TRANSFORMERS MAGAZINE'S
INDUSTRY NAVIGATOR

SUSTAINABILITY AND DIGITALIZATION

Esters & Semi Hybrid Insulations Transformers: Enablers of a low-carbon energy system?

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Hitachi Energy - Transformers
June 2023

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Agenda

1. **The challenge**
2. The objectives
3. Overview: insulation types and transformer design outcomes
4. Results: impact of insulation type on material use and life-cycle GHG emissions
5. Key Takeaways

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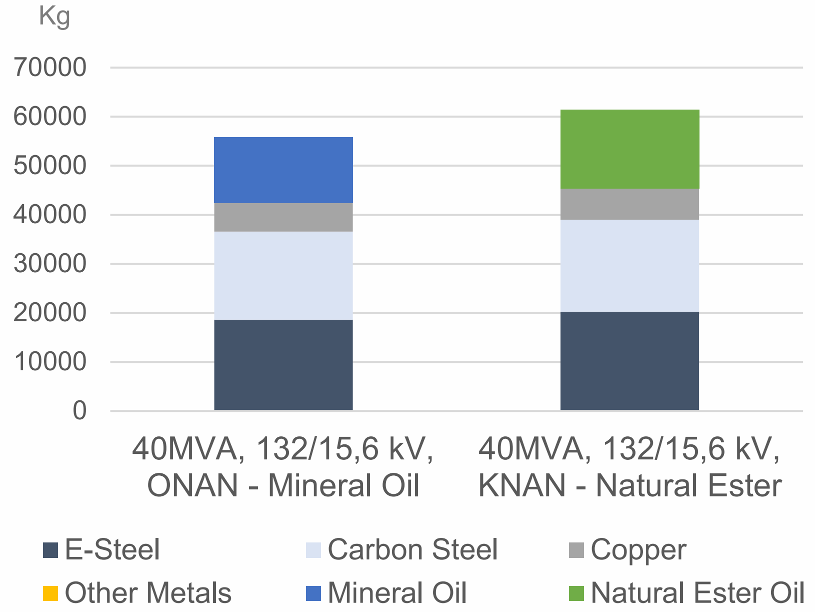
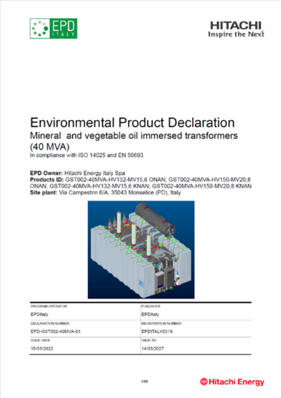
The challenge (1/2): material efficiency matters

Total weight:	+10%
Steel (E- & Carbon Steel):	+12%
Copper	+11%
Insulation Fluid:	+19%
CF Cradle-to-Gate:	+8%





Rationale for higher material use when designing for Natural Ester:

1. Higher viscosity of NE vs. MO: leading to heavier active parts
2. Achieving same temperature rise limits (as for MO):
   - Cooling ducts in Windings to be modified
   - Copper cross-section to be modified
   - More external cooling required

Challenges of increasing material use in Transformers:

+35% Global demand for **Steel** by 2050 (vs. 2020, IEA)**

+51% Global demand for **Copper** for clean energy technologies by 2050 (vs. 2020)*

- Geographical concentration of raw material production
- Mining lead times & costs
- Environmental and social concerns
- Exposure to climate risks

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* SDS IEA Sustainable Development Scenario
Source: Metals for Clean Energy: Pathways for solving Europe's raw material challenges. Report by KU Leuven, commissioned by Eurometaux Europe's metals association
** The Role of Critical Minerals in Clean Energy Transition, IEA

