LIFE CYCLE EVALUATION OF INNOVATIVE SOLID STATE TRANSFORMER

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SSTAR project

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SSTAR project

Development and deployment of next-generation high-voltage solid-state transformers (HV SST) for distribution and transmission grids, aiming to deliver superior performance and broader application potential compared to conventional transformers

Key innovations

- Development of **sustainable & eco-friendly bio-based dielectric fluid,** able to enhance the SST module insulation voltage while achieving up **to 50% CO2 saving** compared to conventional oils
- Design of a **high-efficiency SST Module** using Silicon Carbide (SiC) and a bidirectional Inductive Power Transfer (IPT) system, enabling voltage levels up to **1.5 kV**, switching frequencies up **to 50 kHz**, and achieving a total efficiency of **98.5%.**
- **Scalable CHB Converter for Transmission Grids**: Implementation of a decentralized control **Cascaded H-Bridge (CHB)** converter architecture to scale up the number of SST modules, reaching voltage levels suitable for high-voltage transmission grids.
- **Sustainable approach through a Life Cycle Assessment (LCA) framework:** Quantification of environmental impacts from raw material extraction to decommissioning in terms of reduction of CO_2, use of non-hazardous, recyclable and longer lifetime raw materials.

LCA methodology

Goal & scope

- Assess the environmental impacts and benefits of the proposed SSTAR process pathways throughout all stages of production, operation, and disposal.
- Functional Unit: *Environmental impacts per "**one kilowatt-hour (kWh) of transferred electricity**" e.g. regarding the indicator of Global Warming Potential the results will be calculated in kg CO_2eq/ kWh*

Inventory analysis

- Data compilation for each component of the device

Impact assessment

- LCA model development and perform a sensitivity analysis

Interpretation

- Environmental outcomes discussion

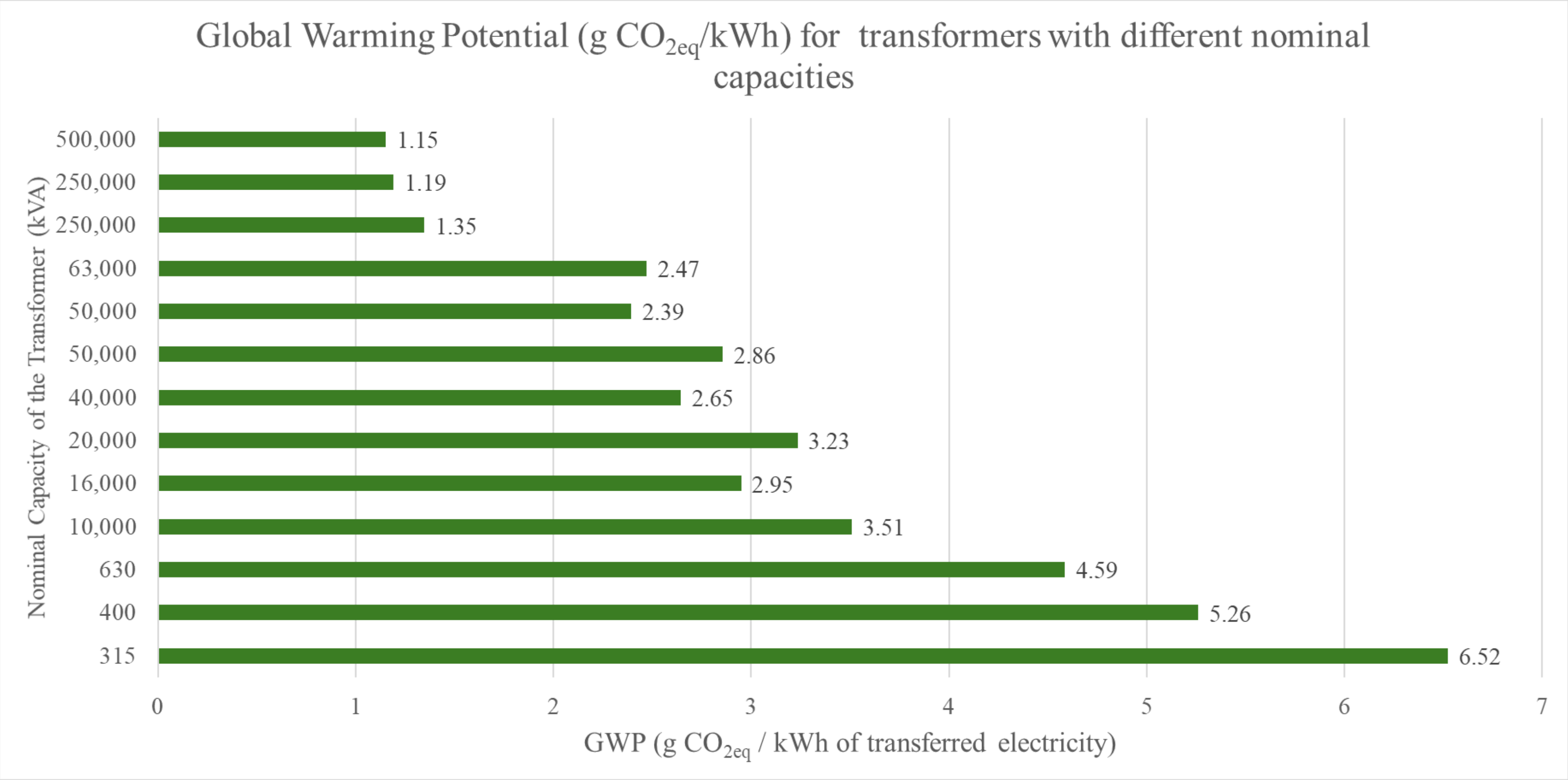
LCA model is "cradle-to-grave"
The boundaries include energy and mass balances of the production, transportation, operation and maintenance and disposal phase

