
# ENVIRONMENTAL EMISSIONS ANALYSIS OF SLAB TRACK SYSTEM USING LIFE CYCLE ASSESSMENT

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# Slab Track

## 🏗 Applications

- **Subways**, **tunnels**, and **tramways**
- **Space-constrained environments**

## ⚙ Key Features

- **Reduced structural depth**
- **Better load distribution**
- **High geometric stability**
- **Long-term alignment accuracy**

## 🌟 Advantages

🕒 **Extended service life**

⚙ **Lower maintenance**

🧩 **Prefabrication & modular design** → *Faster installation & higher quality*

## ⚠ Challenges

💰 **Higher initial construction cost**

🌍 **High carbon footprint** *(due to concrete-intensive materials)*

# LIFE CYCLE CONSIDERATIONS

🔍 Evaluating the **technical, economic, and environmental performance** of railway track systems requires adopting a **comprehensive life-cycle perspective**.

🌿 Among the various parameters, **environmental costs** play a decisive role when comparing **ballasted** and **slab track** alternatives.

📈 The **breakeven point of total costs** between the two systems can take **several years** to achieve, depending primarily on **traffic intensity** and maintenance frequency *(Praticò & Giunta, 2017, 2018)*.

🌍 Reducing the **environmental impact** of railway infrastructure is essential to align with **European sustainability targets** and the broader goal of **decarbonizing the transport sector**.

# In THIS STUDY……

**Objective:**

evaluate the environmental performance of slab track systems through the Life Cycle Assessment (LCA) method.

**Scope:**

cover all production stages: raw material extraction → transportation → manufacturing.

**Cutting-edge technological alternatives:**

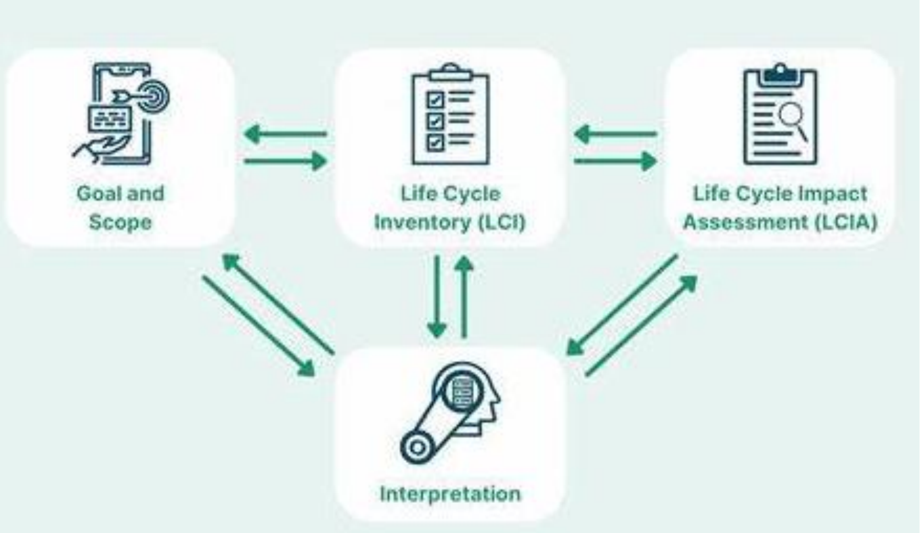
high-performance concrete, fly ash-based mixtures, recycled aggregates, plastics, and slimmer slab designs.

**Outcome:**

highlighting solutions that can significantly reduce environmental impact.