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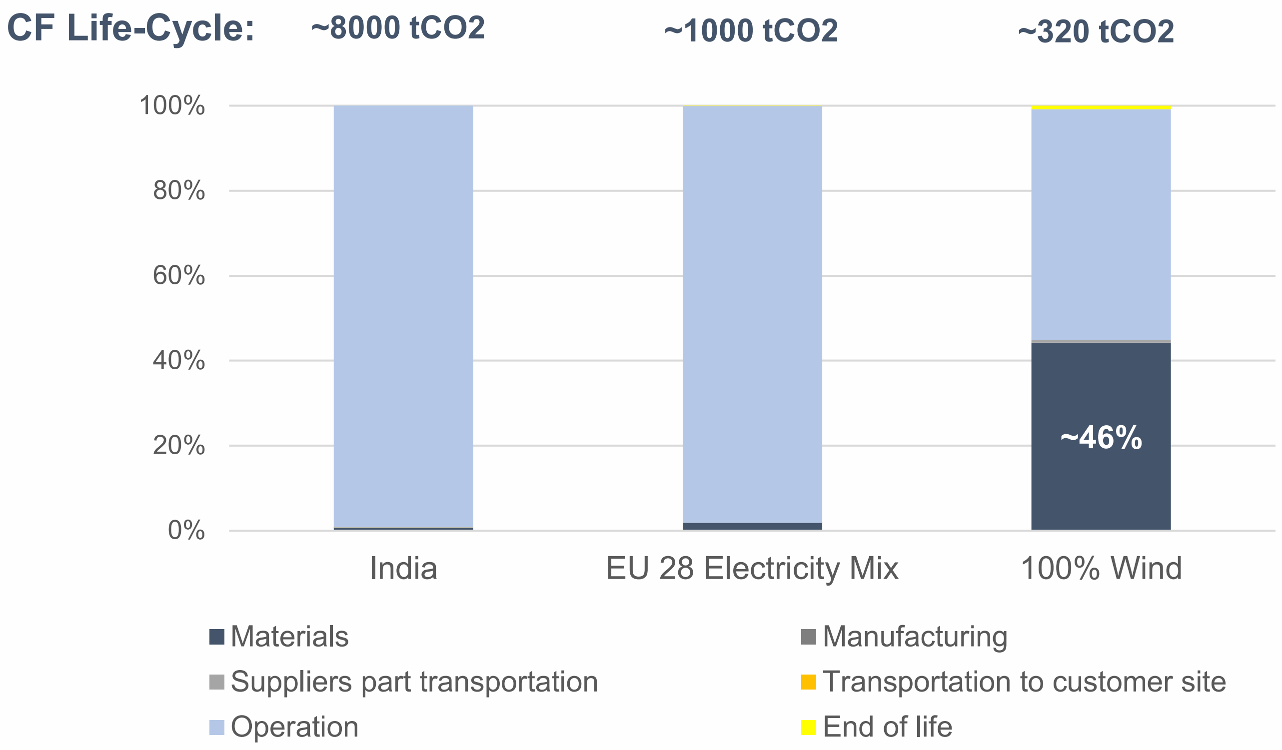
The challenge (2/2): material efficiency matters



40MVA, 132/15,6 kV, ONAN - Mineral Oil

Balancing material and energy efficiency becoming more relevant as grids continue to decarbonize:

1. Decarbonizing electricity grids (with a higher share of renewable and low-carbon power generation): ***first*** lever for lowering GHG emissions from T&D equipment
2. In low carbon electricity grids: material efficiency matters for lowering total life-cycle GHG emissions of transformers

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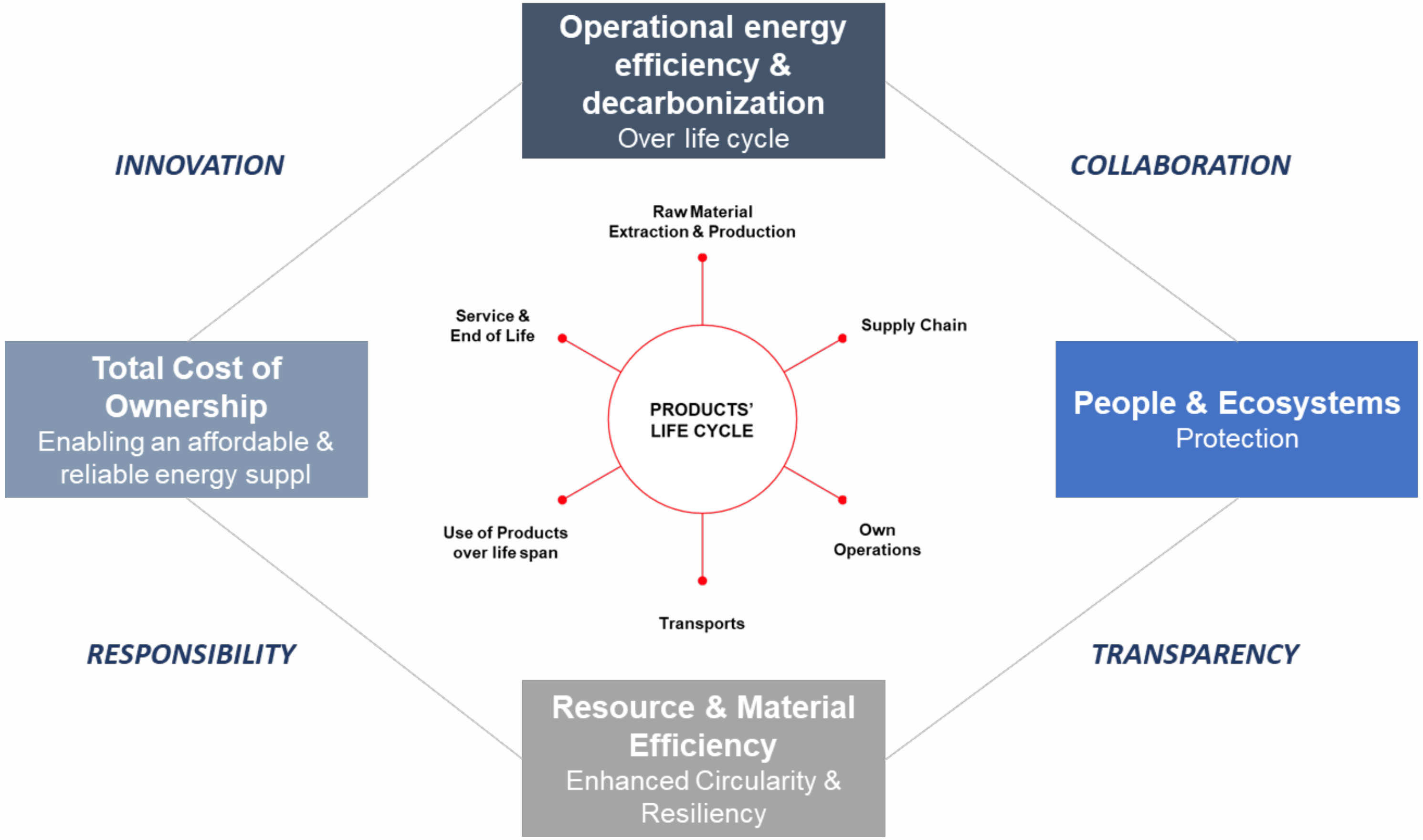
Objectives (1/2)

