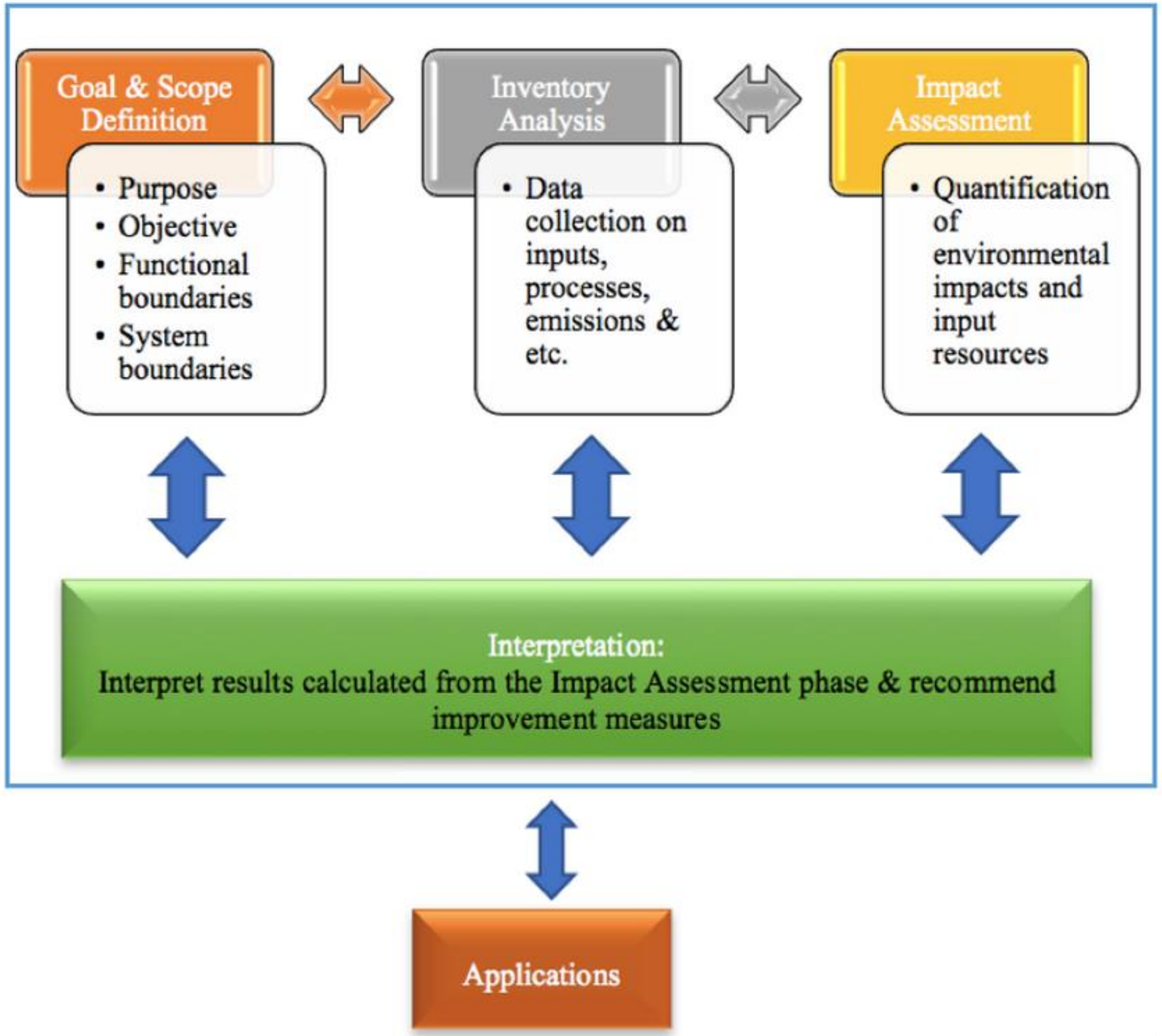
METHODOLOGY - LIFE CYCLE ASSESSMENT (LCA)



Basic concept of LCA:

Adapted from source: (Chau, Leung, & Ng, 2015)

METHODOLOGY - LIFE CYCLE ASSESSMENT (LCA)



Adaptation of LCA framework based on ISO 14040

LCA METHOD COMPARISON

	Process-based LCA	Input-Output (IO) LCA
🔍 Data Type	Detailed process & material data	Economic sector-based data
📏 Granularity	High (specific)	Low (aggregated)
🌍 System Coverage	Incomplete (truncation error)	Complete (entire economy included)
⚠️ Limitation	Misses upstream supply chain steps	Not product-specific
✅ Strength	High accuracy for specific processes	Captures full supply chain impacts

