Cigre Nederland

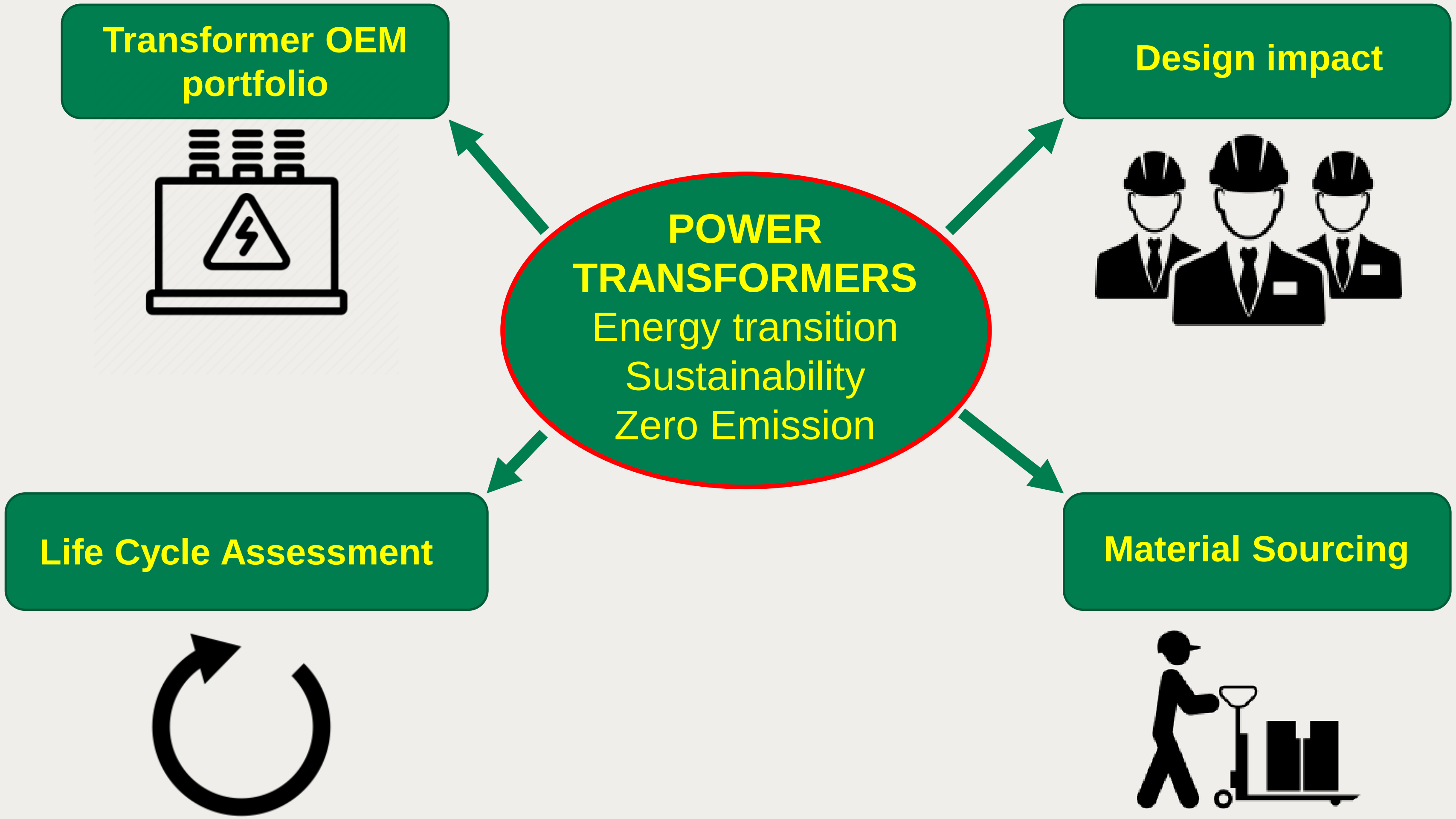
1 February 2024

Towards net-zero emission of T&D grids

Quantifying emission values of transformers

Towards net-zero emission of T&D grids

Erik de Groot (*Chief Engineer*) – Royal SMIT Transformers


Transformer OEM portfolio
Design impact
POWER TRANSFORMERS
Energy transition
Sustainability
Zero Emission
Life Cycle Assessment
Material Sourcing

Central generation plants reducing?

- **Power Station 2400 MW**

- Year of Transf. Manufacture **2011**
- **Power Station Closed in 2016 ….**

Transformers:

4 x 690 MVA, 285r/17 kV Generator Step-up Transformer

- 2760 MVA for 2400 MW
- 4 transformers

Renewables – Offshore windfarms

- **Offshore windfarm 700 MW**

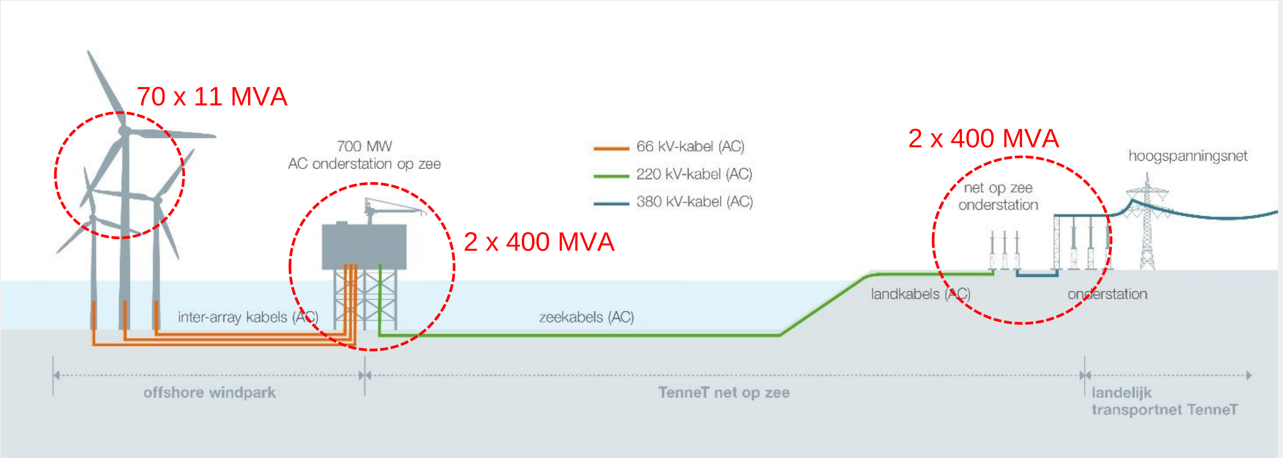
<u>Transformers:</u>

70 x 11 MVA, 66/1 kV offshore

2 x 400 MVA, 220r/66/66 kV offshore

2 x 400 MVA, 380r/225/33 kV onshore

- <u>2370</u> MVA for <u>700</u> MW
- 74 transformers
- Higher transformer demand
- Relatively smaller MVA size
- Reactive power compensation needed



Renewables – More (variable) compensation

- **Power cables generate reactive power**

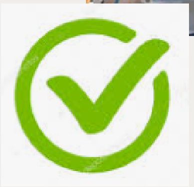
Example 220 kV:

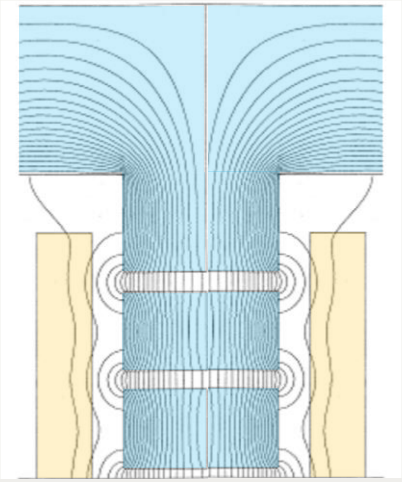
Overhead line (air) → 0,14 MVAr/km

Cable (ground/sea) → 4,00 MVAr/km

<u>Gapped core shunt reactors:</u>

- Voltage control → shunt reactor inductance → losses
- Fixed or regulated reactive power rating
- Example: 50 to 130 MVAr in 32 steps with tap changer.



