Industry NAVIGATOR

SUSTAINABLE DEVELOPMENT STRATEGIES FOR T&D

CONFERENCE 2025

Advanced environmental cost indicators for transformer oils – beyond cradle-to-gate LCAs

Dr. Hugo Campelo

10 April, 2025

NYNAS

Before we start

Quoting latest DNV JIP report: “While reducing emissions related to materials is crucial towards further decarbonization, it is **equally important** to consider the broader picture. Over the lifetime of a transformer, larger savings can be achieved by extending its operational lifetime, reducing power losses, and designing transformers to better handle dynamic loads. “

Broader picture

Reducing losses

Operational lifetime

Before we start

DNV

JOINT INDUSTRY PROJECT

Power Transformer Sustainability Practice

Report No.: 24-0972, Rev. 2
Date: 2024-12-13

- Published in December 2024
- Joint Industry Project led by DNV
- Nynas participated along with other players of our industry
- Certainly an important reference for the topic and for the industry practices
- Basis for the subsequent groups and evolutions
- Scope: Enhanced tendering of high-voltage power transformers

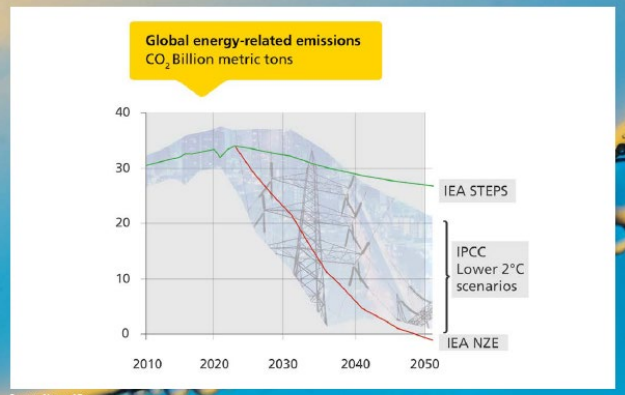
Context (from last year's TMIN)

We need to act sooner rather than later because everything we have already committed to doing will not be enough to reach net zero in 2050

Return on the sustainability of the new transformer liquids – beyond price!

The gap between what is really achieved and all the net zero scenarios already available will depend on the speed of our actions. As seen in the image below, there is a huge scattering between the International Energy Agency STEPS scenario (IEA STEPS) - reflecting the assessment of current policies in place or announced by governments around the world - and the 311 scenarios from the United Nations Intergovernmental Panel on Climate Change (IPCC). This means the only certainty we can have is that we need to act sooner rather than later because everything we have already committed to doing will not be enough to reach net zero in 2050 (IEA NZE).

Independently of which of the above scenarios reveals itself as the most realistic, we also know that the electrical infrastructure is already playing and will keep playing a leading role in this decarbonization route. No matter the route, the world is going electrically either directly (in the case of electrical mobility) or indirectly (in the case of



Source: Nynas AB

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Paper number 1011

Sustainable transformer liquids - options and perspectives

Hugo Campelo and Thomas Norrby*
Nynas AB
Sweden

SUMMARY

The range of insulating liquids for electrical transformers has been widening and diversifying over the last decades and years. The current offer now comprises fluids that fully meet the most widely used standards in the world such as IEC 60296 and ASTM 3487 but also alternative liquids with different requirements such as Natural Esters (IEC 62975:2021) or Synthetic esters (IEC 61099:2010). Given the announced growth of demand of new electrical transformers choosing among this range of insulating liquids is not a question of excluding one option in detriment of the other but more about choosing right liquid for the right application.

The liquids meeting the same standards are in principle meant to be more similar, compatible up to same extent, monitored in the same way and hence do not require extensive engineering changes, and/or different materials like the selection of elastomers, seals, paints etc. In turn liquids meeting different standards are meant to have different properties (some better - some worse – it depends), may not be monitored according to the same maintenance rules and may involve more extensive engineering changes.

However, the choice process becomes denser when inside the same standard the multiple liquids available might have significantly different functional properties and might be of different sub-types - cases of recycled and virgin oils under IEC 60296 – which imply necessarily different performances during the whole life cycle of the transformers.

Navigating through the qualitative merits and de-merits of each liquid for each application can be cumbersome and subjective then establishing a framework to enable more objective comparisons will ease the choice process by the end-users while increasing the rate of adoption of increasingly sustainable solutions in the right applications.

In this work a framework based on Environmental Cost Indicators (ECI) is shown and discussed while being applied for three different generic transformer liquids (oils A, B and C). All of them are IEC 60296 compliant type A oils. Oil A is a low-viscous high grade naphthenic mineral oil, Oil B is a recycled oil and Oil C is a bio-based hydrocarbon liquid.

As a single-score indicator the ECI simplifies and unites the different environmental and operational data associated with each liquid by translating it into a common widely used language – money! The goal of this exercise is to go beyond the upfront purchase prices of the liquids enabling a more holistic (and not rarely fairer) comparison between the different materials that can be used in this societal quest of reducing the carbon footprint of everything we do in life - including the electrical transformers.