Life Cycle Phase	Description
Production	From raw material extraction to the module's production.
Transportation	Materials from China to the production site, module's transport from Portugal to Spain, and additional transportation activities for market distribution.
Operation and Maintenance	Encompasses the O&M of the module over a 35-year period.
Disposal	Vary by material, recycled / landfill.

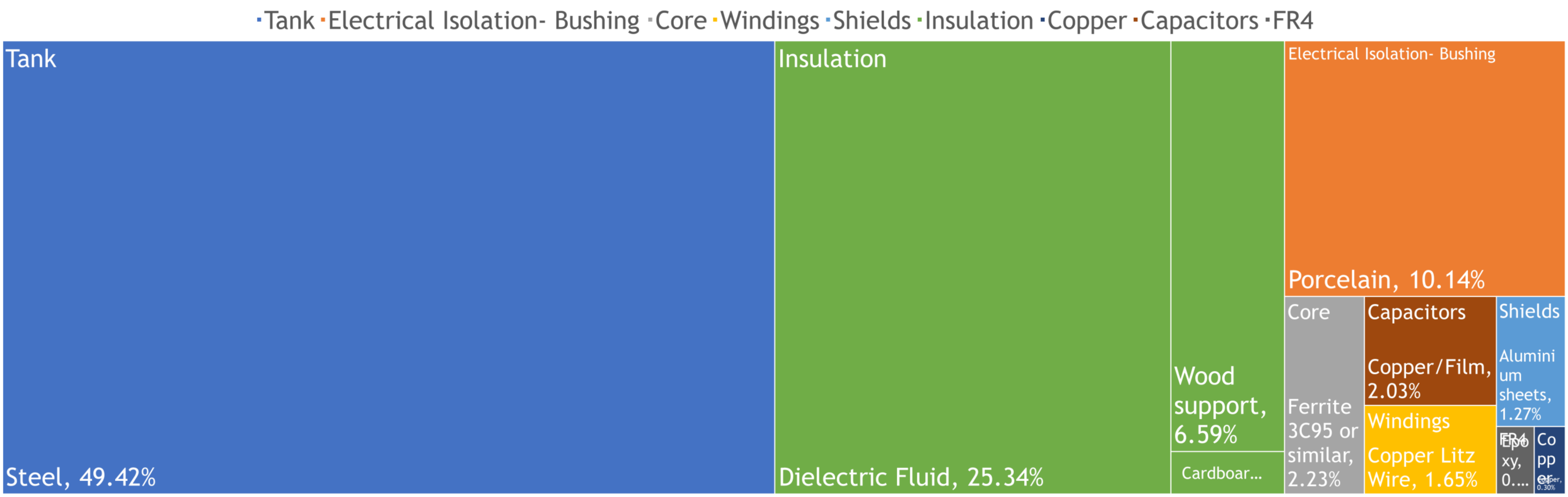
Conventional transformers

- **<u>Baseline Scenario</u>** Literature Review Results:

GWP range 1.15 – 6.52 g CO_{2eq}/kWh of transferred electricity



New SST’s components and materials

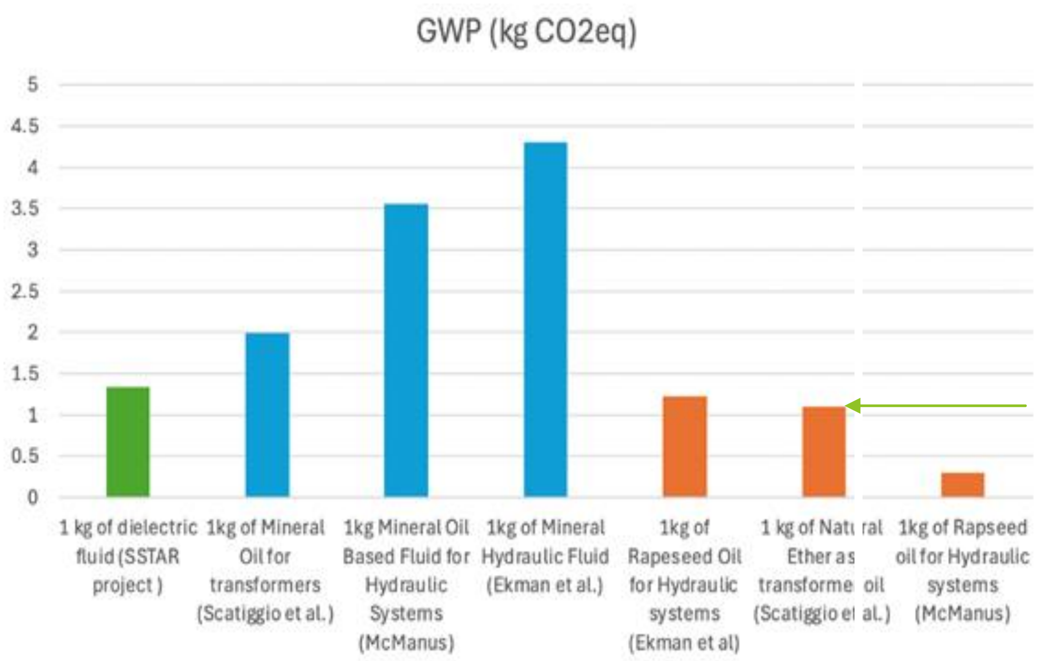


Dielectric Fluid assessment – Comparison with conventional transformer fluids

- 1kg bio-based dielectric fluid

Method	Indicator	Unit	Value
Cumulative Energy Demand (CED)	Non-renewable, fossil	MJ	15.5
IMPACT World+ Midpoint V1.03	Climate change, short term	kg CO_{2eq}	1.35
	Climate change, long term	kg CO_{2eq}	**1.26**
	Fossil and nuclear energy use	MJ	17.5
	Mineral resources use	kg deprived	0.018
Environmental Footprint 3.1 (adapted) V1.00	Climate change	kg CO_{2eq}	**1.32**
	Resource use, fossils	MJ	15.9
ReCiPe 2016 Midpoint (H) V1.08 / World (2010) H	Global warming	kg CO_{2eq}	**1.35**
	Fossil resource scarcity	kg oil eq	0.35

- Dielectric Fluid LCA comparison results



The SSTAR fluid outperforms traditional mineral oils in terms of GWP, with percentage differences ranging from 33% to 69%.

Alternative vegetable oils perform better than the SSTAR fluid in terms of GWP.