Optimizing material use & life-cycle carbon footprint for transformers with Natural Ester

The Hitachi Energy Framework for assessing and advancing sustainability in Transformers



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Objectives (2/2)

1. **Natural Ester benefits:** higher fire safety & biodegradability in case of leakages (protecting people & ecosystems)

2. **Quantifying the impact** of advanced, high-temperature insulations on enhancing material efficiency & carbon footprint **for transformers with natural ester** (particularly when operating in low carbon electricity grids)

Design	Insulation system	Dielectric Fluid	Temperature rise limits	Design imperative
Design 1	Conventional	Mineral Oil	Standard	Lowest initial transformer price
Design 2	Conventional	Natural Ester	Standard	Lowest initial transformer price
Design 3	Semi-hybrid	Natural Ester	High	Lowest initial transformer price
Design 4	Semi-Hybrid	Natural Ester	High	Lowest initial transformer price, but with loss capitalization factors considering the impact of carbon pricing

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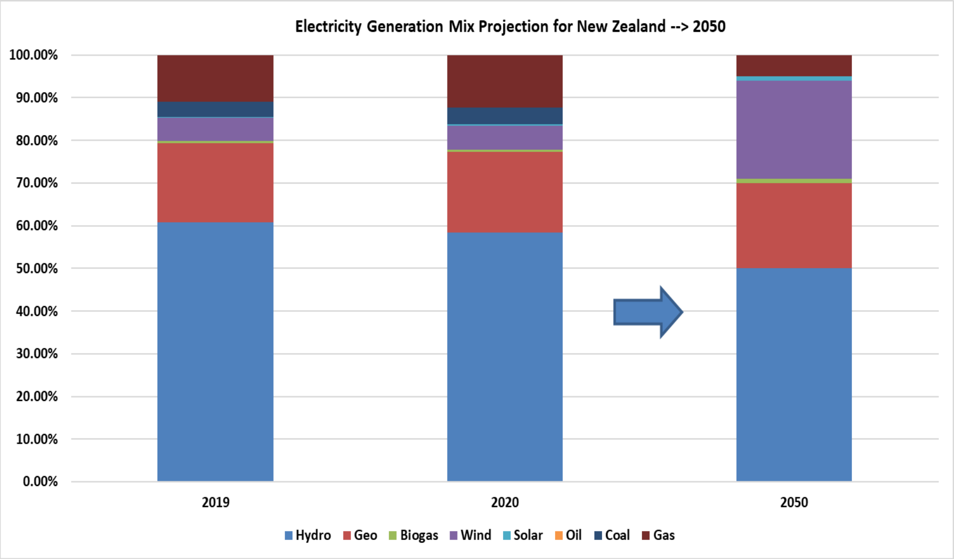
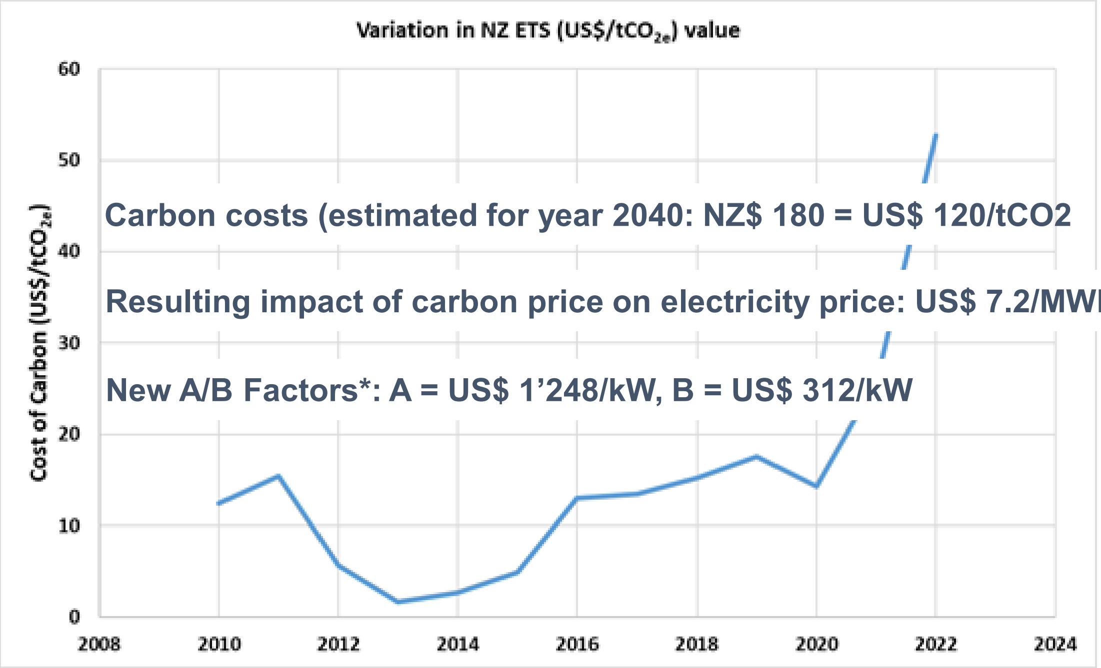
Why design 4? Optimizing for adapted loss capitalization factors