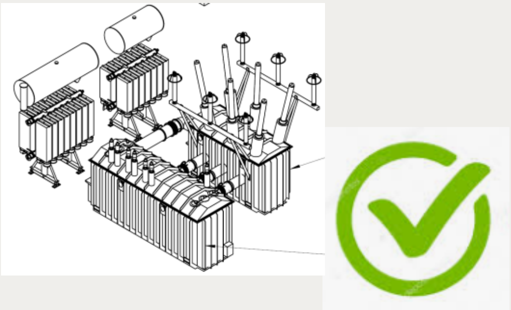


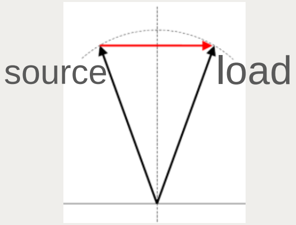
For power system expertise

Renewables – Power flow control

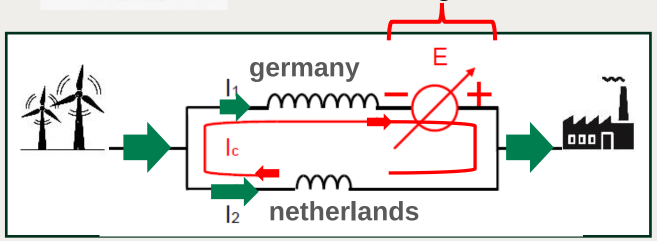
- **Changed power flows**

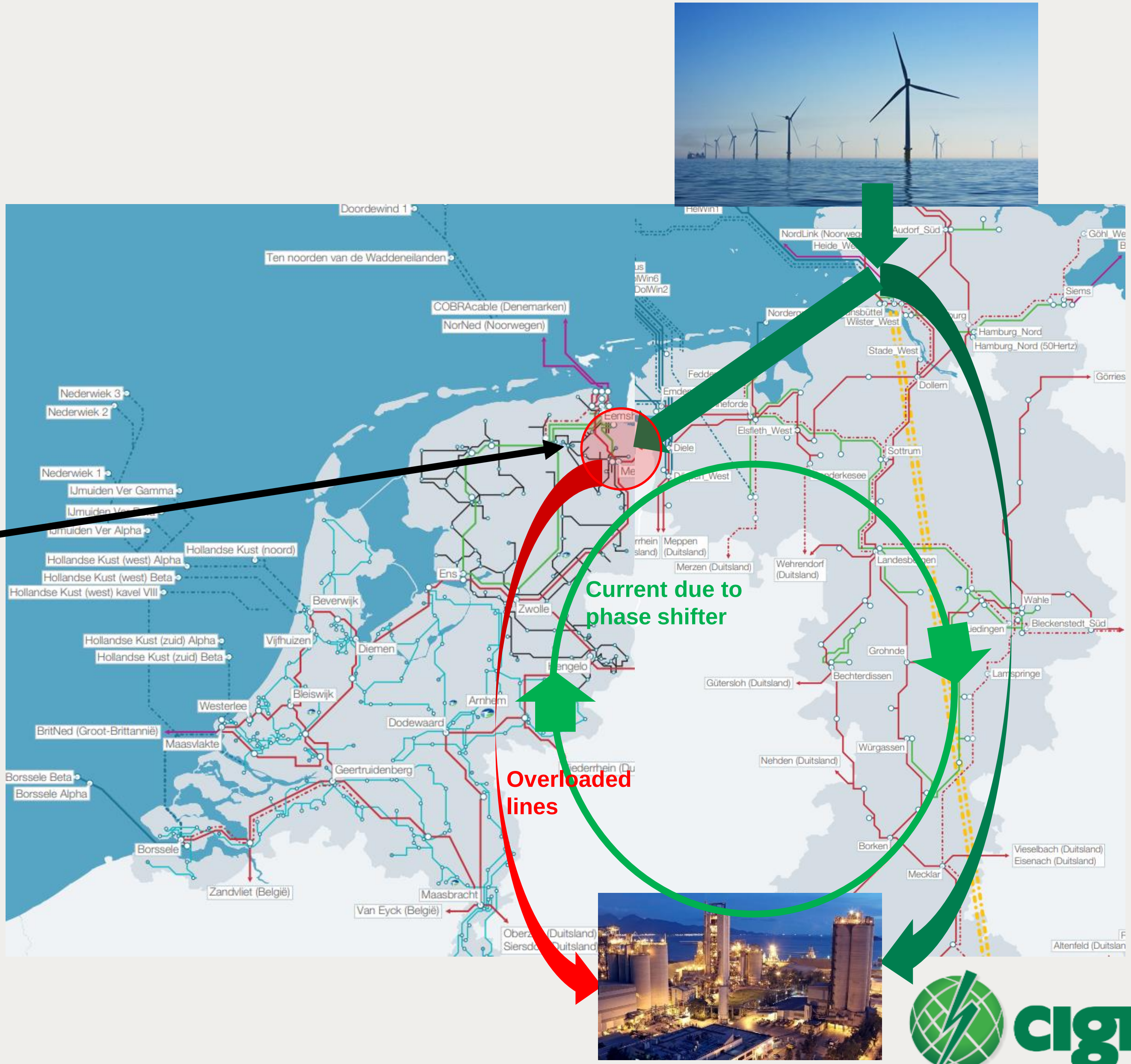
Need for control of power flow





Phase shifting transformer





Phase shifting transformer:

- 1000 MVA 380/380 kV
- +/- 37º phase shift in +/-16 steps
- Efficient loading of grid

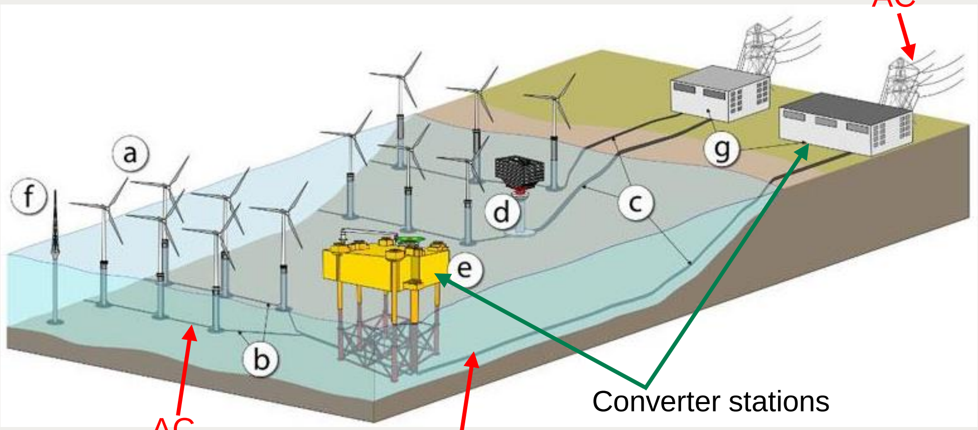
Renewables – HVDC power lines

- **Power flow across larger distances**
  (typically > 100 km)

Loss reduction by HVDC application

HVDC transformer in converter station:

➢ Large voltage and power rating

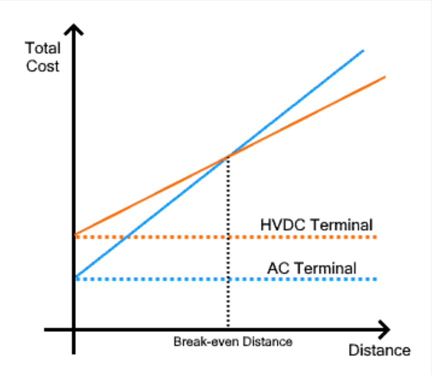


AC

AC

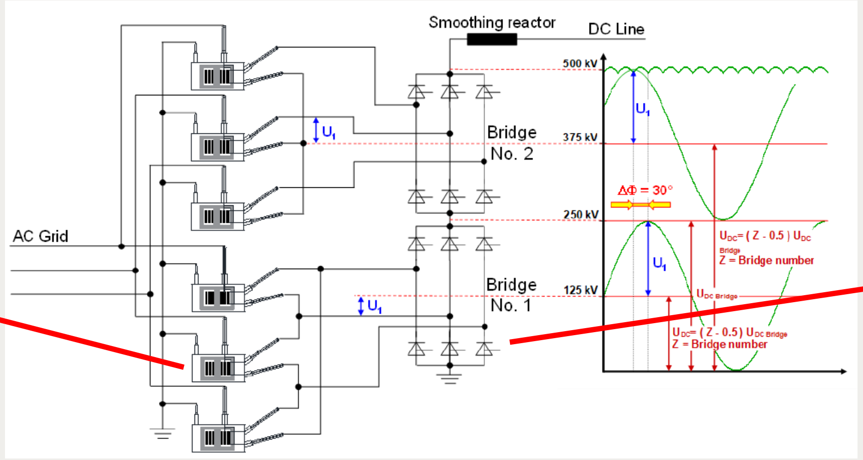
DC

Converter stations



HVDC vs HVAC Transmission Cost

converter station



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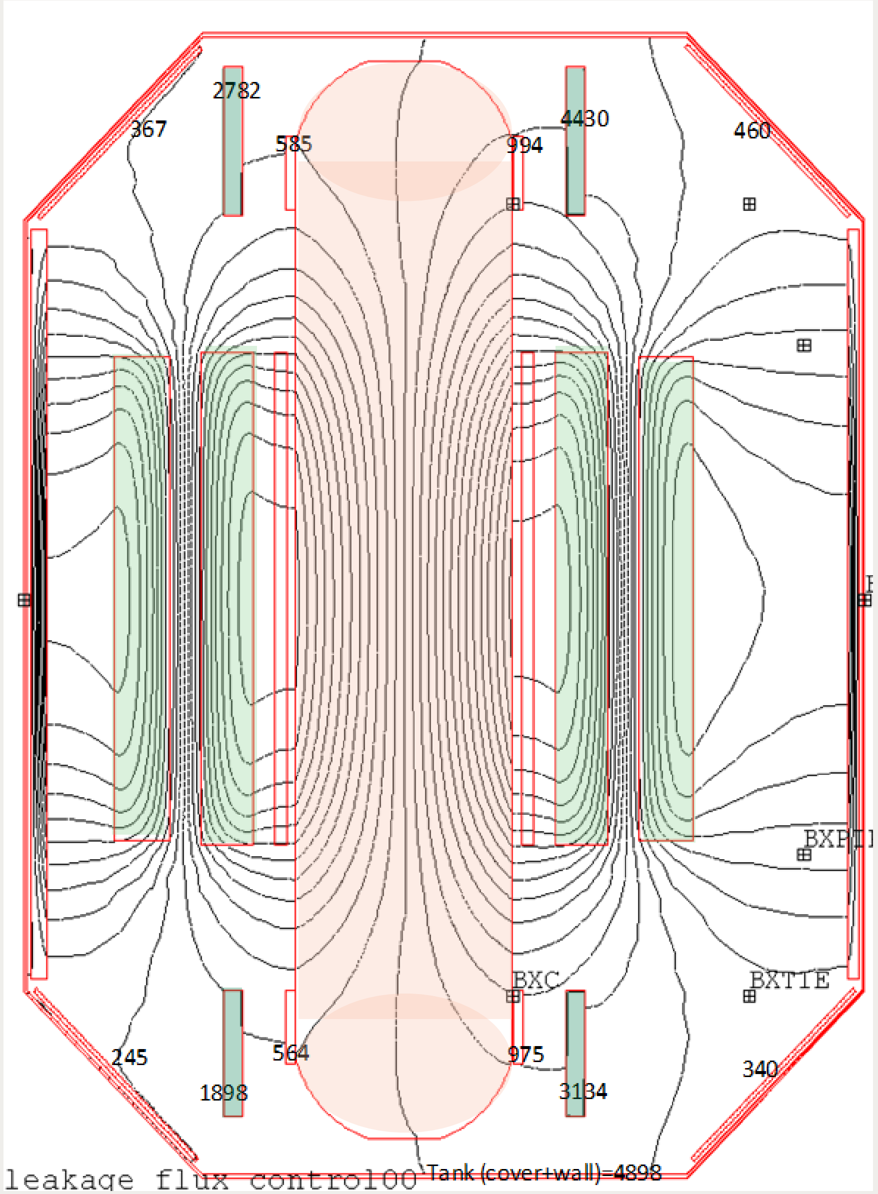
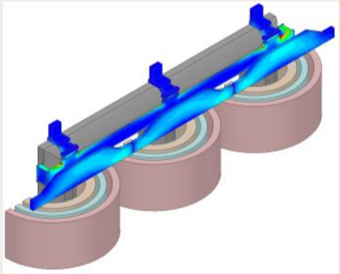
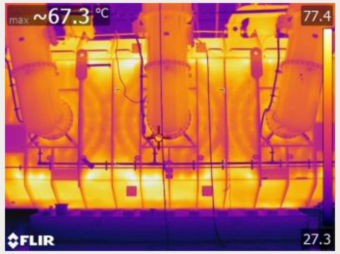
Transformer efficiency

- **Losses**
  - ➢ No-load
    - Core
  - ➢ Load
    - Windings DC & eddy losses
    - Lead losses
    - Extra losses in tank & structural parts
  - ➢ Auxiliary losses
    - Fans
    - Pumps

- **Efficiency**:
  - ➢ Very high efficiency (**99,3 - 99,8%)**
  - ➢ Depending on:
    1. Design
    2. Load
    3. Transformer rating
  - ➢ Peak Efficiency Index (PEI)







