

Benedikt Kehr- Polarixpartner GmbH
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Drive unit comparison with CO₂ emission perspective



Presenters



alvier
MECHATRONICS

Timo REULEIN

VP Operations

- Procurement, Project, Processes
- Passionate engineer - constantly looking for the cost and functional optimum
- Establish cost and CO2 Analysis as an Alvier service



POLARIXPARTNER
a Roland Berger company

Benedikt KEHR

Project Manager, Polarixpartner

- Extensive technical competencies with focus on CO2e calculation on parts level
- Experienced in product tear-downs, CO2e calculations, and alternative materials
- Development of levers for CO2e reduction
- Development and implementation of calculation tools and systems

alvier
MECHATRONICS

Drive unit comparison with CO2 emission perspective

MATERIAL AND SYSTEM COMPETENCE



Main set goals

- Alvier Mechatronics is preferred service provider from material to solutions for innovative electrical transformation
- Alternative materials are implementable throughout value chain enabling new industry standards

Drive unit comparison with CO₂ emission perspective

WAY of WORKING

- Benchmark existing system
- Rebuilt them on SMC optimized design and compare



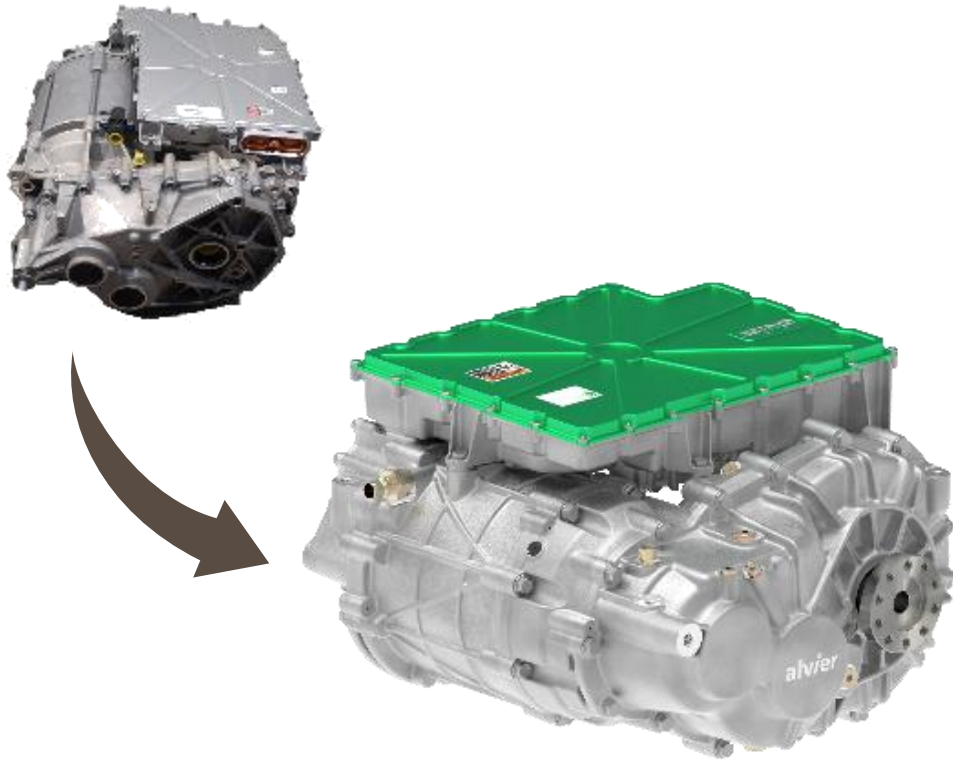
Volkswagen iD3



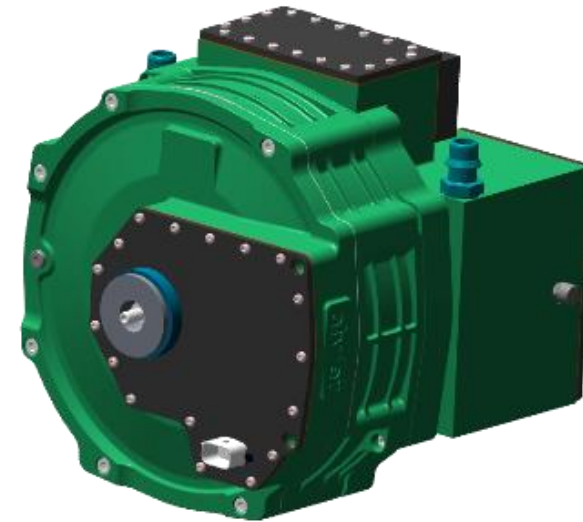
Yasa P400R

Drive unit comparison with CO₂ emission perspective

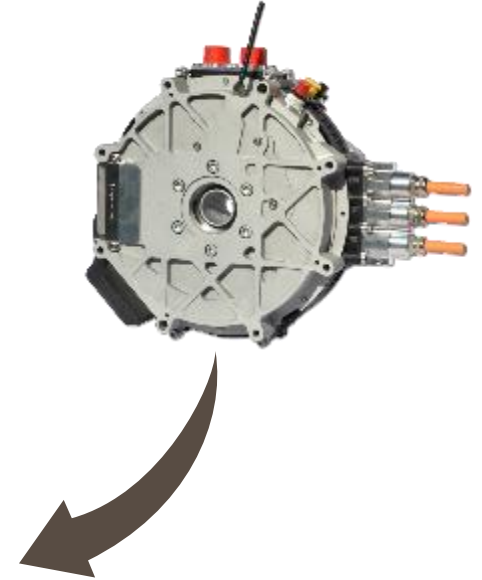