The comparison between the oils shows that the addition of the ECI to the total cost of ownership improves the price parity between the naphthenic oil (A) and recycled or bio-based options (B or C) while in the case of the bio-based option the parity can be significantly inverted namely for transformers where the operating temperatures are comparatively reduced.

Context (from last year's TMIN)

- The range of insulating liquids for electrical transformers has been **widening** and **diversifying** over the last decades
- Liquid *selection* of fluids is frequently based on meeting a suitable technical standard, *i.e.* IEC 60296
- **Sustainability aspects** are becoming very important
- ***Environmental Cost Indicators*** **(ECI)** can be utilized to add some clarity to the fluid selection process – not only from vendor to vendor but also from application to application

$$EXTCO_{(€€)} = TCO_{(€)} + ECI_{(€)}$$

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Inputs

Emissions & Pollutants

Impact Categories

LCA Results

Raw Materials

Products & Related Processes

Energy

CO2

PO4

NOx

Characterisation

Climate Change

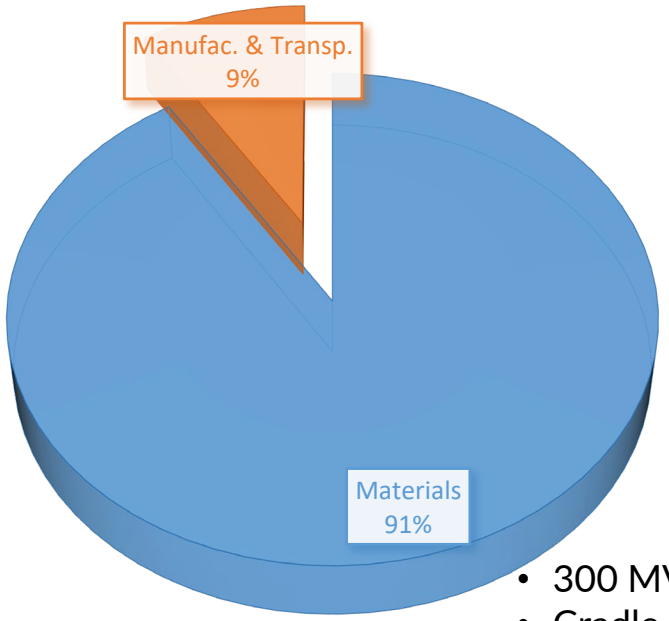
Acidification

Eutrophication

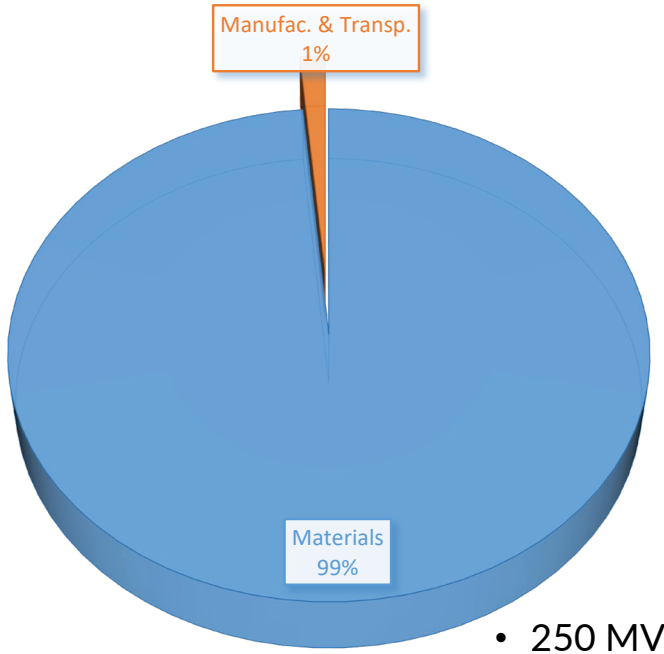
Weighting

Environmental Cost Indicator (ECI)

Context (from last year's TMIN)

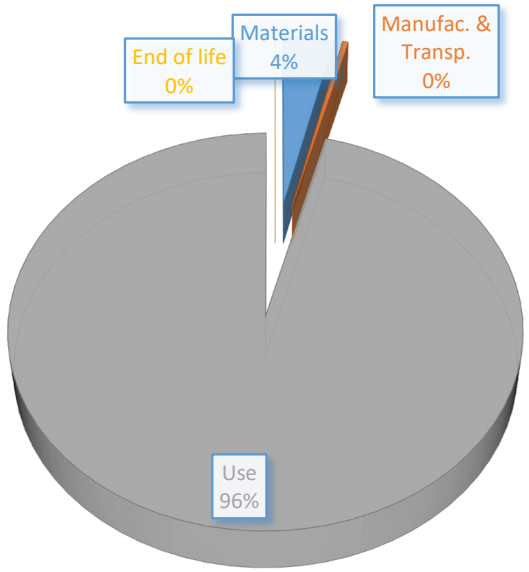


- 300 MVA 232 / 116 / 10 kV from Siemens Energy
- Cradle-to-gate emissions
- Embodied carbon footprint