Transformer efficiency

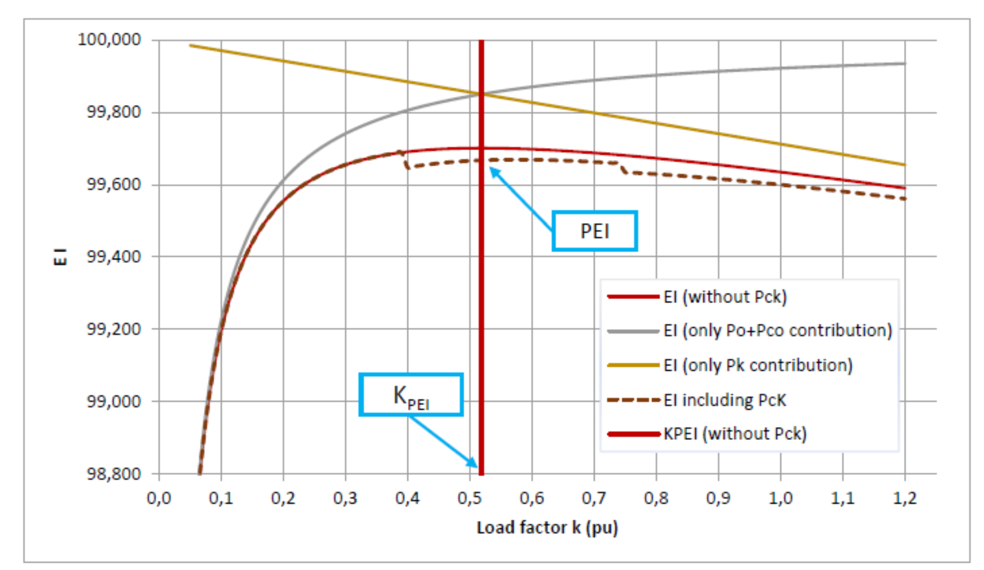
- **Eco Directive Peak Efficiency Index (PEI)**
  - Efficiency mandatory to bring product legally in the market
  - Some exceptions defined (*offshore*)
  - Has bigger impact on distribution & medium power transformers
  - 3 - 5% of generated electrical energy is wasted in transformer losses

Three phase or single phase transformers shall be evaluated against the rated power of the individual transformer.

Table 1 — Values of minimum Peak Efficiency Index for liquid immersed large power transformers

S_r (MVA)	Minimum Peak Efficiency Index (%) Tier 1	Minimum Peak Efficiency Index (%) Tier 2
100	99,737	99,770
125	99,737	99,780
160	99,737	99,790
≥ 200	99,737	99,797
	2015	2021

EUROPEAN COMMISSION



The Ecodesign Directive from the European Commission takes effect for transformers in July 2015. The new regulations will apply throughout Europe starting from July 2015; an additional stage with stricter minimum standards is planned for 2021.

General information

Name of the directive:
No. 548/2014 from the commission for implementing the Ecodesign Guideline 2009/125/EG

Scope of application: Distribution and power transformers

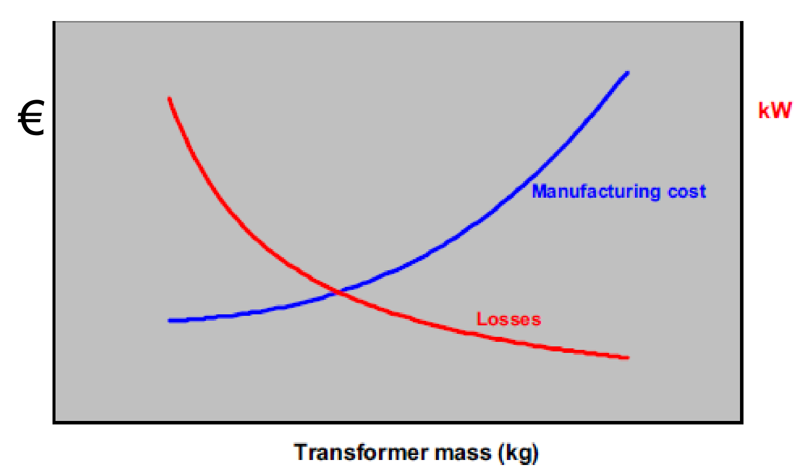
Contents: The Ecodesign Guideline defines a framework for the requirements for the environmentally-friendly design of energy consumption-relevant products. The objectives include improved energy efficiency and a general environmental compatibility and thus the reduction of CO_2 emissions.