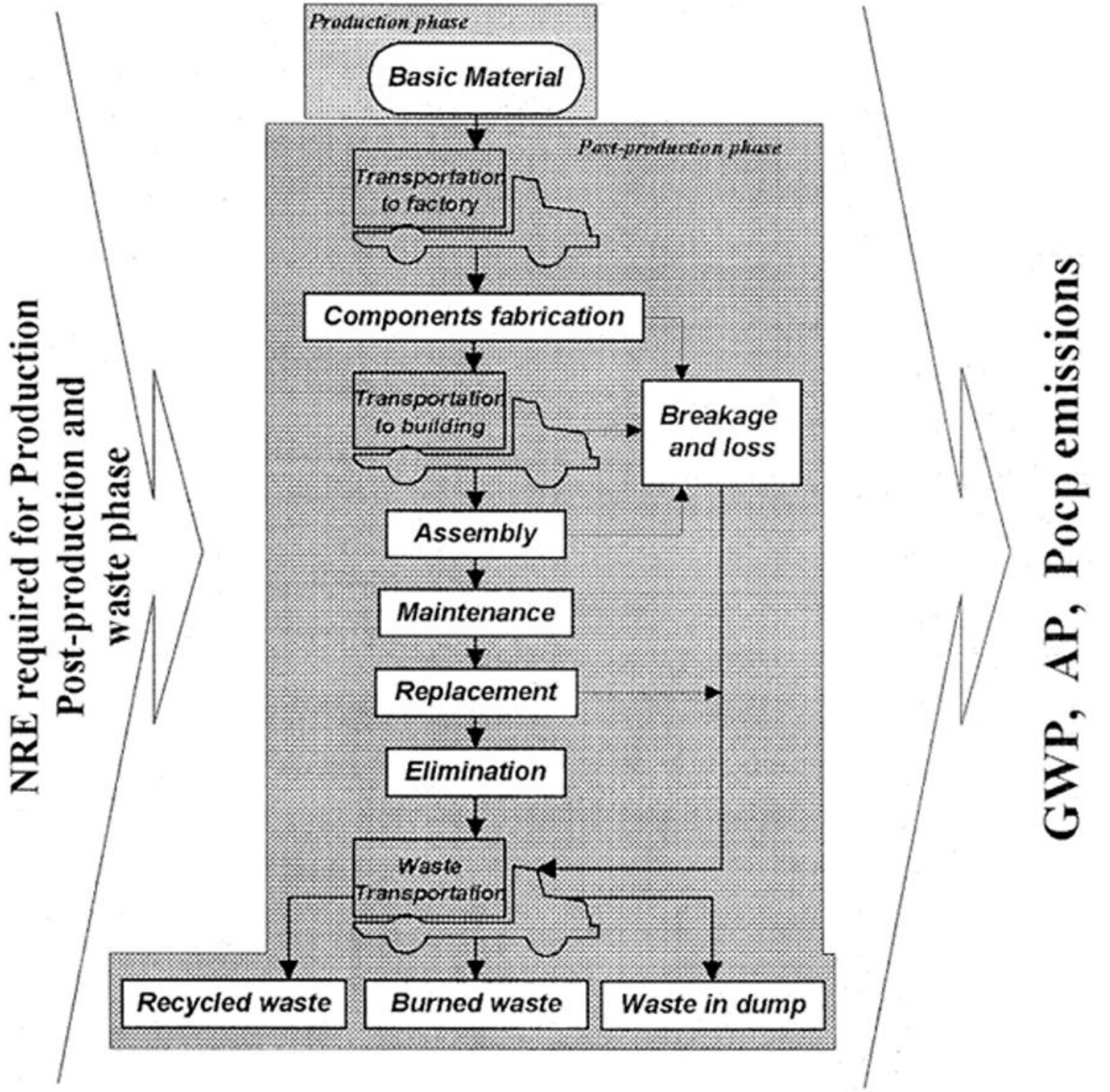
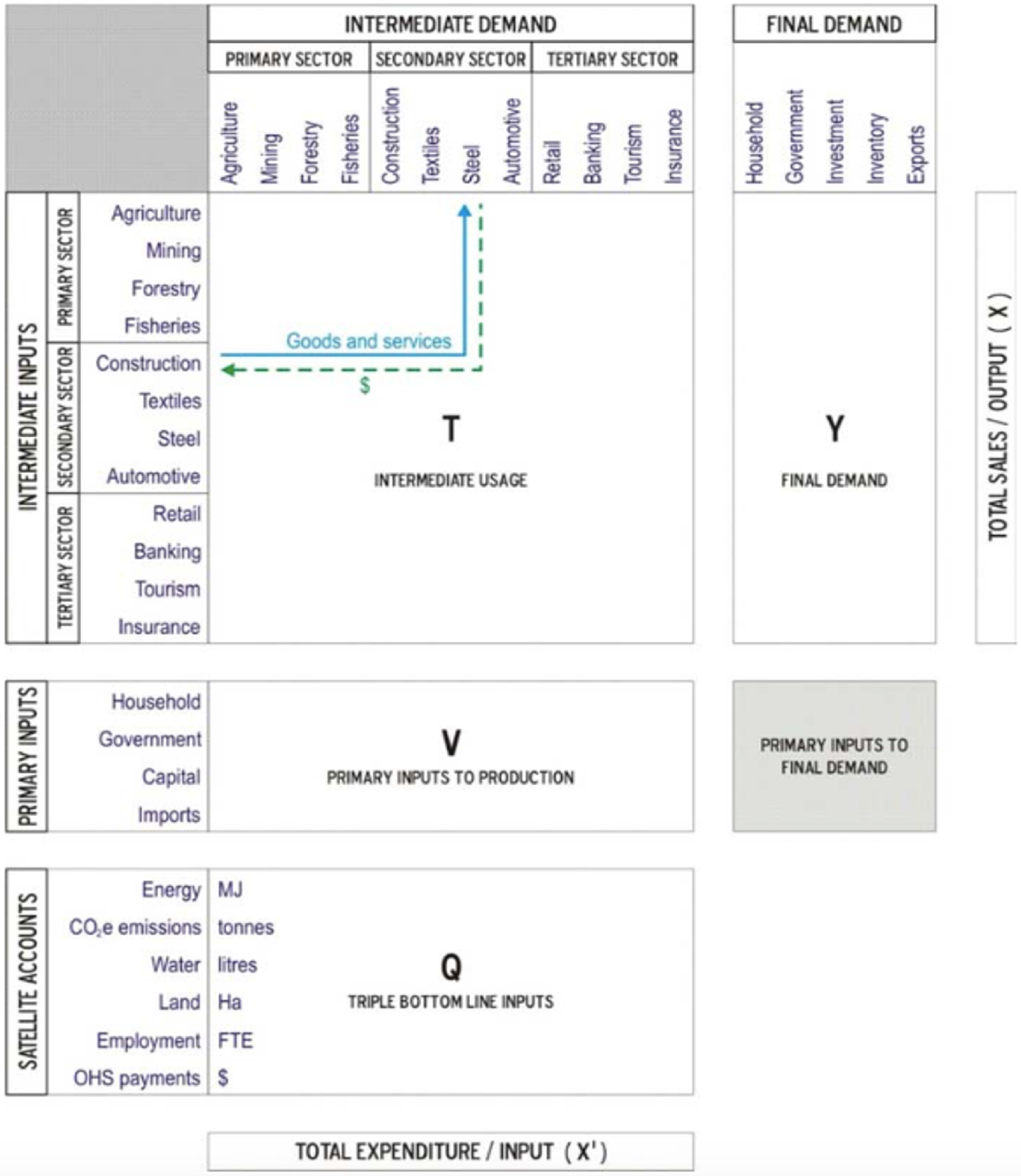