# METHODS · TOOLS · DATA

**APPROACH**: Life Cycle Assessment (LCA) (ISO 14040 standard)

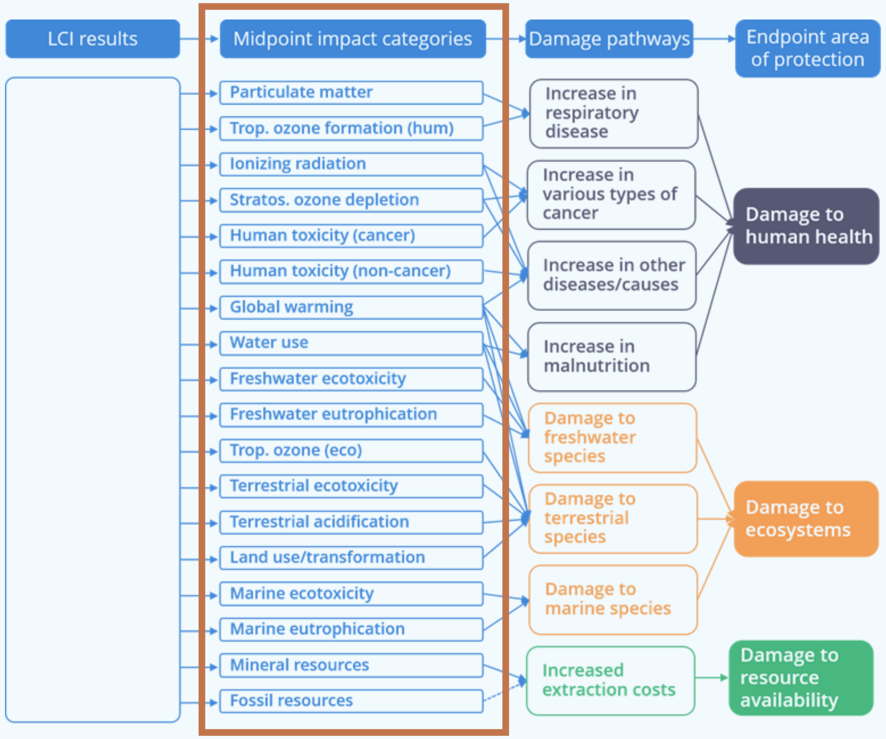



**DATABASE**: ecoinvent V 3.11

**SOFTWARE** openLCA

**LCIA METHOD:**

**RECIPE**



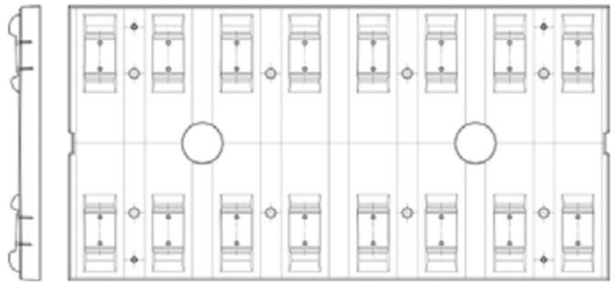

## FUNCTION UNIT AND SYSTEM BOUNDARY

- **Functional Unit**: ***one slab***.
- **Life cycle system boundary** models implemented are: ***Cradle to gate***, this life cycle assessment considers the resource extraction phase up to the manufacturing site.

# EXAMINED SCENARIOS

BENCHMARK

1. Arianna ST



*Arianna ST*

ALTERNATIVES

2. Recycled aggregates (RA)
   - *30% of aggregate by weight from recycling of ballast*
3. Geopolymer concrete (GC)
   - *20% of the clinker weight replaced by fly ash*
4. High Performance Concrete (HPC)
   - *low W/C ratio, high content of concrete, high-performance superplasticizers*
5. Fiber Reinforced Concrete (FRC)
   - *30% of the traditional reinforcement replaced with steel fibers*
6. Thin slab
   - *16 cm instead of 18 cm*
7. Polymer Modified Concrete (PMC), recycled polymer (PMC-R)
   - *10% substitution of cement by weight with recycled styrene-butadiene (SBR)*
8. Polymer Modified Concrete (PMC), not recycled polymer (PMC-NR)
   - *10% substitution of cement by weight with styrene-butadiene (SBR)*