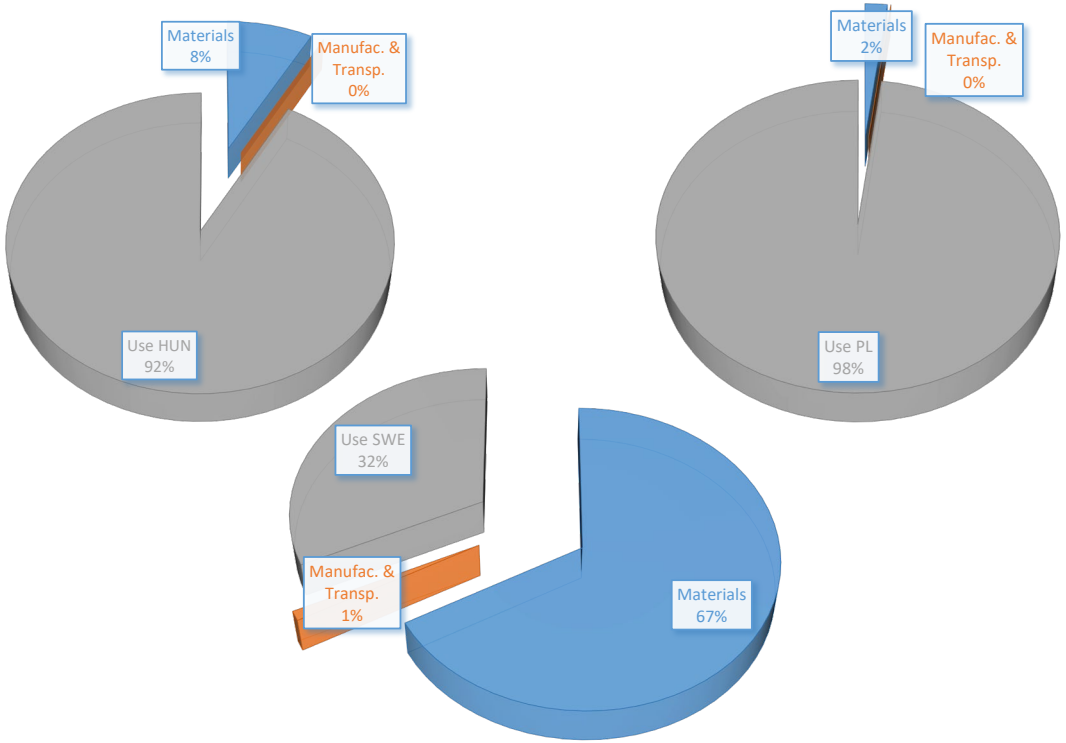


- 250 MVA 400 / 120 / 18 kV from Ganz
- Cradle-to-gate emissions
- Embodied carbon footprint

Context (from last year's TMIN)



- Same 300 MVA 232 / 116 / 10 kV from Siemens Energy
- Cradle-to-grave emissions
- Operational carbon footprint. Non-explicit energy mix used.