WAY of WORKING – integrated Drive System (iDS)



iDS Radial flux (Rx)



iDS Axial flux (Ax)



Drive unit comparison with CO₂ emission perspective

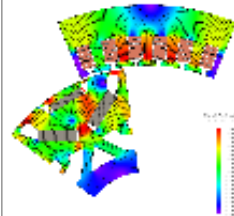
WAY of WORKING – development phase



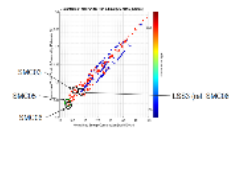
Benchmark spec.

- Voltage: 400V_{DC}
- Peak Power: 150 kW
- Peak Torque: 3.000 Nm
- Target Vol.: 100-350 k/a
- Highest Drive Cycle Efficiency
- Weight: <80 kg
- Size
 - Height: 310 mm
 - Length: 480 mm
 - Width: 540 mm

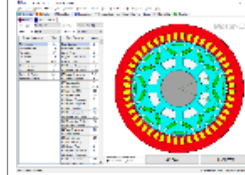
EM simulation



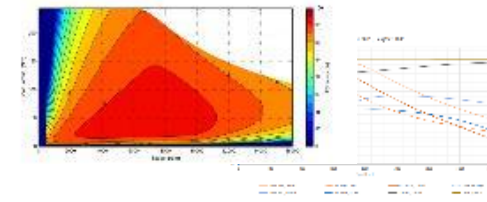
Concept evaluation



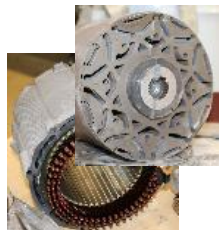
Concepts and topologie



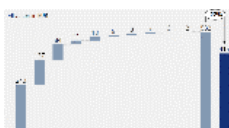
Motor Performance + Eff. map



Evaluation of different concepts and combinations



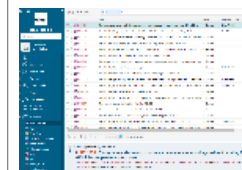
Benchmark study



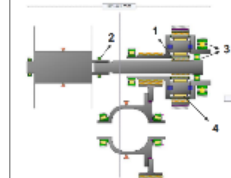
Cost analyses



CO₂ Footprint



Requirement definition



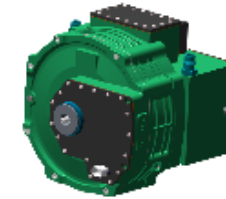
Transmission feasibility



Input for Höganäs
reg. material
requirements SMC

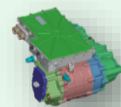
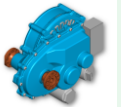
Drive unit comparison with CO₂ emission perspective

OVERVIEW



	VW - iD3	iDS Rx	iDS Ax	Yasa – P400
Benchmark / Concept analyse	✓	✓	✓	✓
Design Freeze		✓	✓	
Prototypes		✓ Q2/24	Q4/24	
Measurement	✓	✓ Q3/24	Q1/25	✓
Cost definition	✓	✓	✓	✓
Check CO2 impact	✓	✓	✓	✓