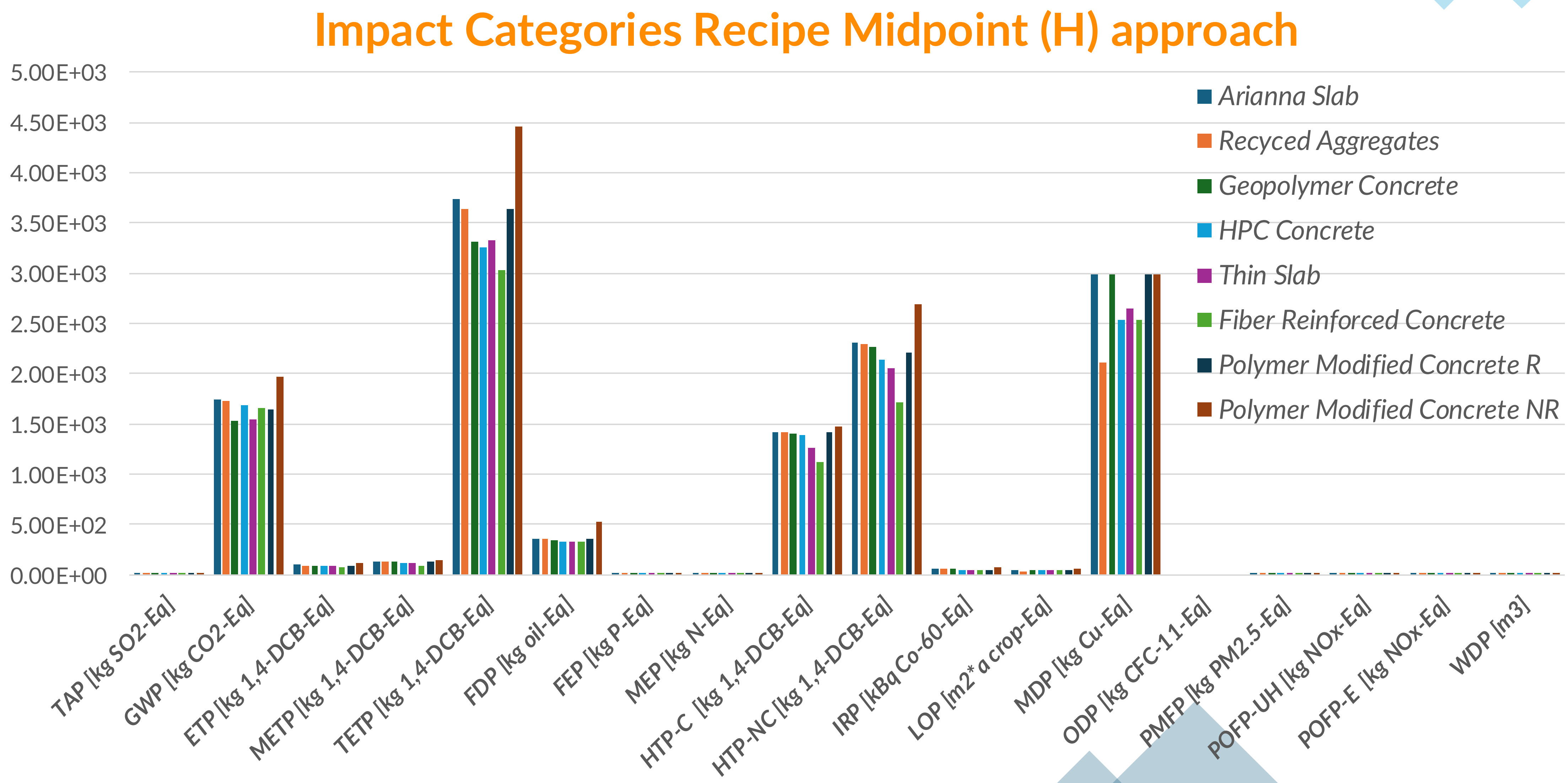
# LCI · LCIA

**For all alternatives, a detailed LCI was performed**, covering all inputs and outputs associated with raw material extraction, transportation, and production processes.