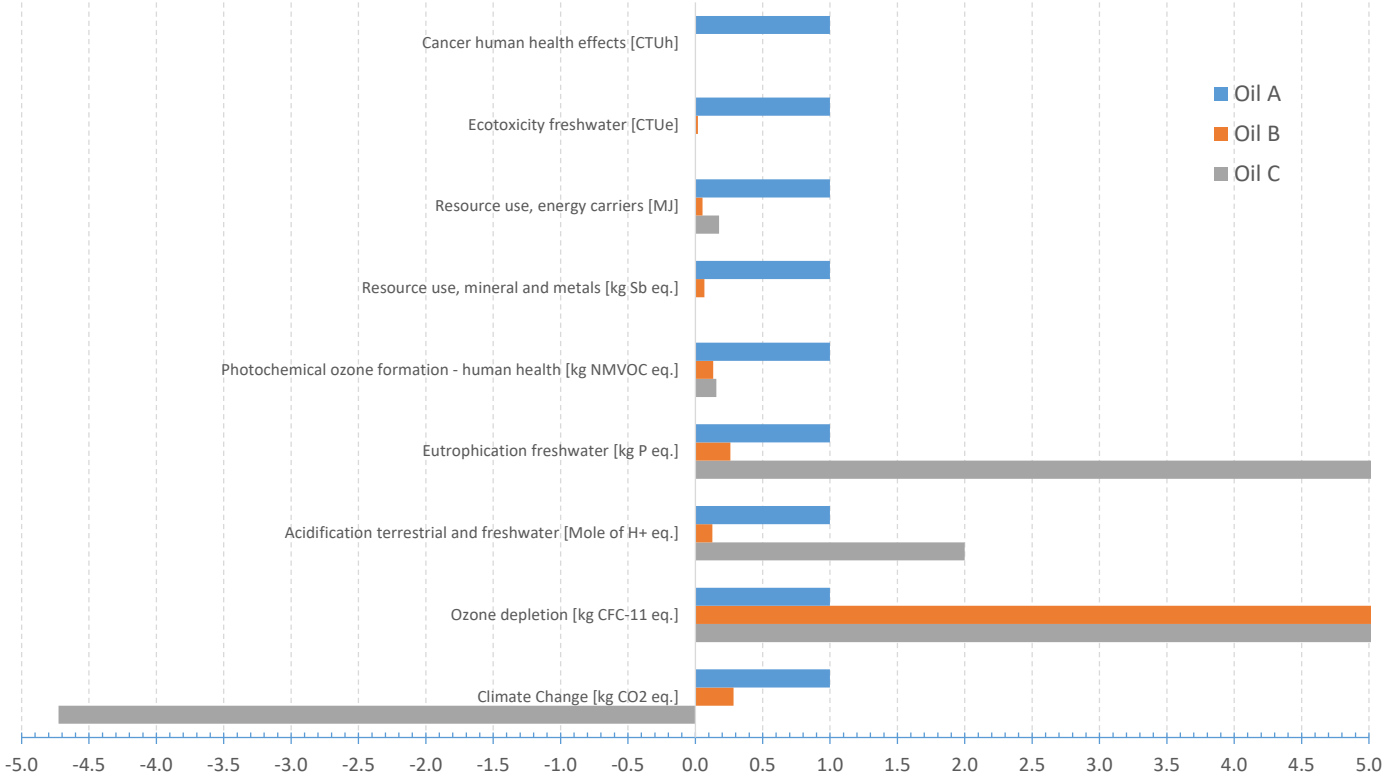


- Same 250 MVA 400 / 120 / 18 kV from Ganz
- Cradle-to-grave emissions
- Operational carbon footprint. Energy mixes of HUN, PL and SWE.

Nynas LCA practices

- **Independent LCA datasets for all our products**
  These may be:
  - Generic industry average
  - Nynas specific based on primary data
  - Generic based on reference / secondary data, or combinations of these
- **Reviews / updates of the LCA will be made regularly**
  - In general we provide an LCA per ISO 14040/14044
- **Avoid simple and direct competitive comparisons**
  - Making direct comparisons of competitor products requires a deep understanding on the quality of the data used (e.g. primary vs. secondary data)
- **PCF** shared upon request
- **Full LCA summary** shared under NDA; mainly for customers who are to make their own product calculations

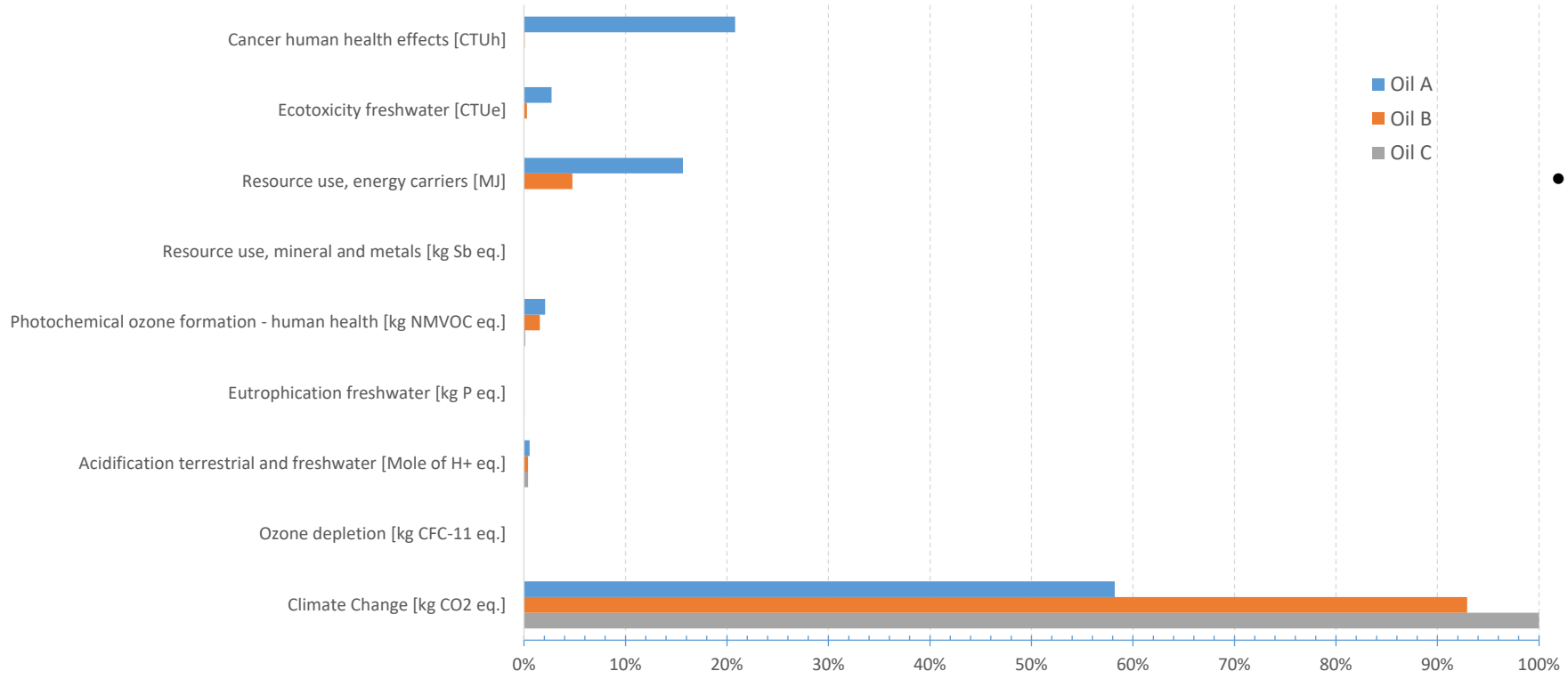
About LCAs and environmental cost indicators