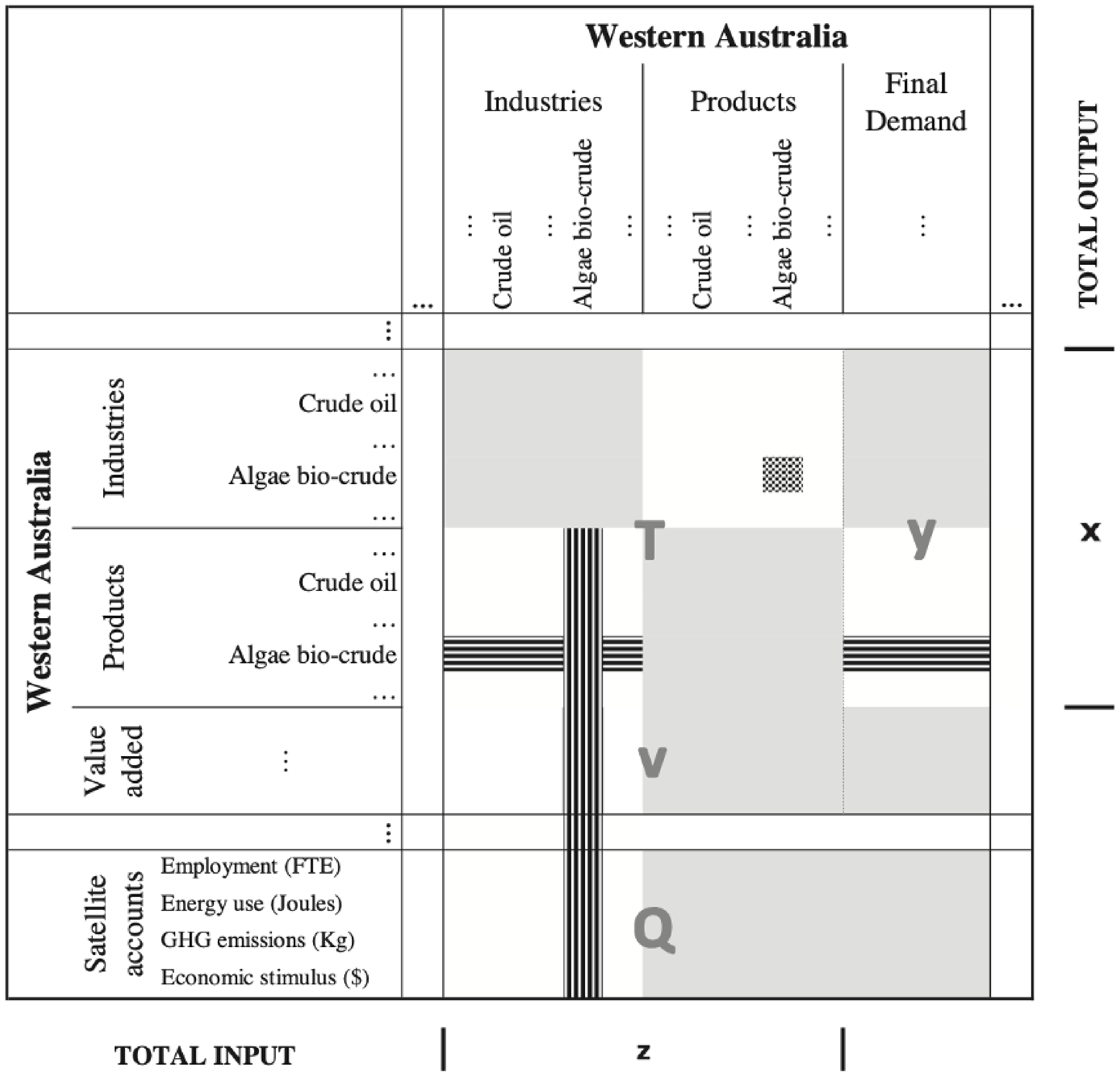
Fig. 1. Life-cycle assessment method for the advanced glazing system.

Source: (Citherlet et al., 2000)



WHY HYBRID LCA?

- ✅ Combines strengths of both methods
- 🛠️ Uses detailed process data where available
- 🌐 Supplements with IO data to capture entire supply chain
- ⚖️ Minimizes truncation and aggregation errors
- 📊 Suitable for complex products like VIG with multi-tiered suppliers



Key:

...	Other regions of the MRIO table	y	Final demand matrix, e.g. household consumption ($)
…	Different categories	Q	Satellite accounts matrix
x	Total output		Blank spaces - No data
z	Total input		Sale of algae bio-crude to different industries
T	Intermediate transactions matrix ($)		Inputs needed for the production of algae bio-crude
v	Primary inputs matrix, e.g. wages and salaries ($)		Total amount of bio-crude produced by the algae biofuel industry

Source: (Malik et al., 2015)

PHASE 1 – GOAL & SCOPE

🎯 **Goal**	Quantify embodied energy and GHG emissions in the supply chain of VIG and IGU
🌱 **Scope**	Assess environmental impacts related to energy & emissions
📦 **System Boundary**	Economy wide
📐 **Functional Unit**	1 m^2 of VIG/IGU

PHASE 2 – INVENTORY ANALYSIS

📂 **Data Sources**

🧪 **Process Analysis (PA)**

- 📈 Historical data & theoretical calculations
- 🔍 Literature review on VIG & IGU manufacturing
- 💼 Analysis of cost parity and production inputs

✅ **Outcome**:

- VIG:29 expenditure categories
- IGU:18 expenditure categories

🔗 **Input–Output (IO) Data**

🌐 **MRIO table (2019)** – U.S. economy, from GLORIA database

📊 Structure:

- 164 Regions
- 120 IO Sectors
- 6 Final Demand Categories
- 6 Value Added Categories
- Includes energy satellite account