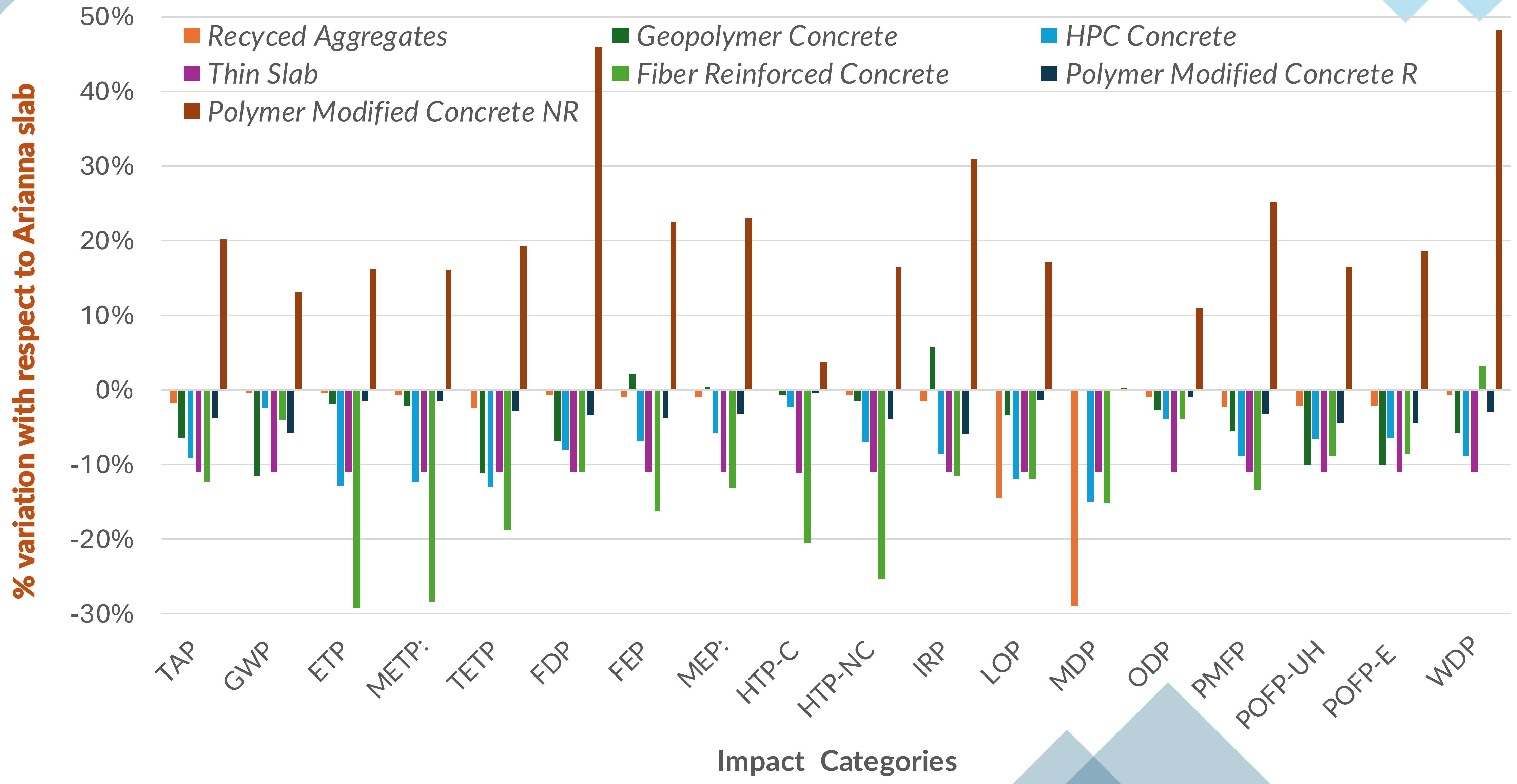
This inventory is the foundation for quantifying the impact categories in the subsequent **LCIA**.

| | |
|---|---|
| TAP | Acidification: terrestrial |
| GWP | Climate change |
| ETP | Ecotoxicity: freshwater |
| METP | Ecotoxicity: marine |
| TETP | Ecotoxicity: terrestrial |
| FDP | Energy resources: non-renewable, fossil |
| FEP | Eutrophication: freshwater |
| MEP | Eutrophication: marine |
| HTP-C | Human toxicity: carcinogenic |
| HTP-NC | Human toxicity: non-carcinogenic |
| IRP | Ionising radiation |
| LOP | Land use |
| MDP | Material resources: metals/minerals |
| ODP | Ozone depletion |
| PMFP | Particulate matter formation |
| POFP-UH | Photochemical oxidant formation: human health |
| POFP-E | Photochemical oxidant formation: terrestrial ecosystems |
| WDP | Water use |