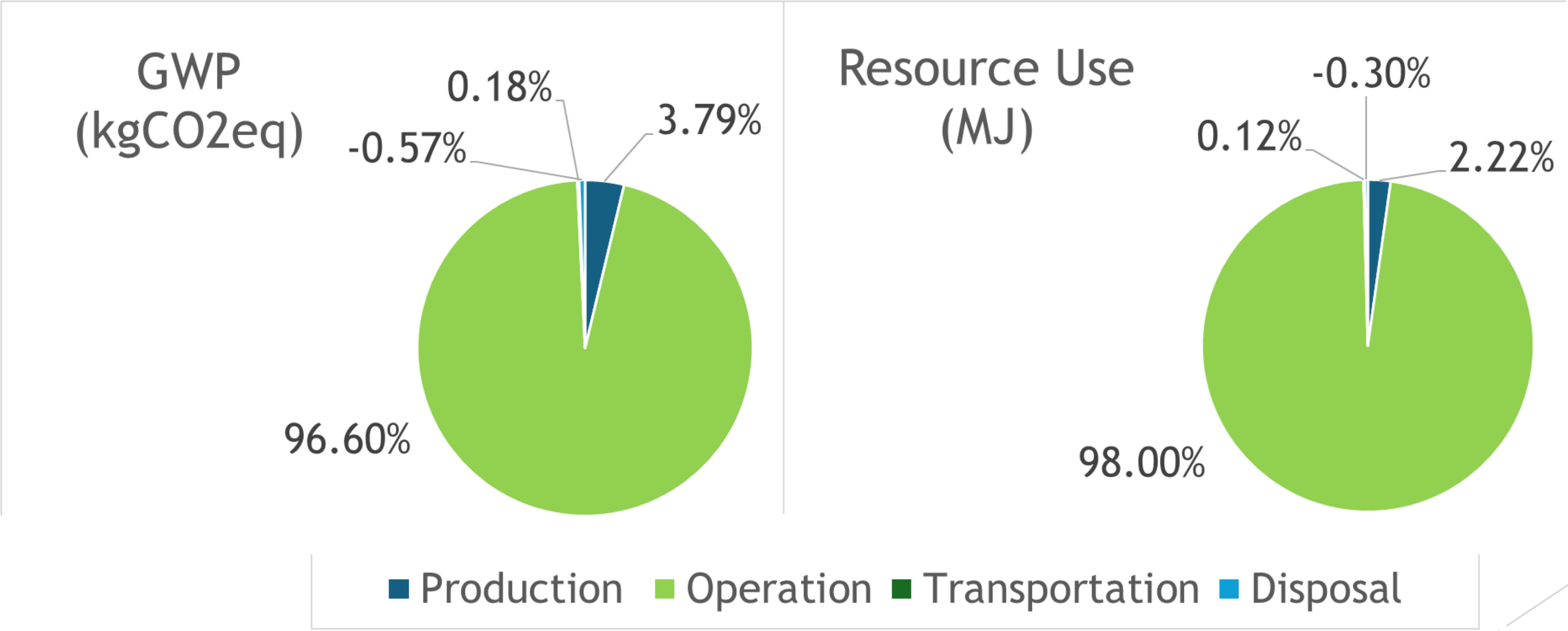
Except for the natural ester fluid from Scatiggio et al., the other oils are not specifically designed for transformers.

This highlights gaps in the literature and the necessity for more targeted LCA studies on transformer-specific dielectric fluids like SSTAR.