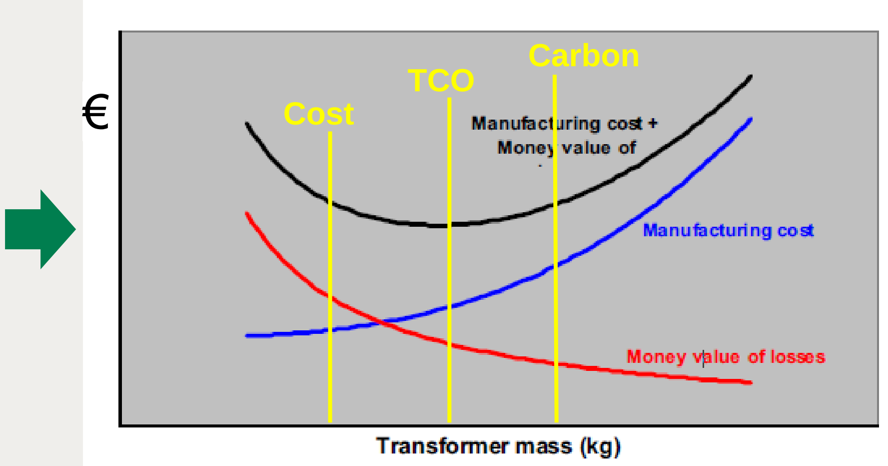
Transformer efficiency

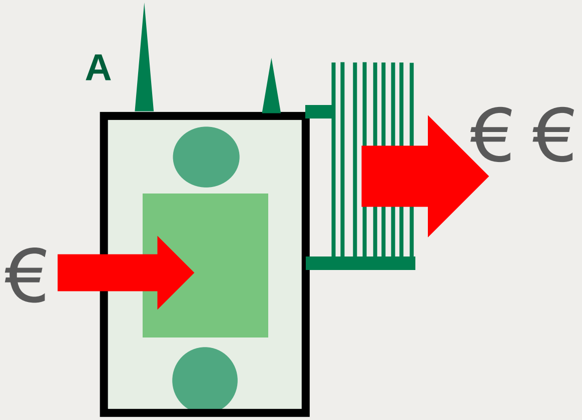
- **Effect of higher efficiency**

➢ Design
  - Bigger
  - Heavier
  - More complex
  - More expensive

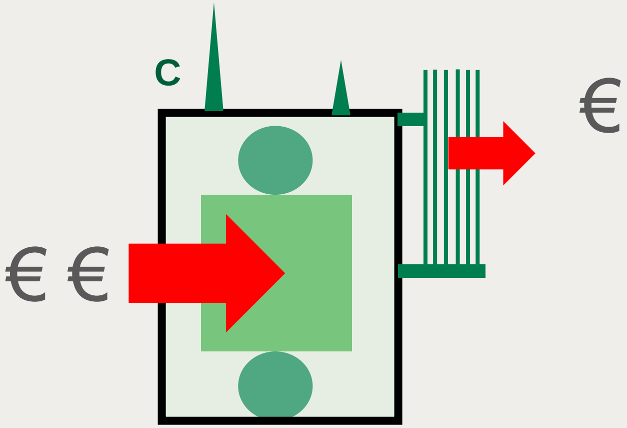
➢ Materials
  - High-end quality
  - Volume increased
  - Availability under pressure







Lower efficiency



Higher efficiency

Materials – Core steel

- **Grain Oriented Electrical Steel GOES**

➢ Largest (weight) component in a transformer

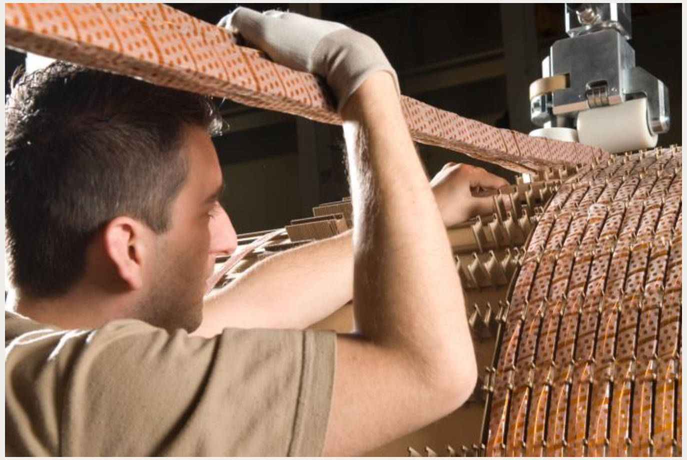
➢ Losses:
  - Core material quality requirement for better grades

  - Global shift to produce higher grades only
  - Supply chain under pressure
  - Amorphous core material → future?

➢ Core steel manufacturers → CO_2 emission reduction
  - Recycling is already done → does not cover the demand
  - Optimize steel making processes:
    ~~Coal~~ → Green electricity → Hydrogen → new steel plants
  - Carbon neutral in 2050 (-30% by 2030)

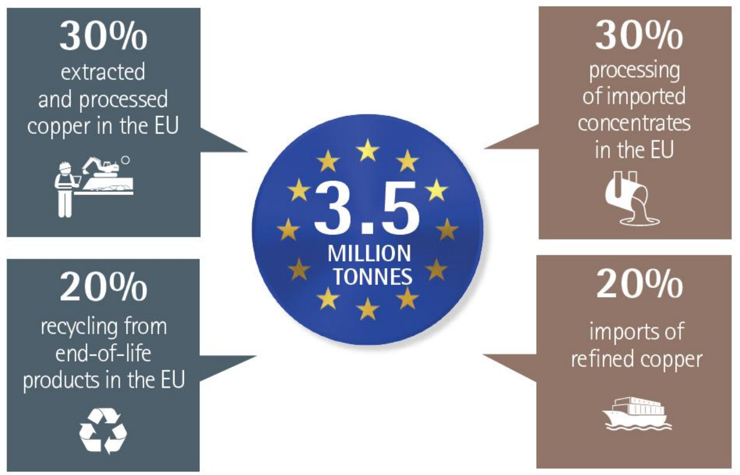
Materials – Winding Conductor

- **Copper conductor**
- ➢ Highest (loss) component in a transformer
- ➢ Losses:
  - Copper with high conductivity (purity) in transformers
  - Mainly depending on design parameters
    - Current density
    - Strand size
  - Can be endlessly recycled



- ➢ Copper manufacturers → CO_2 emission reduction
  - Mining of copper ore is 60% of emission
  - High grade scrap → 85% less emission than ore

    Global availability of scrap is 20% of total demand
  - Oil filled transformers have high degree of circularity
  - Carbon neutral in 2050 (-30/40% by 2030)