(considering the impact of carbon costs at mid-life)



Year	% Share of renewables	Grid Emission Factor
2020	~83% (Actual)	0.101 tCO_{2e}/MWh
2040	***~90% (Estimated)***	***0.059 tCO_{2e}/MWh***
2050	*~95% (Target)*	*0.024 tCO_{2e}/MWh*



Carbon costs (estimated for year 2040: NZ$ 180 = US$ 120/tCO2

Resulting impact of carbon price on electricity price: US$ 7.2/MWh

New A/B Factors*: A = US$ 1'248/kW, B = US$ 312/kW

* Assumptions: Discount Rate: 4%; Lifetime: 40 Years, Load factor: 50%

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Semi-hybrid vs. conventional insulations: overview

	Semi-hybrid insulation system		Conventional insulation system
Insulation Fluid	Mineral Oil	Ester Fluid	Mineral Oil or Ester Fluid
Insulation of Conductor	TU Paper	TU Paper	Kraft Paper
Top Oil Rise	60 K	90 K	60 K
Average Winding Rise	75 K	95 K	65 K
Hot Spot Rise	90 K	110 K	78 K

Semi Hybrid Temperature Rise Limits (Source: IEC 60076-14)

Transformer Design Outcomes

40/60 MVA, 132/33kV, ONAN/ONAF, 14%, 50Hz

Parameters	Design 1 @75ºC	Design 2 @75ºC	Design 3 @115ºC	Design 4 @115ºC
Type	Conventional Mineral Oil	Conventional Ester Fluid	Semi Hybrid Ester Fluid	Semi Hybrid Ester Fluid optimized at \$120/tCO_{2e}
No Load Loss (kW)	22.9	25.8	23.8	17.8
Load Loss (kW)	344.9	302.0	388.9	345.5
Total Loss	367.8	327.8	412.7	363.35
K_{PEI}	0.258	0.292	0.247	0.227
PEI Design output	99.704%	99.706%	99.679%	99.738%

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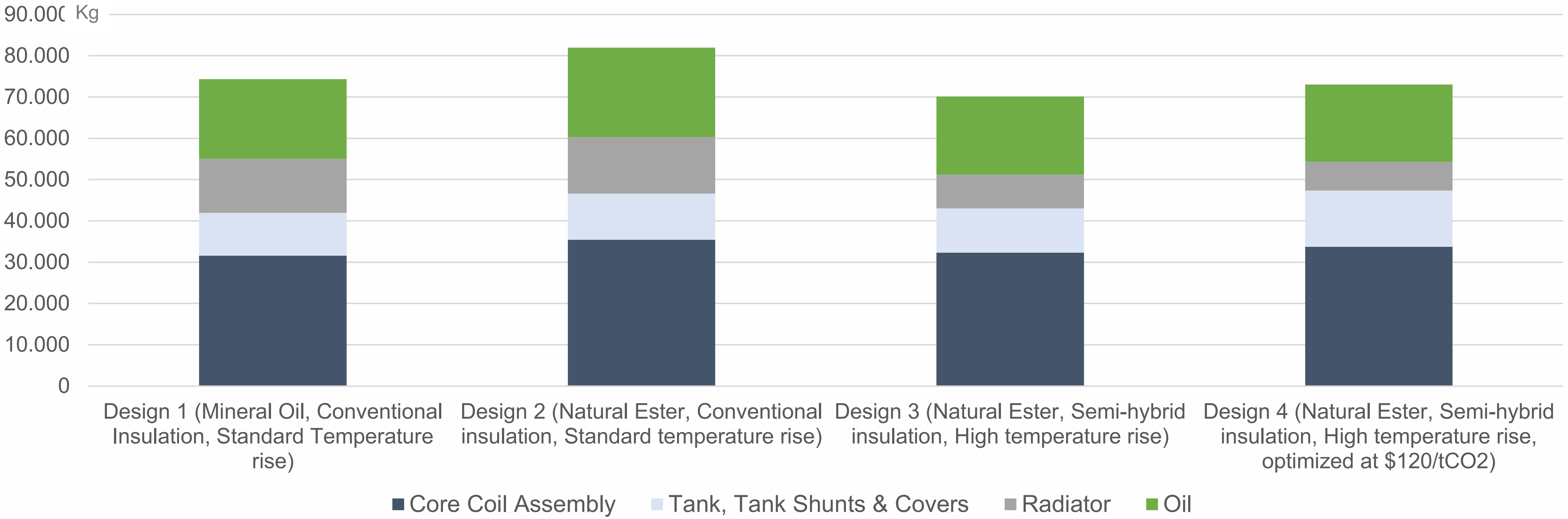
Results: impact on material use