PHASE 3 - IMPACT ASSESSMENT

A matrix : → $Aij = \frac{Tij}{xj} = T\hat{\mathbf{x}}^{-1}$

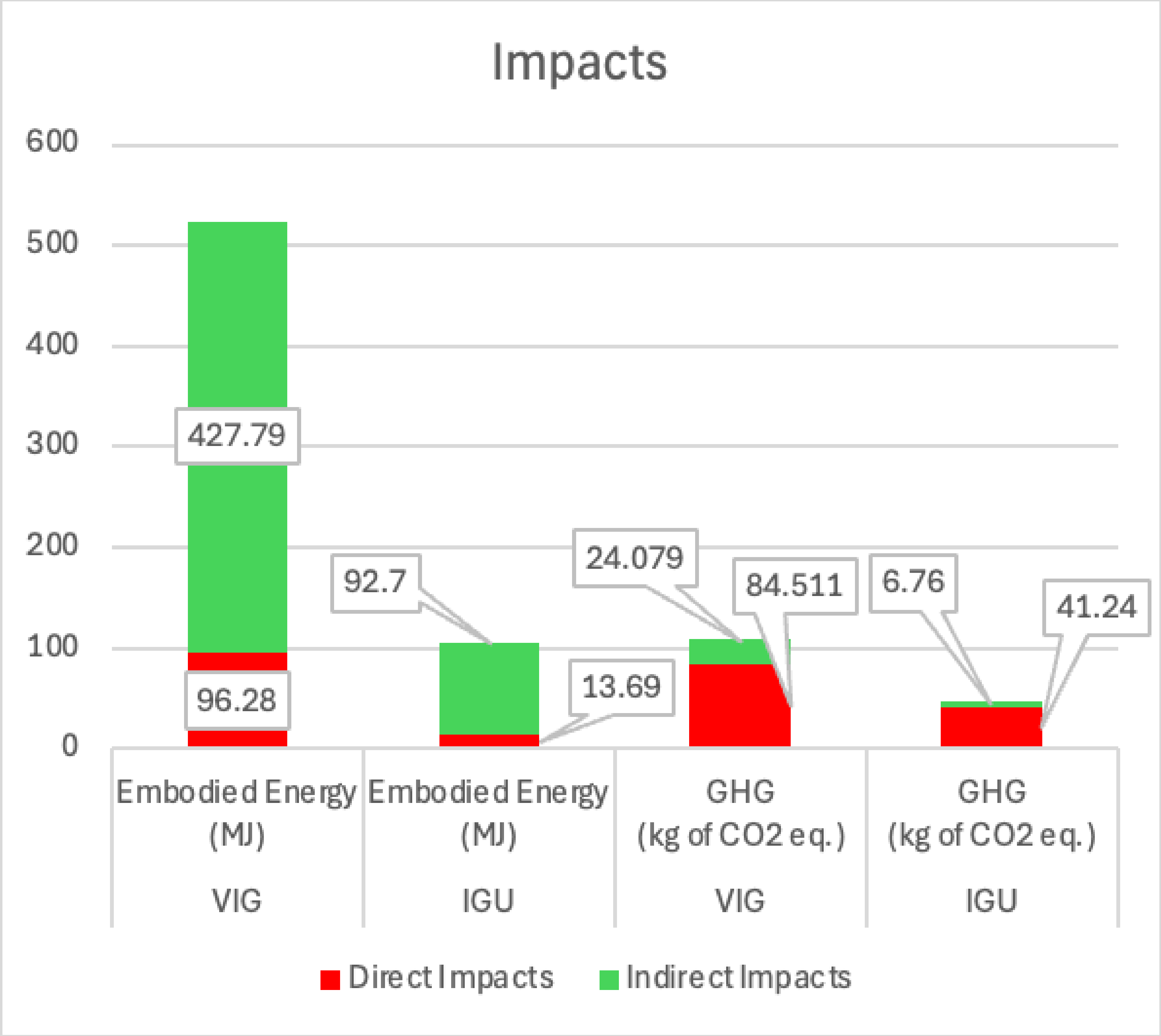
L matrix : → $L = (I-A)^{-1}$

Direct intensity (q) : → $\mathbf{q} = \mathbf{Q}\hat{\mathbf{x}}^{-1}$

Total intensity (m) : → $\mathbf{m} = \mathbf{q}(\mathbf{I} - \mathbf{A})^{-1}$

Energy Footprint : → **Footprint = qLy**

PHASE 4 - INTERPRETATION:



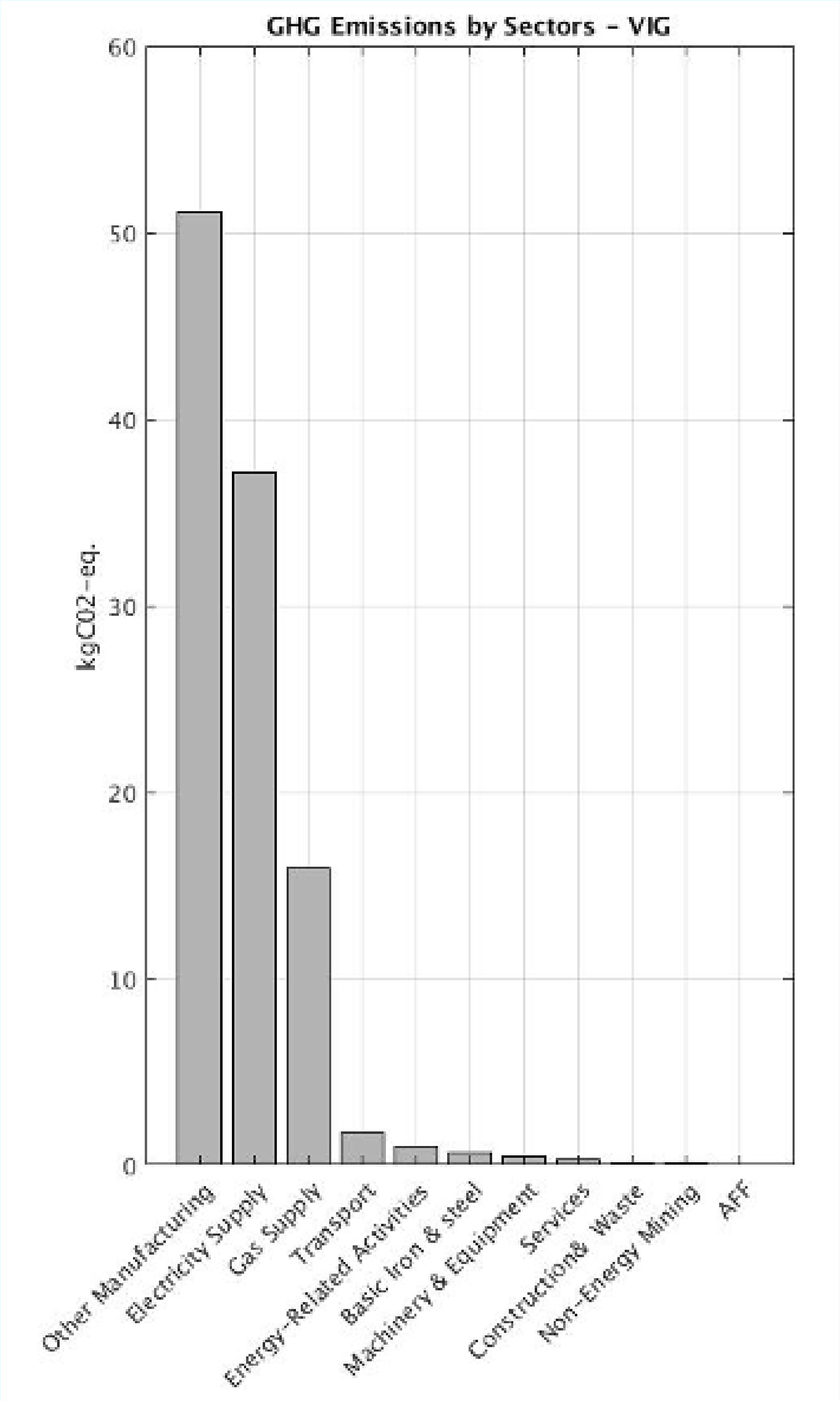
PHASE 4 – INTERPRETATION: GHG by Sectors for VIG & IGU