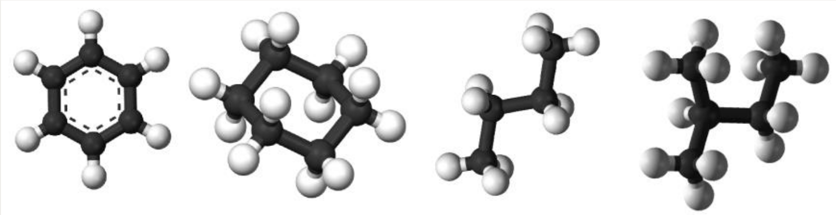
Materials – Insulation fluid

- **Fluid (mineral oil)**

➢ Insulating / Cooling properties

➢ Can be recycled & retro-filled

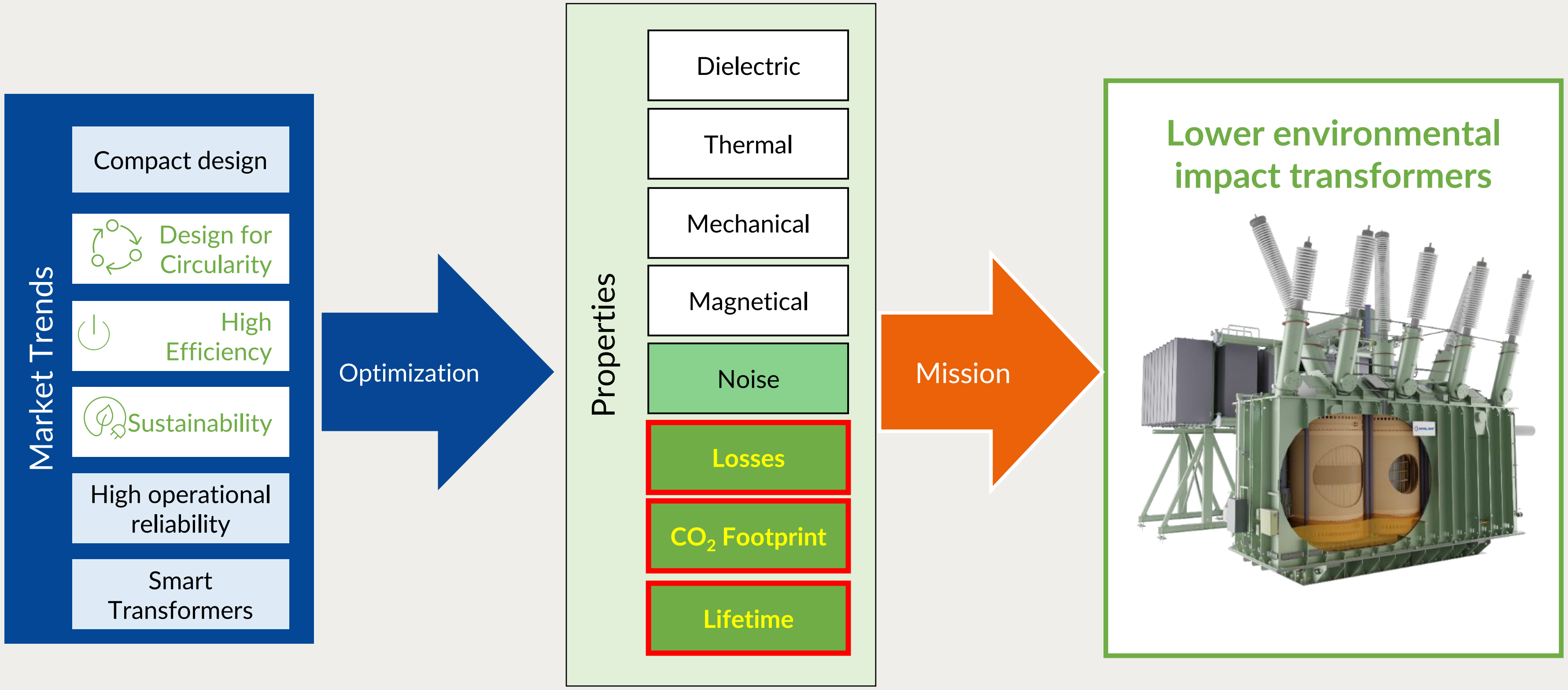
1. Mineral oil → virgin oil
2. Bio based oil → renewable hydro carbon
3. Circular oil → re-refined



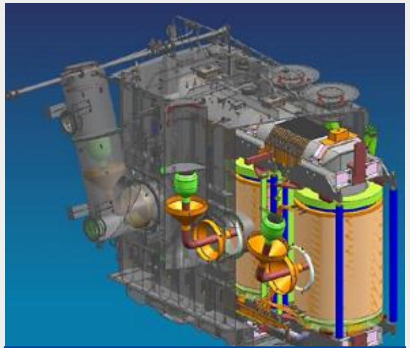
➢ CO_2 emission numbers:

- Mineral oil → 0,40 kg CO_2/kg oil
- Bio based → -2,40 kg CO_2/kg oil *(negative !)*
  - + 0,7 kg raw material sourcing
  - - 3,1 kg CO_2 absorption by biogenic livestock

How does sustainability impact transformers and value chain?