Total weight (Design 1 as baseline): *+10%* *-6%* *-2%*

Total weight (Design 2 as baseline): *-14%* *-11%*



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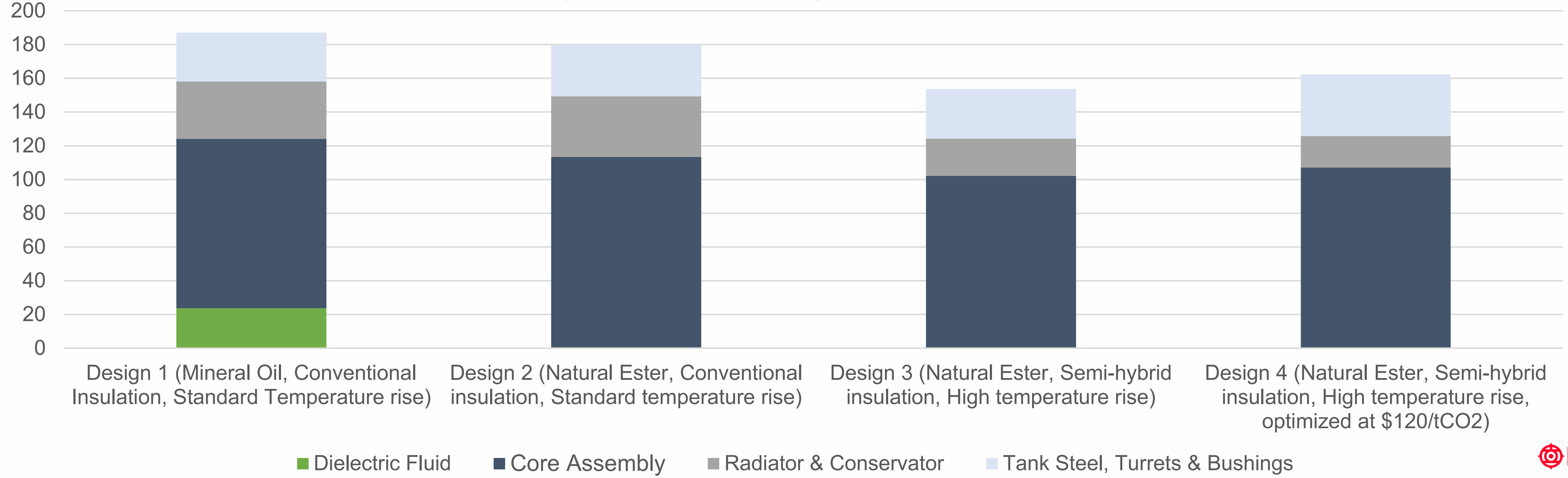
Results: impact on carbon footprint from materials

Carbon footprint from materials by component (Design 1 as baseline): *-4%* *-18%* *-13%*

Carbon footprint from materials by component (Design 2 as baseline): *-15%* *-10%*