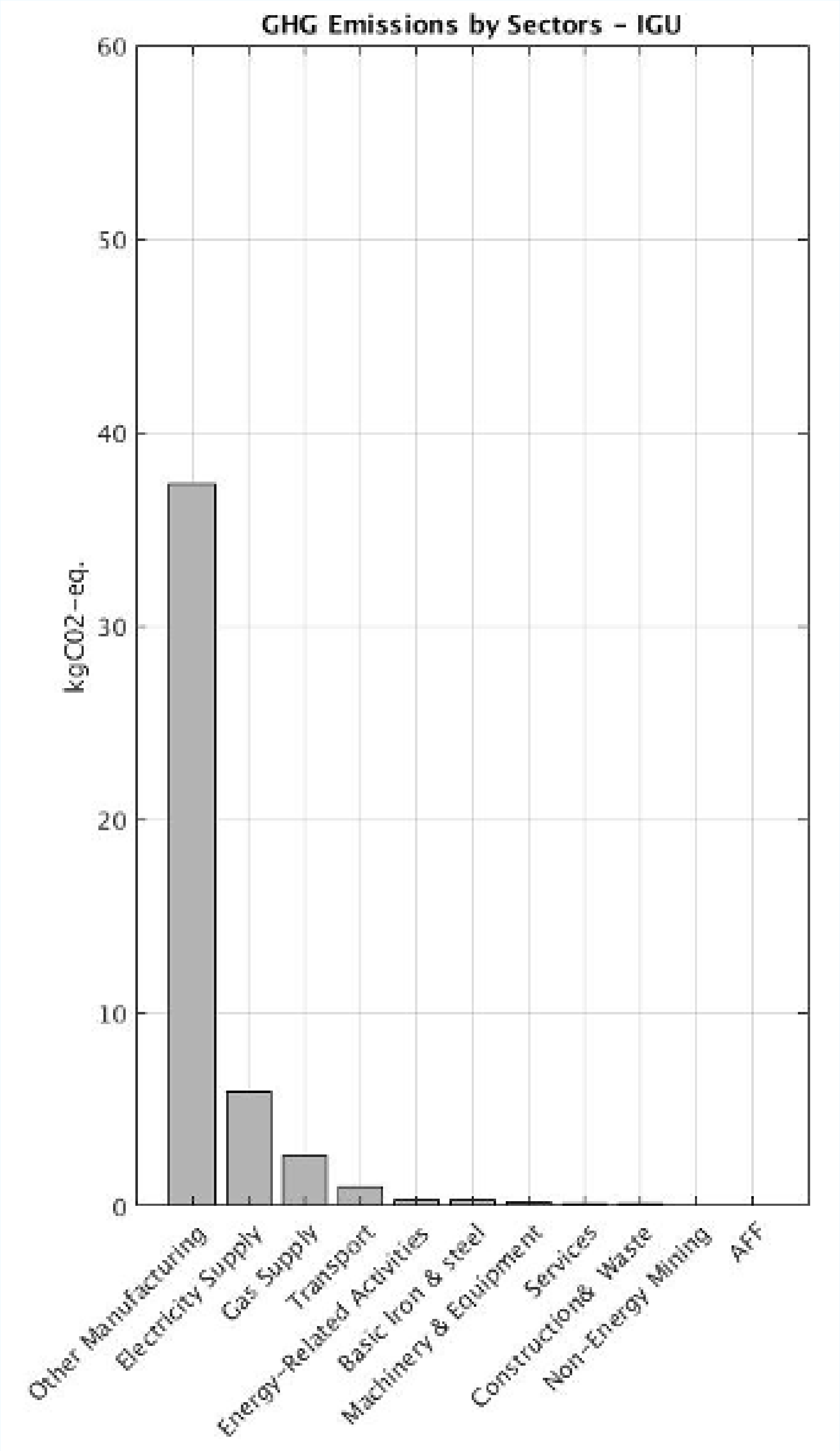
VIG – GHG Emissions

🏭 'Other ceramics' = 46% (main contributor – manufacturing inputs)

🔌 Electricity = 34.2% (linked to U.S. grid; ~40% natural gas)

⛽ Gas supply = 14.6% (upstream impacts; not directly purchased)





IGU - GHG Emissions

🏭 Other manufacturing = 75.1% (mainly float glass production)