Transformer life cycle



MATERIALS

- GOES
- Copper/Aluminium
- Steel
- Oil
- Insulation material

MANUFACTURING

- Energy Mix
- Energy consumption
- Water consumption
- Material waste

USE PHASE

- Lifetime
- Energy Mix
- Losses
- Noise

END-OF-LIFE

- Recycling
- Incineration
- Reuse

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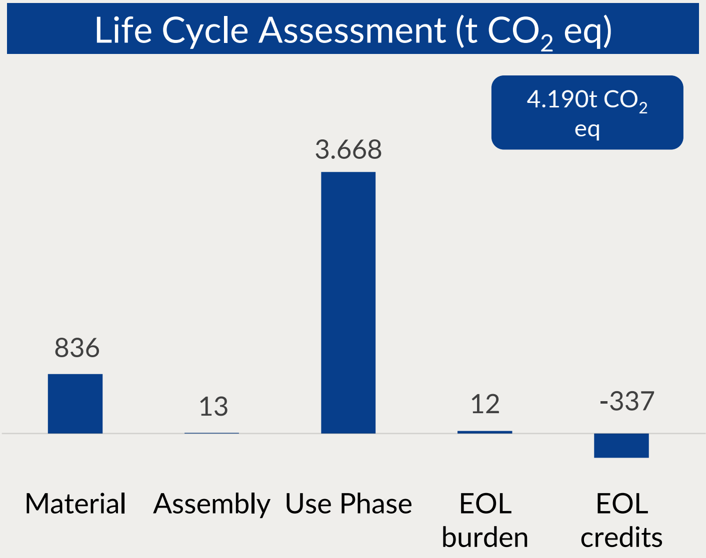
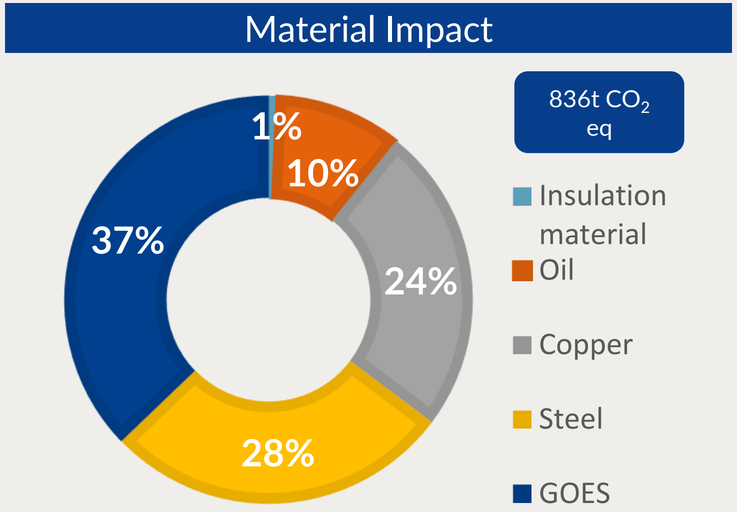
Cradle to Grave LCA of a large power transformer





GWP = Global Warming potential
depends on the transformers operating mode:

- the load factor is only 20%
- the use phase 40 years
- considered energy mix for assembly sourced from Europe (European Wind) and grid mix for use phase
- impact of the use phase on GWP of 87% !!

Due to recycling of the unit 8% is credited to the GWP.

Material impacts around 20% to the GWP. The highest contribution is from steel.

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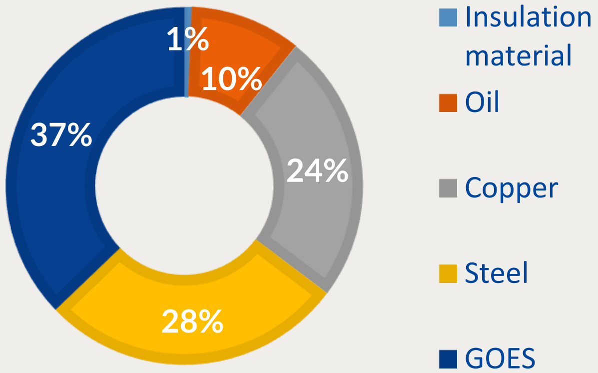
Material impact on Global Warming Potential (large power transformer)

materials large power transformer

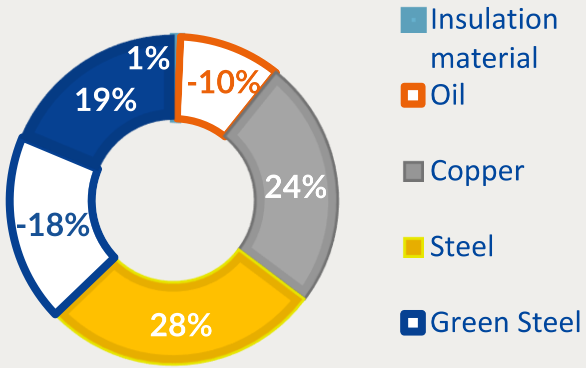
836t CO_2 eq



20% of GWP

Approx. -28% t CO_2 eq

605t CO_2 eq



15% of GWP

Exchange of Standard GOES with CO2 reduced Steel

Exchange of mineral oil with bio- or circular oil

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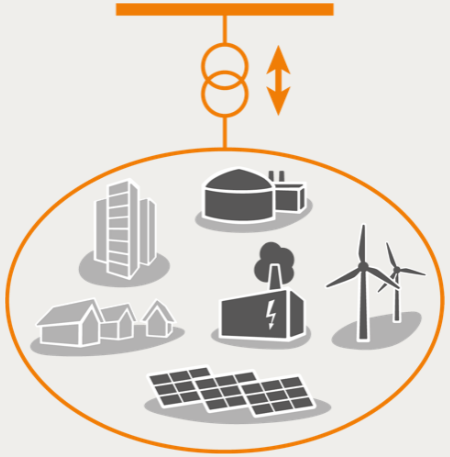
Future emission figures of the component "transformer"

- TSO's demanding "materials passport"
- Specification of "Cost of Carbon"→ € / tCO_2
- Industry standardization of LCA calculation → future energy mix !
- Investments by main material suppliers (GOES, Steel, Copper, Oil)
- Government regulations (efficiency) → tier 3
- R&D effort by transformer manufacturers



Thank you for your attention

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