Impact category – IC	Weighting factor - WF (Euros/Unit)
Climate change	0.116
Ozone depletion	32
Acidification terrestrial and freshwater	0.39
Eutrophication freshwater	1.96
Photochemical ozone formation	1.22
Resource use, mineral and metals	0.3
Resource use, energy carriers	0.00033
Ecotoxicity freshwater	0.00013
Cancer human health effects	1096368

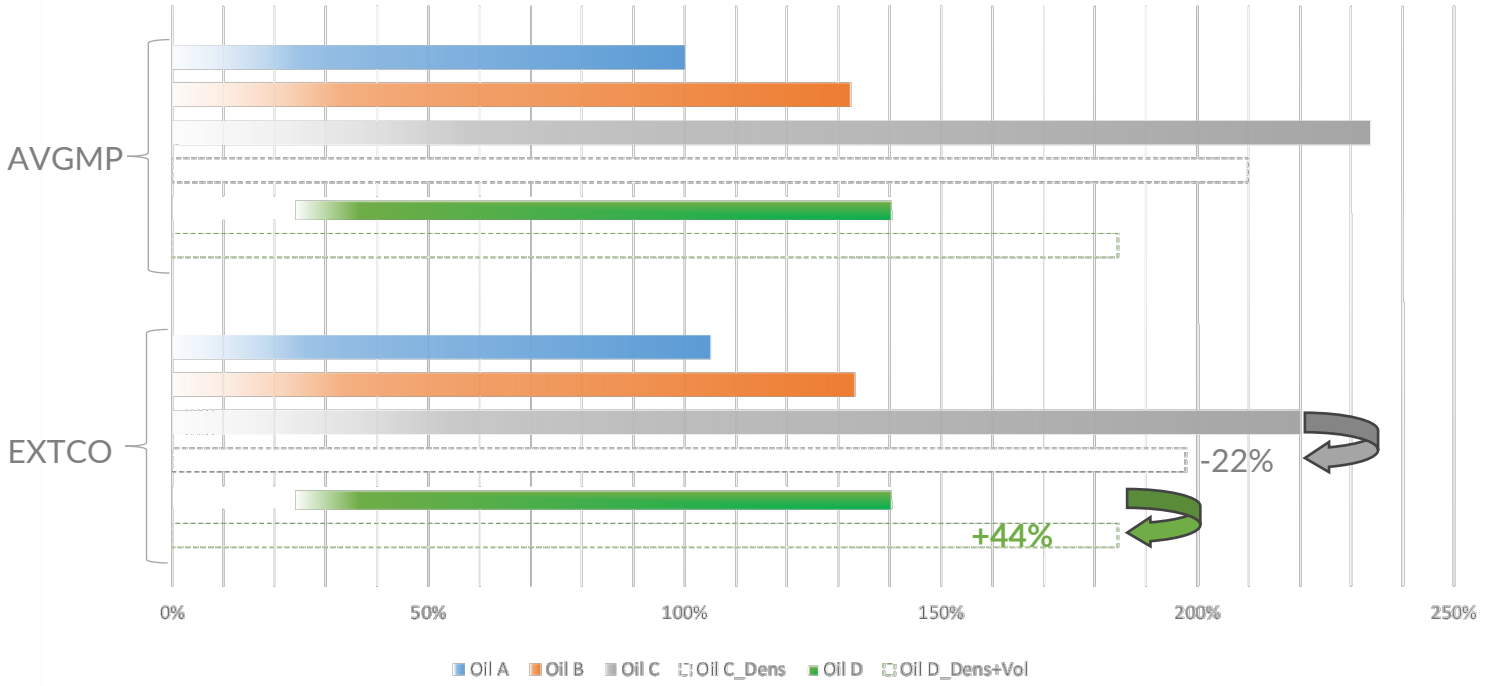
$$ECI_{oil\ A/B/C} = \sum_{IC=1}^{n} LCA_{oil\ A/B/C}\,(IC) * WF(IC)$$

About LCAs and environmental cost indicators



- A full LCA is more than a climate change impact category. **TRUE!!!**
- But the relative weight of climate change is dominant over all the others (representing over 90 % of the ECI in some products). **VERY TRUE!!!**
  - Even with a conservative value for the carbon emissions (116€/ton).