🔌 Electricity = 12.3%

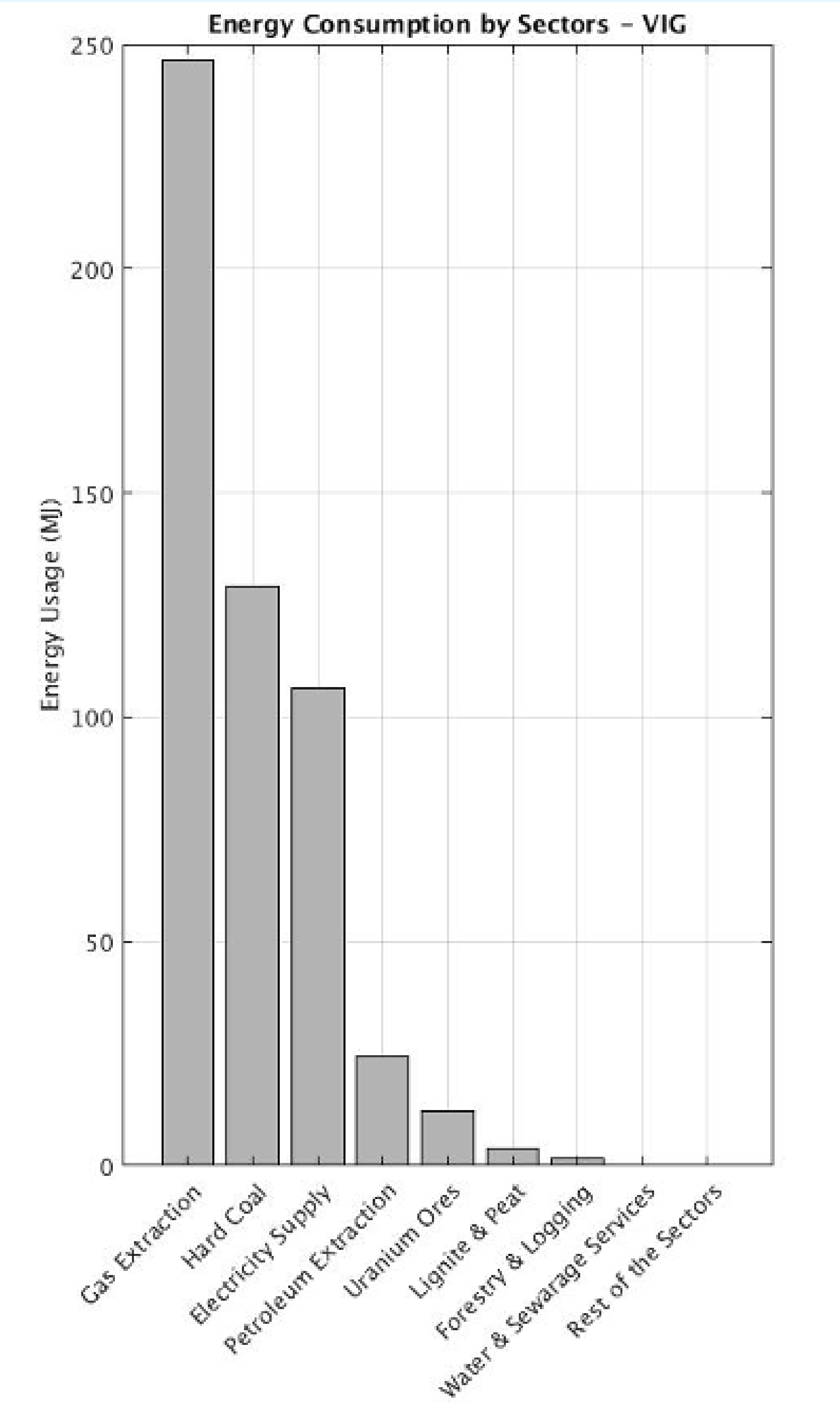
⛽ Gas supply = 14.6% (upstream impacts; not directly purchased)

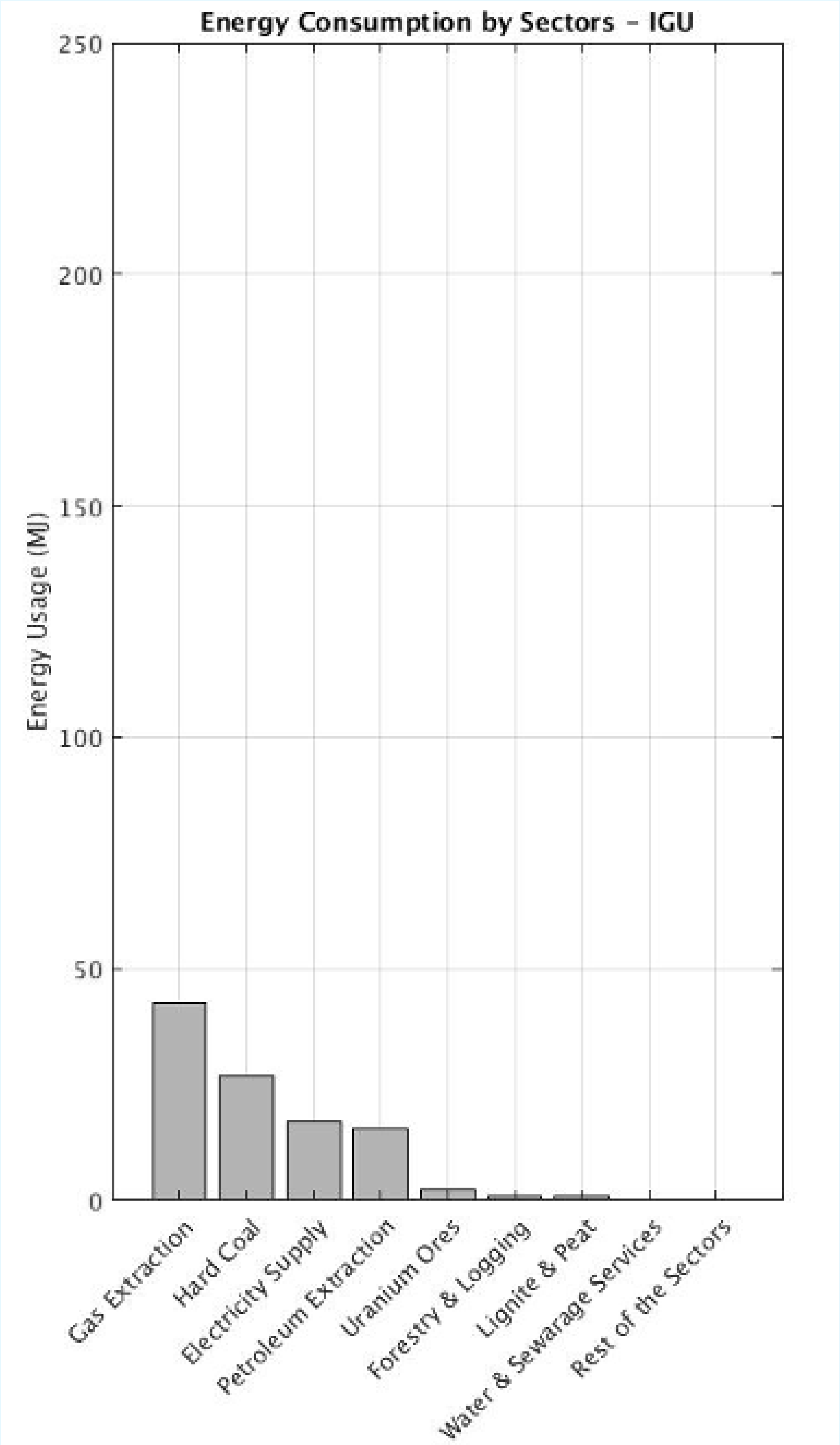
PHASE 4 – INTERPRETATION: Energy by Sectors for VIG & IGU