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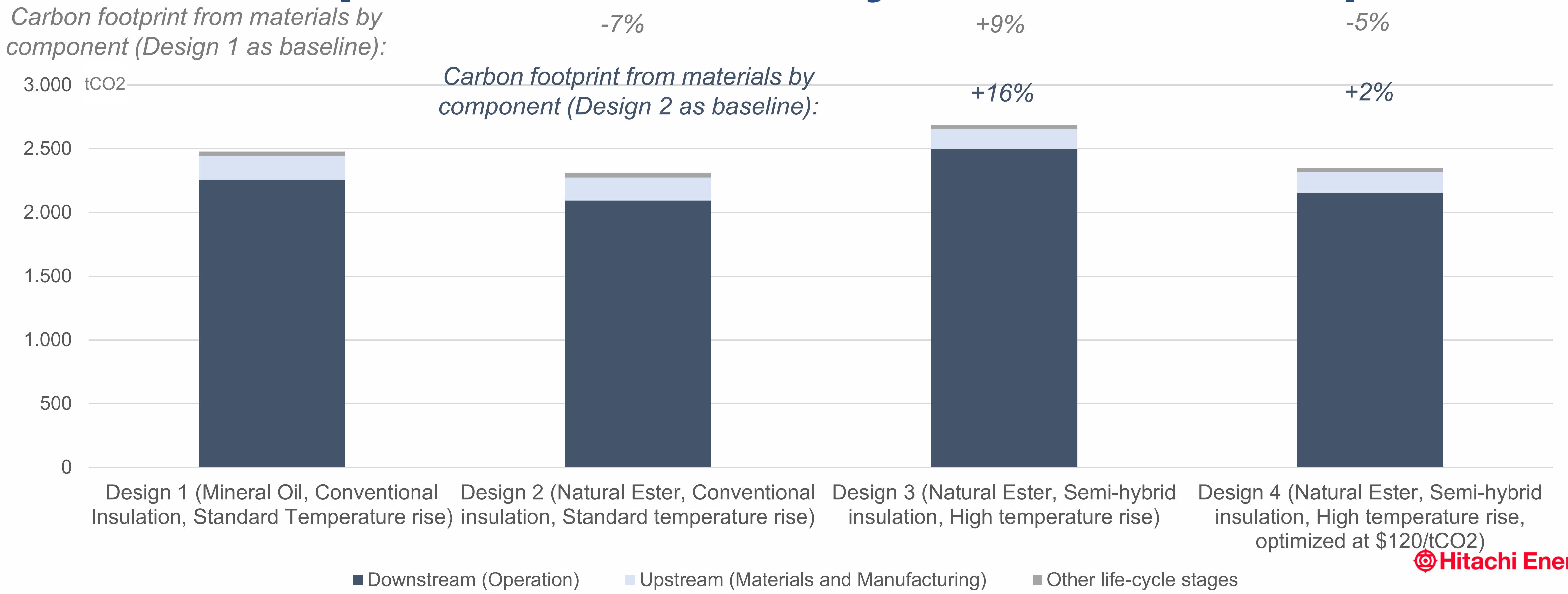
Results: impact on total life-cycle carbon footprint



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Grid EF @ transformer mid-life (Year: 2040, 0.059 KgCO2/MWh)

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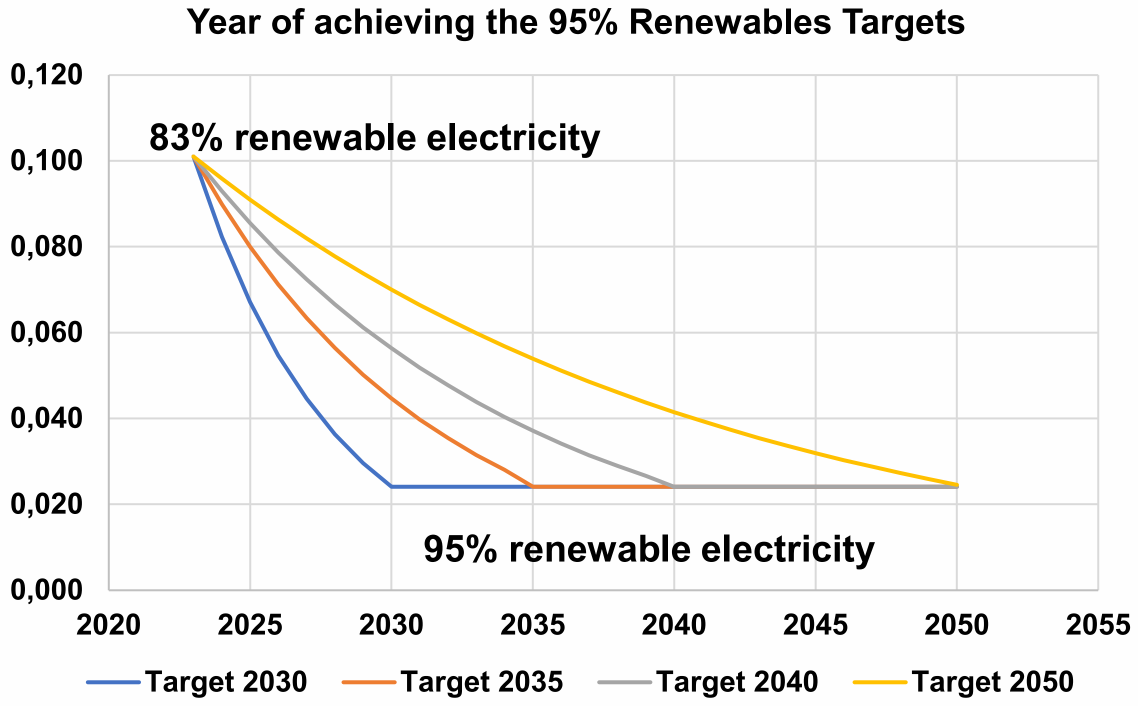
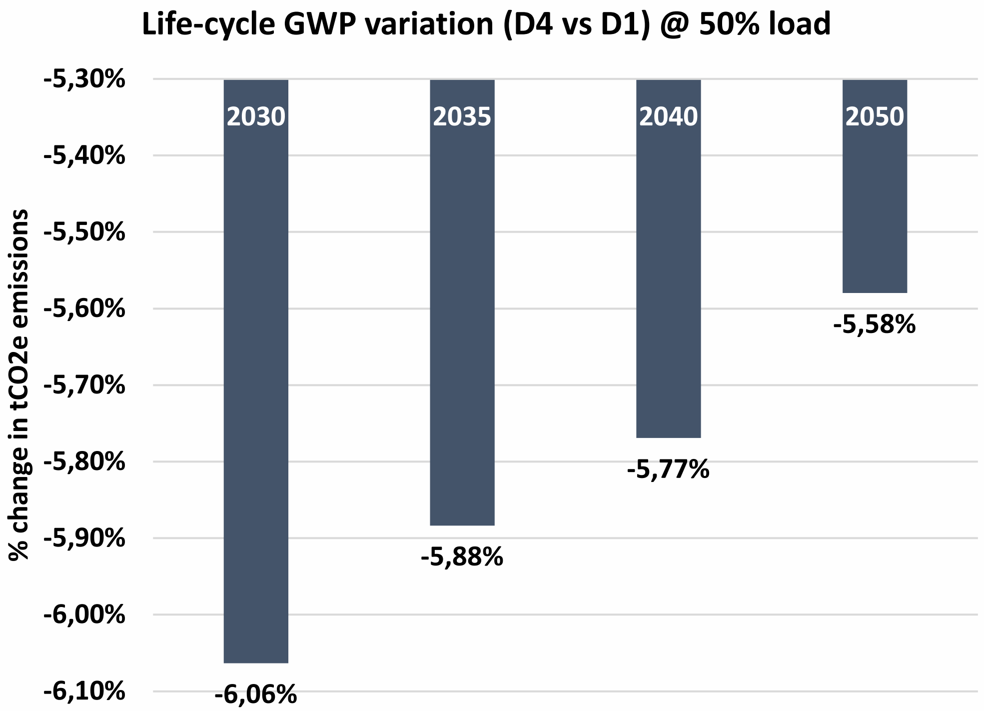
Results: Variation in GEF (Design 4 vs 1)