About environmental cost indicators



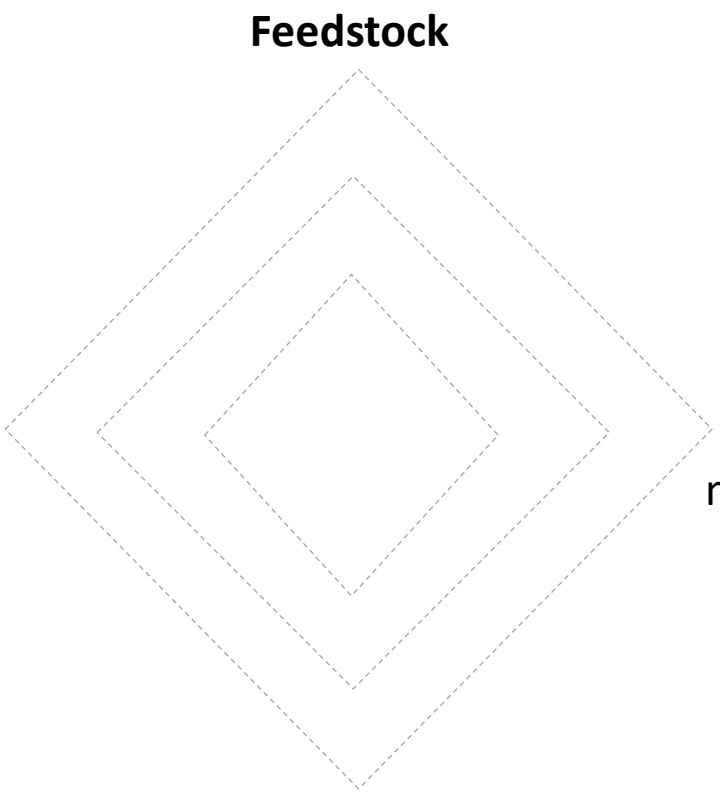
	Average Market Prices - AVGMP	Environmental Cost Indicators – ECI1	Extended Total Cost of Ownership - EXTCO
Oil A	100%	5%	105%
Oil B	132%	1%	133%
Oil C	234%	-14%	220%
Oil C*	210%	-12%	198%
Oil D	140%	0%	140%
Oil D**	184%	0%	184%

- Keep in mind - when making comparisons - that transformers are fixed-volume equipment.
  - Need to consider density differences (Oil C* versus oil C)
  - Need to consider design implications (Oil D** versus oil D)

About the broader picture

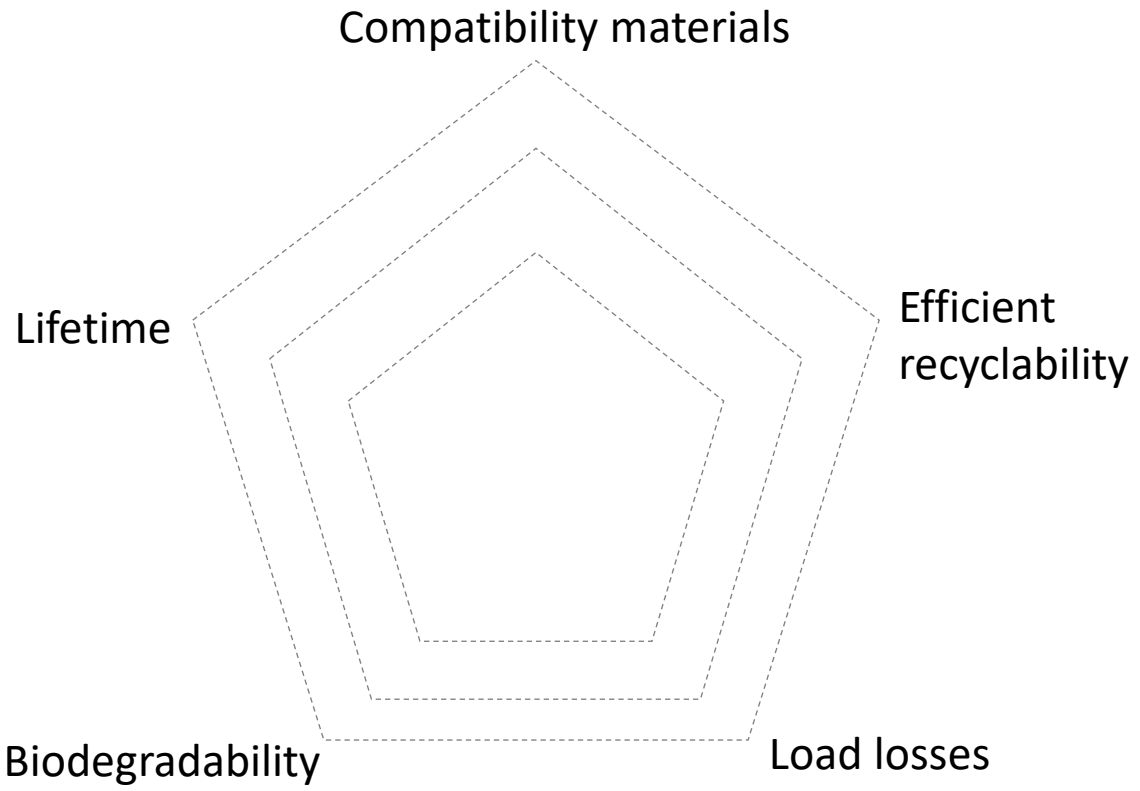
- ECI *simplifies* and *unites* the different environmental and operational data associated with each liquid by **translating** it into **money**
- ECI offers beyond the upfront *purchase prices* of the liquids, a more **holistic** comparison between the different **transformer oils selected** for use in electrical transformers
- The *comparison* between the oils shows that the **addition** of the ECI to the Total Cost of Ownership (TCO) calculations….
- *..improves* the **price parity** between the reference naphthenic oil (A) and the alternatives listed in this exercise (B)(C)(D) **but not sufficient yet to conclude.**