VIG – Embodied Energy

⛏️ Gas extraction & coal = highest energy use (due to fracking, processing)

🔋 Electricity = 3rd highest (used in vacuum sealing & equipment)



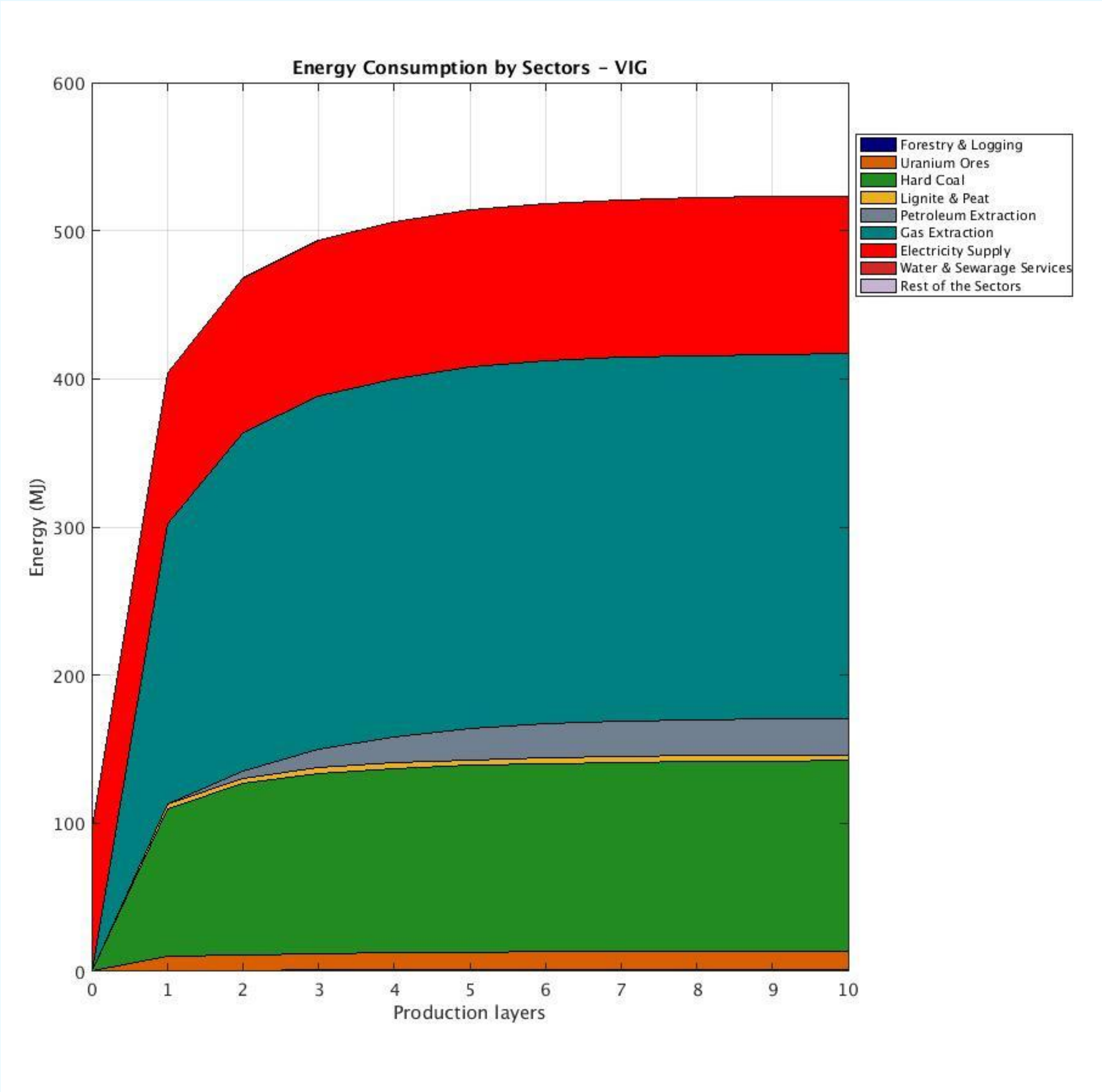


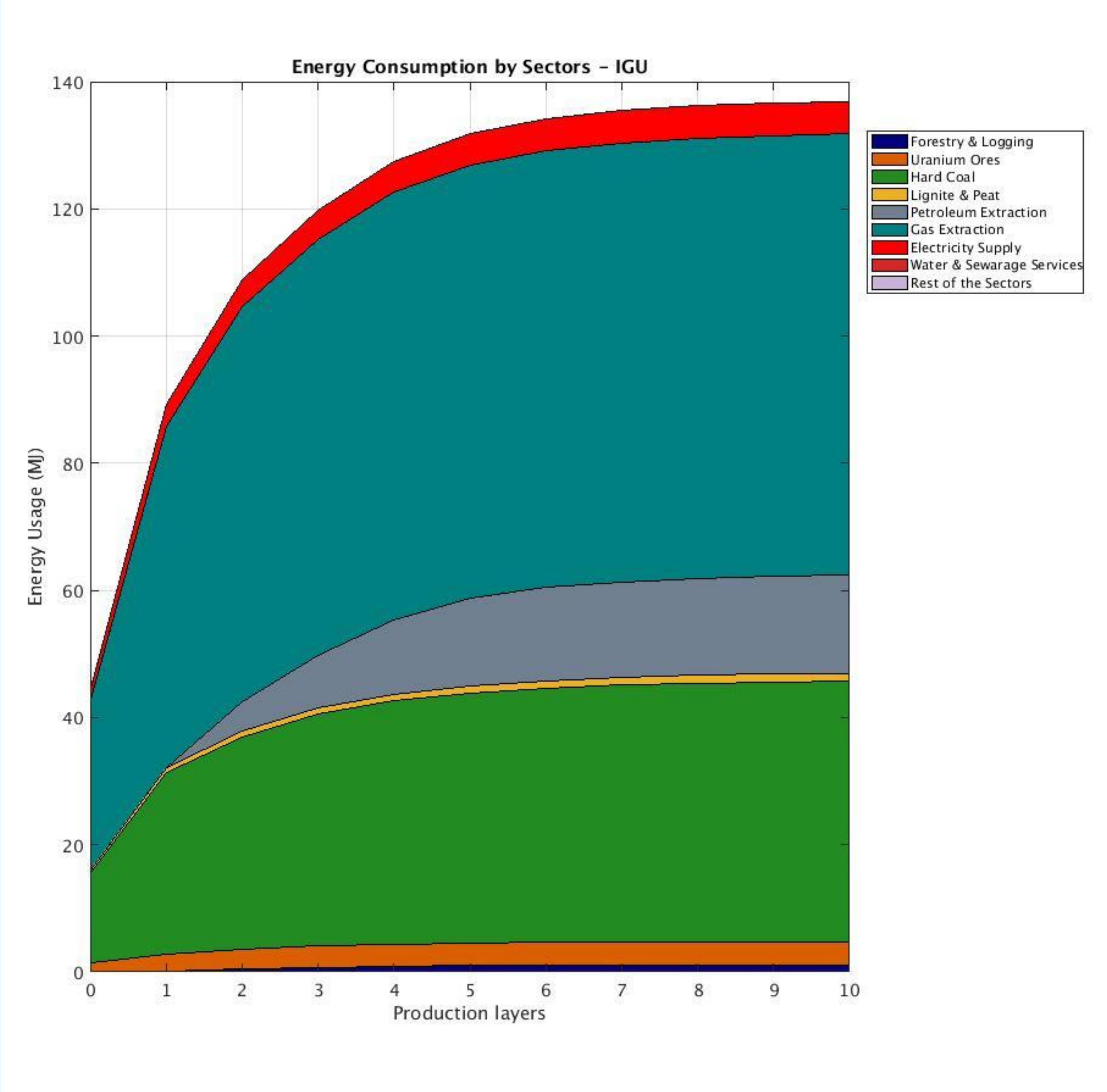
IGU – Embodied Energy

🏭 Manufacturing steps fewer → lower energy overall

⚒️ Less upstream energy use than VIG

PHASE 4 - INTERPRETATION:





ENVIRONMENTAL ROI

⚡ **Annual Energy Savings**
- Heating: 120–180 kWh/m²·yr
- Cooling: 15–30 kWh/m²·yr
- Total: 135–210 kWh/m²·yr

⏱ Embodied Energy Payback

VIG extra energy: 418 MJ/m²
- Primary energy savings: 610–1037 MJ/m²·yr

- **Payback: ~5–8 months (cold climates)**
- **Up to 5–7 years (mild climates)**

🌍 **Result:**
- Rapid energy payback in colder zones; environmental MROI achieved in less than a year.

Data Source: (Arasteh *et al.* 2006)

ECONOMIC ROI

💵 **Cost Premium: $150–200/m²**

📈 **Annual Savings**
- Cold: $15–25/m²·yr
- Moderate: $10–18/m²·yr
- Mild: $5–12/m²·yr

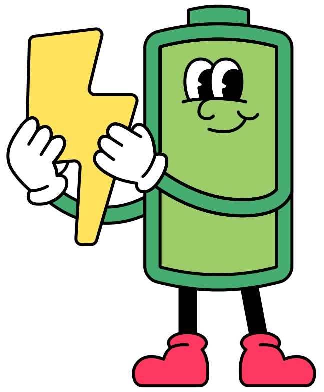
📅 Economic Payback

- **Cold: 6–13 years**
- **Moderate: 8–20 years**
- **Mild: 12–40 years**

💰 **Results**
- Savings vary based on energy tariffs and HVAC profiles