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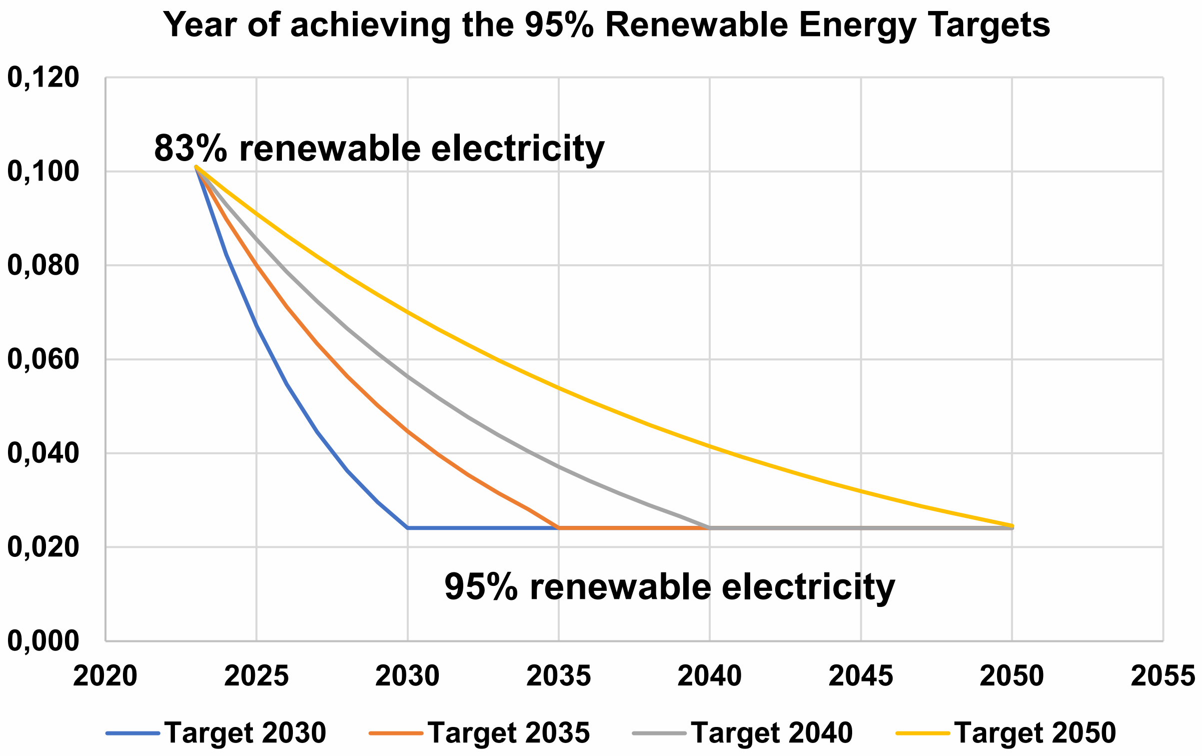
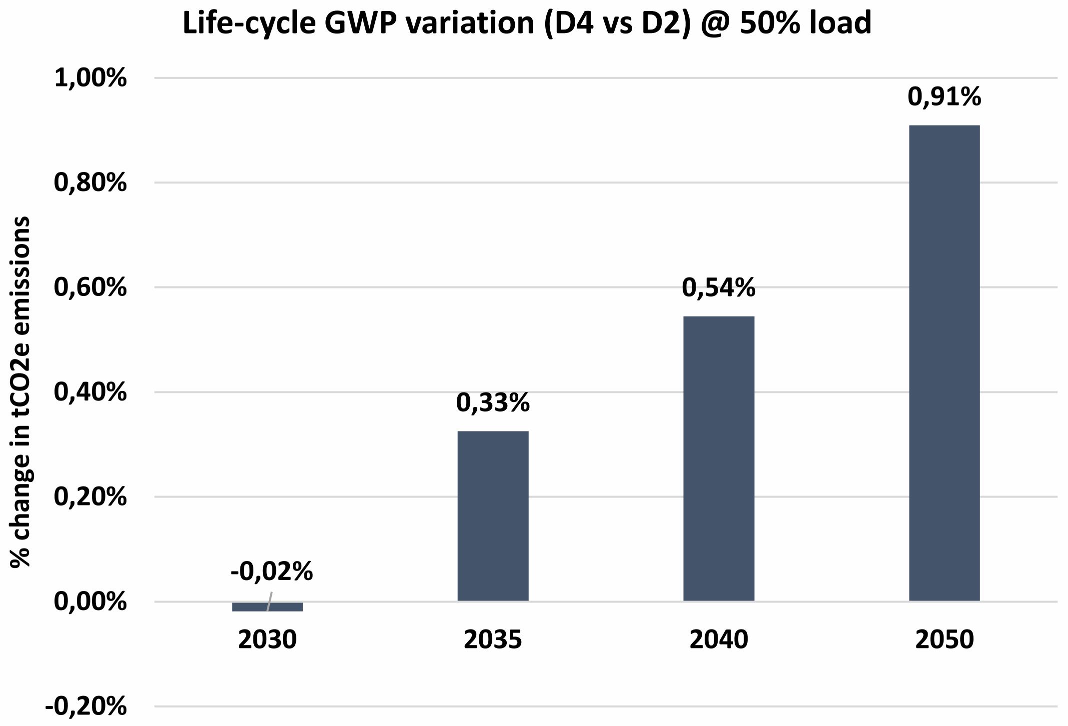
Results: Variation in GEF (Design 4 vs 2)