About the broader picture



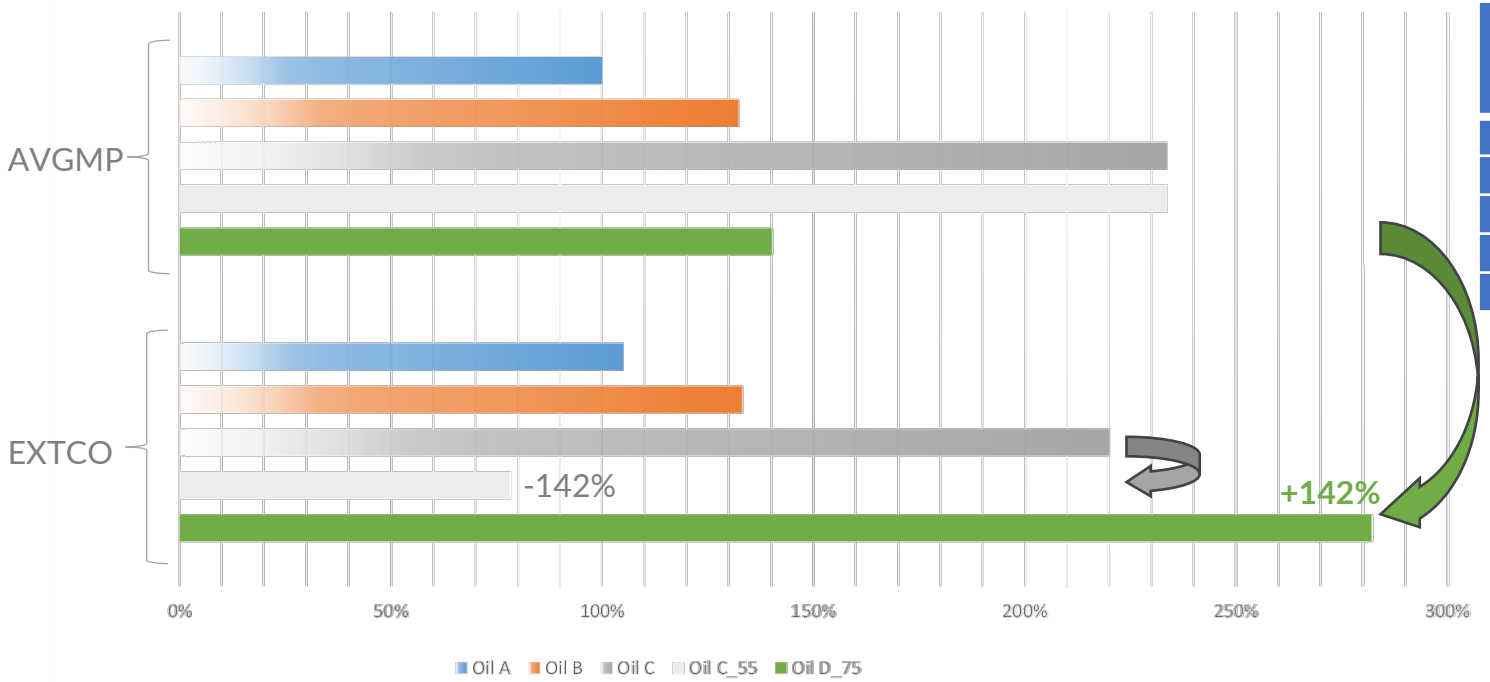
- There are important cradle-to-gate functional characteristics that **are not** fully captured in a LCA
- **Feedstock** type or quality, biogenic or recyled content can be captured indirectly through some impact categories (namely through GWP)
- **Embodied carbon footprint** – which may include effects from production and transportation – can also be captured
- **But compatibility,** meaning implicit changes in the design and / or manufacturing, **are not fully captured / capturable in a LCA**