# RESULTS


Impact Categories Recipe Midpoint (H) approach
5.00E+03
4.50E+03
4.00E+03
3.50E+03
3.00E+03
2.50E+03
2.00E+03
1.50E+03
1.00E+03
5.00E+02
0.00E+00
Arianna Slab
Recyced Aggregates
Geopolymer Concrete
HPC Concrete
Thin Slab
Fiber Reinforced Concrete
Polymer Modified Concrete R
Polymer Modified Concrete NR
TAP [kg SO2-Eq]
GWP [kg CO2-Eq]
ETP [kg 1,4-DCB-Eq]
METP [kg 1,4-DCB-Eq]
TETP [kg 1,4-DCB-Eq]
FDP [kg oil-Eq]
FEP [kg P-Eq]
MEP [kg N-Eq]
HTP-C [kg 1,4-DCB-Eq]
HTP-NC [kg 1,4-DCB-Eq]
IRP [kBq Co-60-Eq]
LOP [m2* a crop-Eq]
MDP [kg Cu-Eq]
ODP [kg CFC-11-Eq]
PMFP [kg PM2.5-Eq]
POFP-UH [kg NOx-Eq]
POFP-E [kg NOx-Eq]
WDP [m3]

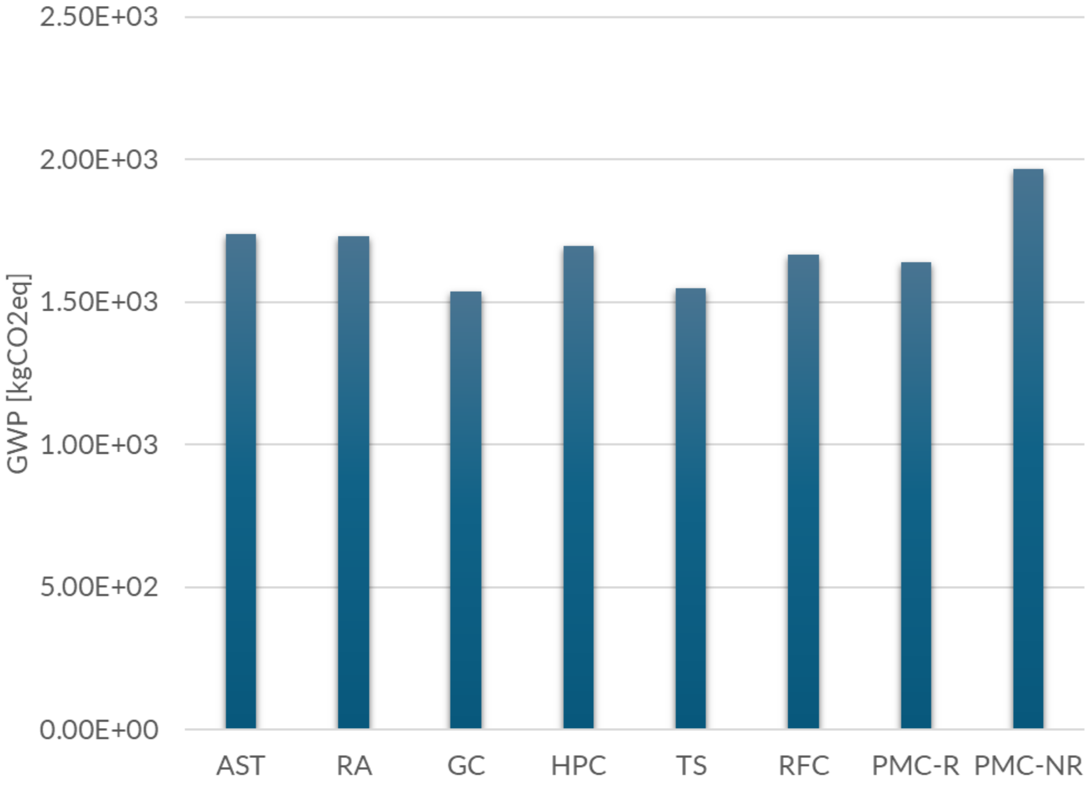
# RESULTS



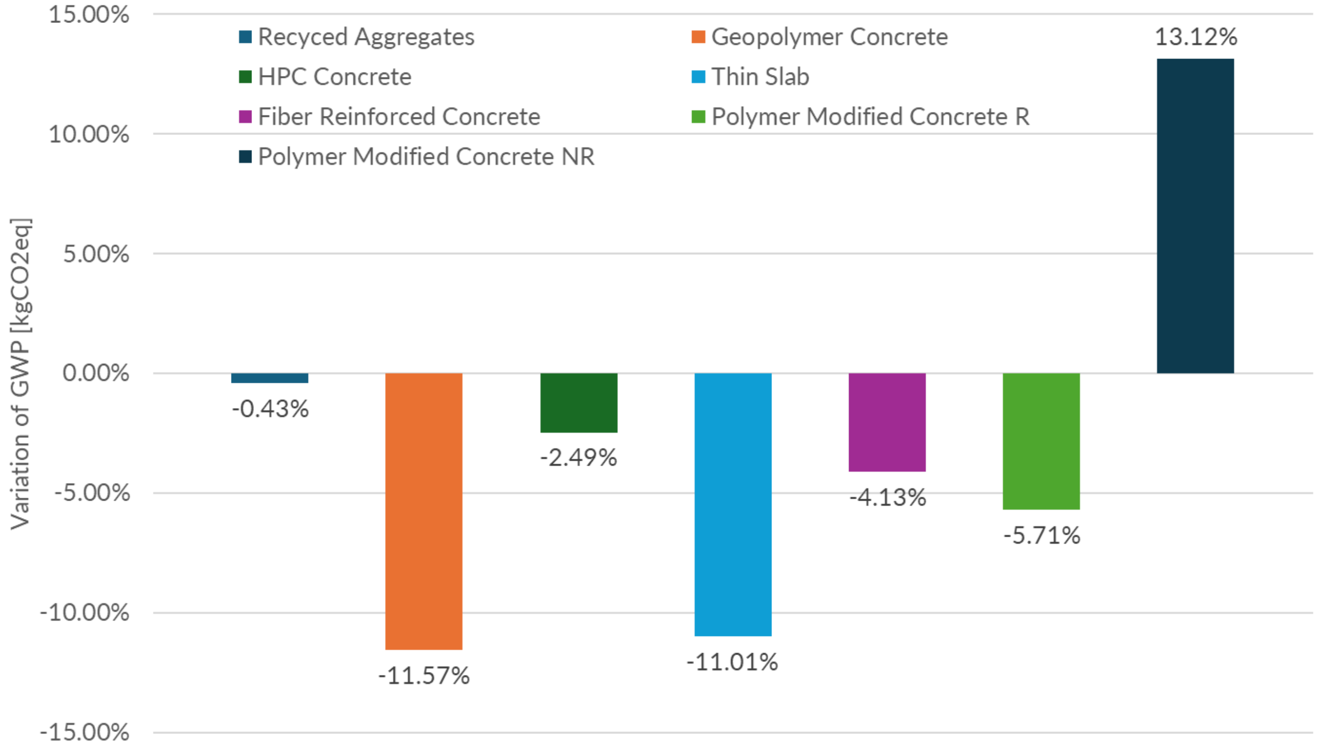
% variation with respect to Arianna slab
50%
40%
30%
20%
10%
0%
-10%
-20%
-30%
Recyced Aggregates
Geopolymer Concrete
HPC Concrete
Thin Slab
Fiber Reinforced Concrete
Polymer Modified Concrete R
Polymer Modified Concrete NR
TAP
GWP
ETP
METP:
TETP
FDP
FEP
MEP:
HTP-C
HTP-NC
IRP
LOP
MDP
ODP
PMFP
POFP-UH
POFP-E
WDP
Impact Categories