Unit overview e-Drive Unit

	VW ID3 RADIAL FLUX DRIVE UNIT	ALVIER RADIAL FLUX DRIVE UNIT	Yasa (P400 R Series) AXIAL FLUX DRIVE UNIT	ALVIER AXIAL FLUX DRIVE UNIT
Picture				
Peak power	150 kW / 310 Nm	150 kW / 230 Nm	160 kW / 370 Nm	150 kW / 438 Nm
Axle torque	3.574 Nm	3.000 Nm	Tbd. Nm	3.000 Nm
Ratio	11.53	13.0	-	7.0
Unit voltage / nominal voltage	210 V / 470 V	Tbd. V / 400 V	700 V / Tbd. V	Tbd. V / 350 V
Active length EM	170 mm	165 mm	106.7 mm	Stator 41.9 mm/ w rotors (2x) 87.1 mm
Stator diameter	220 mm	170 mm	250 mm	Tbd. mm
Cooling	Water	Water	Oil	Oil
Inverter	Si	SiC	-	SiC
Efficiency	13.9 kWh / 100 km	Tbd. kWh / Tbd. km	Tbd. kWh / Tbd. km	Tbd. kWh / Tbd. km
Weight	89 kg	80 kg	28.2 kg (without gearbox)	Approx. 70-75 kg

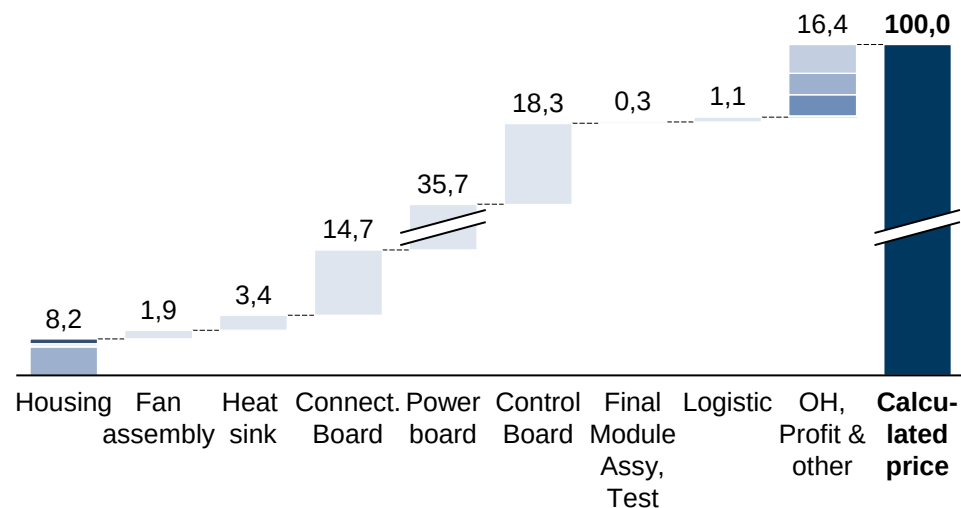
CO₂e Calculation in POLARIXCOSTING

Cost and CO₂e will always be linked with each other.

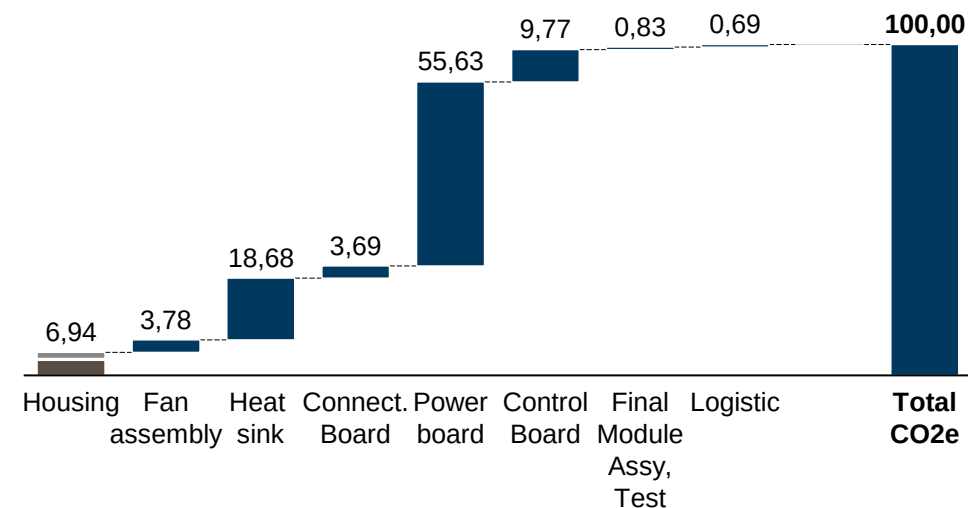
Therefore, it is recommended to calculate both numbers in the same system