About the broader picture



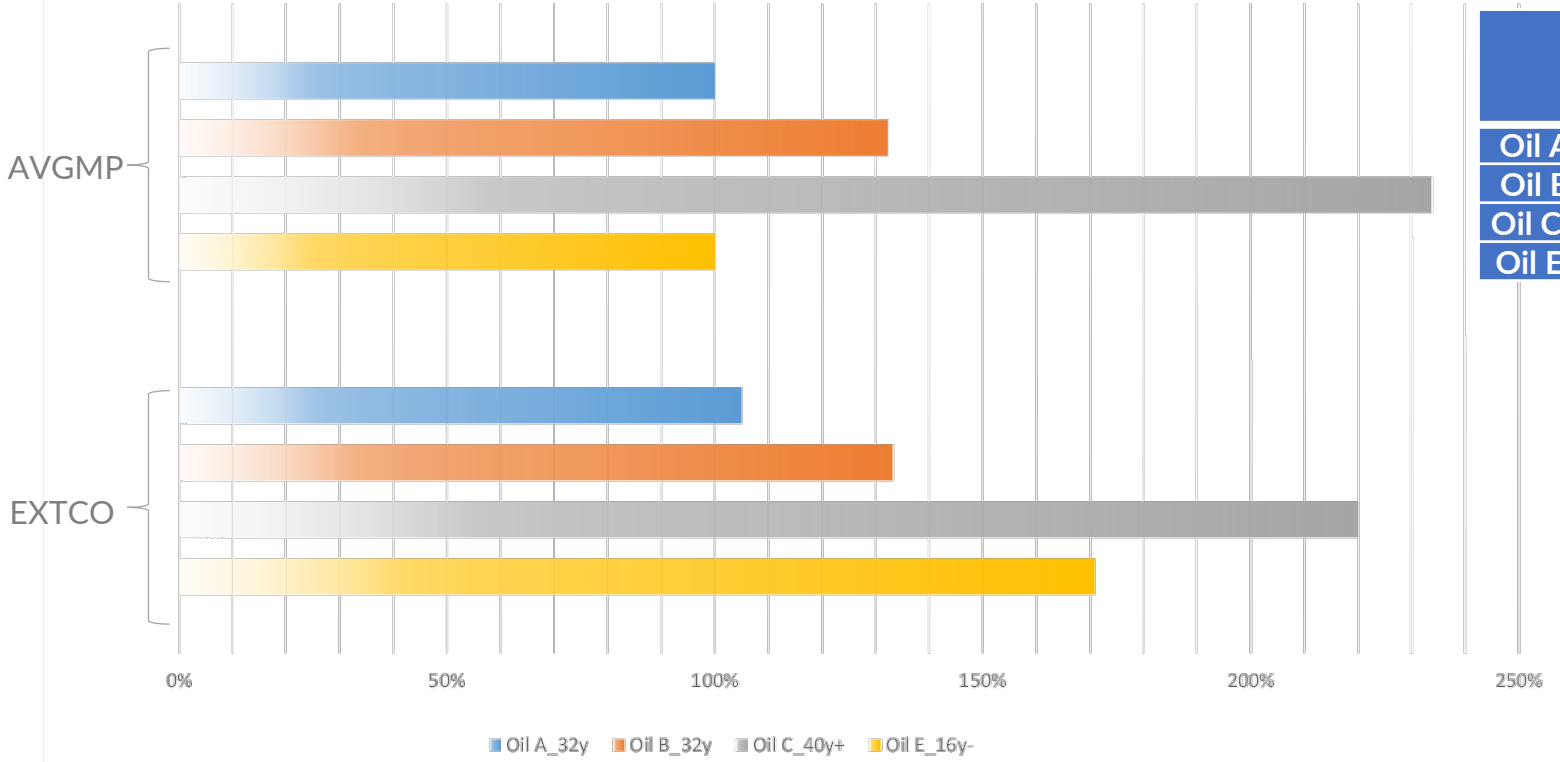
- Many other relevant use-phase characteristics **are not** fully captured in a LCA

About the broader picture (How to include load losses?)



	Average Market Prices – AVGMP	Environmental Cost Indicators – ECI1+3	Extended Total Cost of Ownership - EXTCO
Oil A_65	100 %	5 %	105 %
Oil B_65	132 %	1 %	133 %
Oil C_65	234 %	- 14 %	220 %
Oil C_55	234 %	- 156 %	78 %
Oil D_75	140 %	142 %	282 %

About the broader picture (How to include liquid lifetime?)



	Average Market Prices – AVGMP	Environmental Cost Indicators – ECI1	Extended Total Cost of Ownership - EXTCO
Oil A_32y	100 %	5 %	105 %
Oil B_32y	132 %	1 %	133 %
Oil C_40y+	234 %	- 14 %	220 %
Oil E_16y-	100 %	71 %	171 %

About the broader picture:

- How to include manufacturing related aspects such as impregnation / treatment times, handling aspects? Include the throughput time....
- How to include the efficiency of recyclability? Include direct and indirect costs associated with the quantity of material that is lost in the recycling loop. Not all recycling processes are the same...
- How to include the compatibility with materials? Include the cost difference associated with the material change. Include maintenance costs if the ageing of the materials is affected. Affect the depreciation time of the equipment if the impact is critical...
- How to include the biodegradability?
- How to include the fire safety?

Concluding remarks

- Multiple transformer liquids are already available, allowing increased environmental and operational performances. Comparing them is not a straightforward exercise.

- ECIs are a valuable framework. A JIP report has already been released since the end of 2024 explaining how to do it. The weighting factors used to convert the units of each LCA impact category are disputable. The sensitivity analysis modelled here shows that this framework is unfinished and will need to be adapted to different business contexts.

- This is meant to be an evolutive framework with a vast set of parameters still under discussion and/or definition. In any case, including parameters in advanced ECIs - beyond cradle-to-gate LCA datasets - is key to capturing all the relative benefits of each material for the right application.

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Make it happen! Thank you!

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