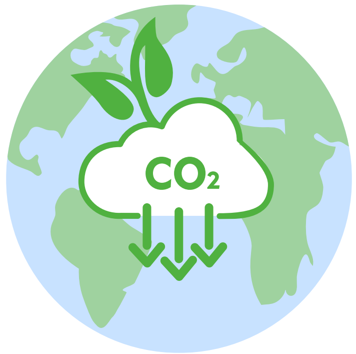
LIFETIME SAVINGS

Lifespan: 25–30 years



Total Energy Saved:
15,174–29,876 MJ/m^2
(over 25 years

Energy savings equivalence:
Enough energy to power a fridge for 10–20 Yrs
(Avg fridge uses ~1,500 MJ/year)



Total Emissions Avoided:
910–1,793 kg CO_2e/m^2
(over 25 years)

CO_2e savings equivalence:
Same as planting 45–89 trees per m^2
(Based on 1 tree absorbing ~20 kg CO_2 per year over 25 years)

VIG offers a long-term environmental return that grows with time!

Why this study?

- Buildings account for ~40% of global energy use. Glazing is a key contributor.
- VIG represents one of several pathways toward energy-efficient, low-carbon buildings

How we measured it?

- Hybrid Life Cycle Assessment (hLCA): combining detailed process data with global IO tables for accuracy.

CONCLUSION

What we found?

- Embodied energy payback: 5–8 months (cold climates)
- GHG savings: Up to 1.8 tonnes CO_2e/m^2 over 25 years
- Operational energy savings: Up to 29,876 MJ/m^2

Why it matters?

- VIG may cost more upfront but delivers lasting environmental and economic returns.
- Ideal for net-zero and cold-climate buildings.

THANK YOU