# RESULTS

## GWP

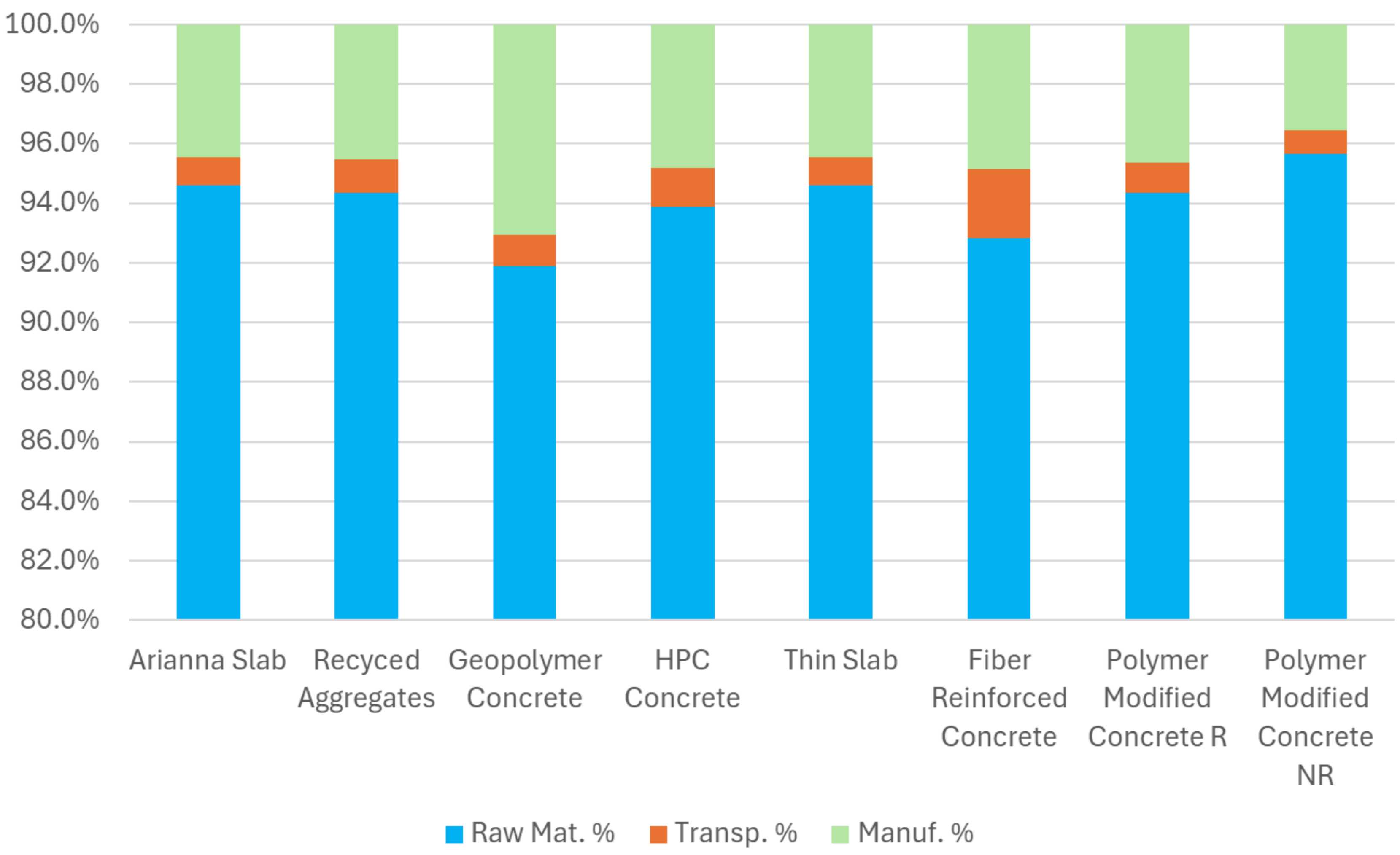



## % of reduction of GWP



# RESULTS

Contribution of production stages to the environmental impact categories of slab track



# CONCLUSIONS

- Slab track systems offer clear advantages in durability, maintenance, and modular construction, but their carbon footprint is high.
- Life Cycle Assessment is essential to quantify the environmental impacts across all production stages.
- Performance of the analysed alternatives:
  - Geopolymer concrete and thin slabs → ~11% reduction in impacts
  - Fiber-reinforced concrete and recycled polymer-modified concrete → significant improvements
  - Recycled aggregates alone have limited effect
  - Virgin polymer-modified concrete increases impacts.
- By combining innovative materials, smart design, and recycling strategies, we can build railway infrastructures that are not only efficient and durable, but also truly sustainable — meeting today's needs without compromising the environment for future generations.


# THANK YOU

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***Acknowledgments.*** *This study was carried out within the MOST – Sustainable Mobility National Research Center and received funding from the European Union Next-Generation EU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033 17/06/2022, CN00000023). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.*