SSTAR transformer

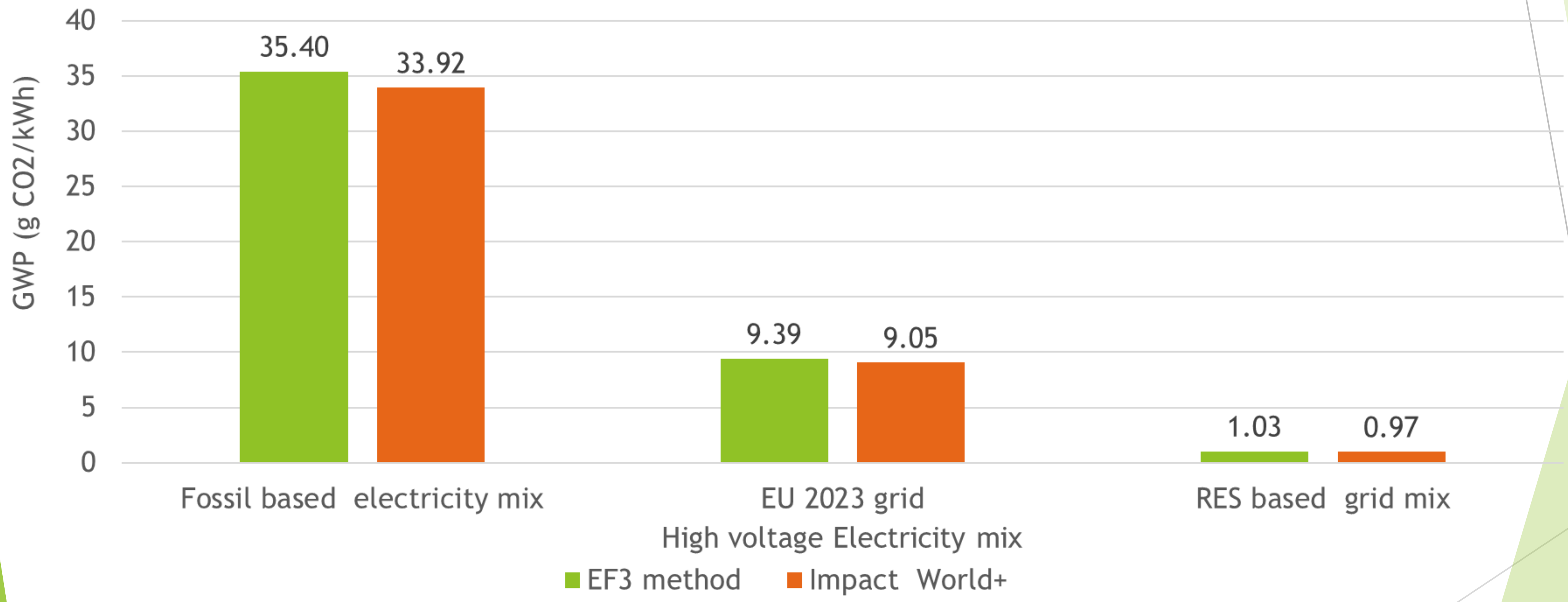
- **SSTAR Scenario:** LCA results for one module

Parameters	Transformer Capacity (kVA)	Lifetime (y)	Average load	Transferred Electricity (MWh)	Transformer Capacity (kVA)
SSTAR module	75	35	100%	22,995	75