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Results: summary

Design 4: Most optimized design (compared to Design 2): by combining higher material efficiency and lower total life-cycle carbon footprint under more realistic operational condition (*Grid EF, Cost of Electricity at mid-life*)

Parameters	Design 1 @75ºC	Design 2 @75ºC	Design 3 @115ºC	Design 4 @115ºC
Type	Conventional Mineral Oil	Conventional Ester Fluid	Semi Hybrid Ester Fluid	Semi Hybrid Ester Fluid optimized at $120/t$CO_{2e}$
K_{PEI}	0.258	0.292	0.247	0.227
PEI Design output	99.704%	99.706%	99.679%	99.738%
Material efficiency (total weight in Kg)	75’540	83’140	71’315	74’090
Carbon footprint from materials (tCO_2)	187	180	154	162
Total life-cycle carbon footprint (tCO2) (@50%load, Grid EF at mid-life: 0.059 Kg CO_2/MWh, 40 years)	2’478	2’313	2’689	2’351

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Key Takeaways

Transition to a more sustainable, low-carbon energy system = transition from fossil-fuel to a material-intensive energy system

- Use of esters & high-temperature insulation can be an effective tool in **reducing the carbon footprint** while simultaneously improving material efficiency. This is particularly relevant for countries with high renewable penetration, such as New Zealand.
- **Ester fluids** (Biodegradable and higher flash point fluids): fire safety benefits and environmental risk mitigation solution (biodegradability) in case of leakages.
- Reflect on the choice of temperature rise limits specified with conventional insulation in mineral oil and ester fluids. **Maximize the economic, environmental, and safety** benefits of transformers considering the application type, (future) energy-mix and surrounding ecosystems!
- Adoption of **TCO optimized solutions**, including carbon costs, for losses or from material usage in transformer specification, with quantified sustainability metrics, such as life cycle analysis data.

Thank you very much for your participation and attention!!!

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