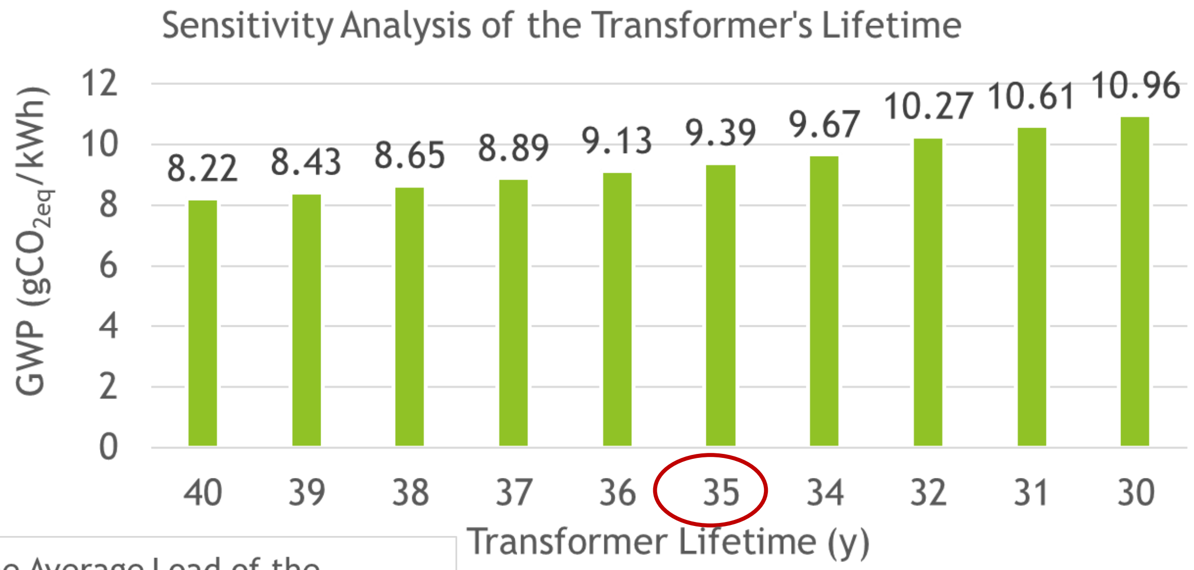


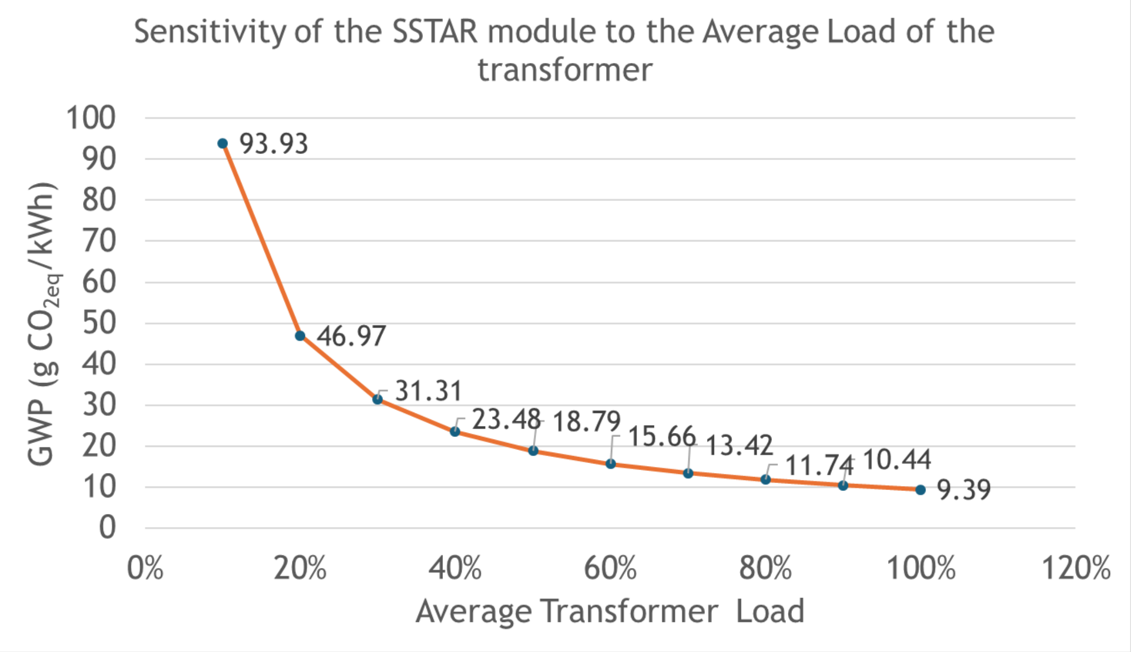
The **electricity losses** of the operational phase are the predominant contributors to GWP and Energy Use.

LCA sensitivity analysis



LCA sensitivity analysis





Conclusions

- The **bio-based fluid** produced in the project's framework outperforms traditional mineral oils, in environmental performance, in terms of GWP, with decreases ranging from 33% to 69%.
  - This finding increases the possibility the transformers manufacturers and energy suppliers to use the obtained results as a decision making tool.
  - Highlights the necessity for more targeted LCA studies on transformer-specific dielectric fluids.
- **Dominant Impact Source:** Operational phase electricity losses are the main contributors to both GWP and Resource Use.
- **Importance of Energy Mix:** The **environmental impact is highly dependent on the grid's energy source**. Results show higher GWP than literature benchmarks, but:
  - **Grids with high renewable penetration ("green grids")** significantly reduce impact.
  - Emphasizes the value of clean electricity supply.
- **Critical parameters:**

Renewable energy share in the electricity grid is crucial to improving environmental performance.

Key parameters influencing impact:

System lifetime: A longer lifetime leads to more significant environmental savings
Average load: Higher utilization improves environmental efficiency.

Thank you!

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