System: Alu Machined															
55 Input Shaft: Soft & hard machining						CO2 Calculation		Logistics: 0,00		Material: 4,00		Process: 0,55		Total: 4,56	
Index	Quantity	Type		Supplier			Logistic: kg CO2e	Material: 3,85	Mac + Tool: 0,06	Setup: 0,00	Area: 0,02	Cons.Mat.: 0,47	Operator: 0,00	Overhead: 0,00	4,56 kg CO2e
	1	Main-Part		PPS											
Function Group		Weight [kg]		Part count											
55.1 Cold Forging Input Shaft						CO2 Calculation		Logistics: 0,00		Material: 3,55		Process: 0,15		Total: 3,71	
Index	Quantity	Type		Supplier			Logistic: kg CO2e	Material: 3,42	Mac + Tool: 0,07	Setup: 0,00	Area: 0,00	Cons.Mat.: 0,09	Operator: 0,00	Overhead: 0,00	3,71 kg CO2e
	1	Sub-Part		Foundry/Forge (DE)											
Function Group		Weight [kg]		Part count											

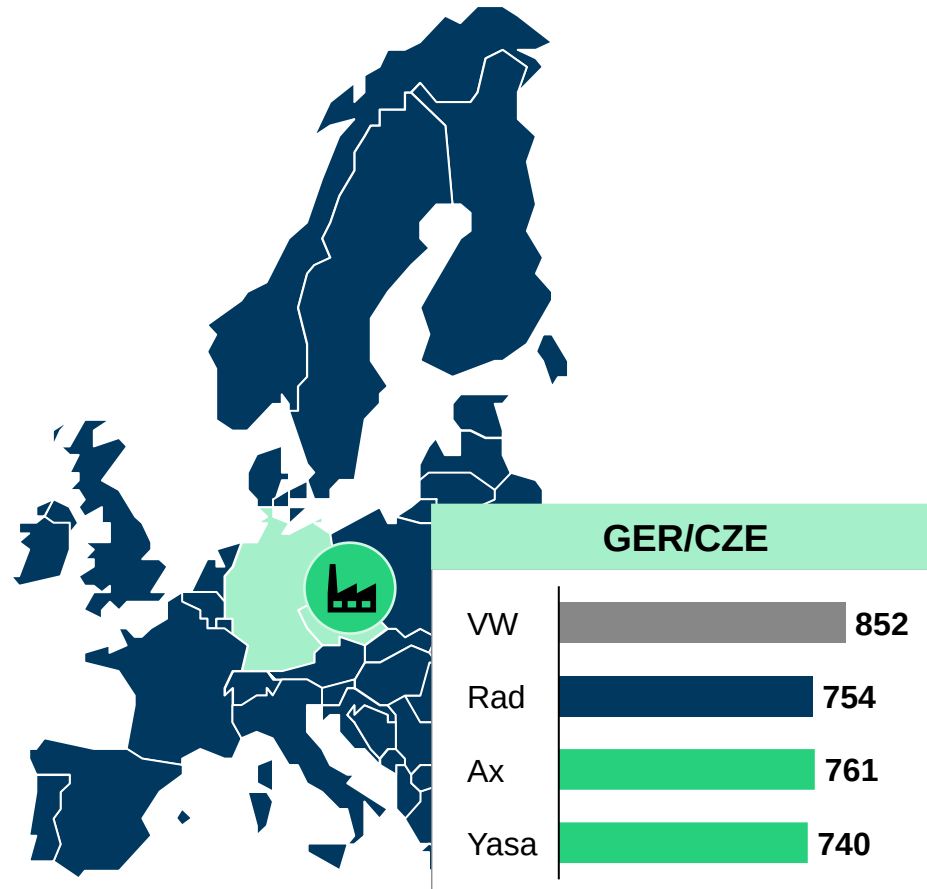
Cost share [%]



CO₂e share [%]



The results show an advantage in terms of CO₂e emissions for the Alvier drive units



All variants assume local sourcing of raw materials

Main differences in CO₂e

- Advantage for Alvier SMC stator instead of electrical sheets
- Housing differences needed for Axial Flux Drive Unit leads to more CO₂e
- Different Transistor technologies increase emissions for Alvier drive units in Inverter
- Different types and number of magnets lead to differences (lowest Alvier Radial, highest: Alvier Axial)
- Main influence of the supply chain are the Tier 2 supplier and especially the raw material sourcing
 - Main material influence by aluminum

Calculations

- The calculations give the possibility to switch between different scenarios, easily adjustable are:
 - Region of Tier 1 / Tier 2 Supplier
 - CO₂e of raw materials
 - Recycling share in different processes
 - Used electricity mix for countries
 - Used factors for logistic calculation

Cockpit overview

Region selection for CO₂e calculation

OEM Country	Germany
Tier 1 Country	Czech Republic

Process	Recycling Share	Remark
Casting aluminum	40%	
Casting Iron	30%	
Forging	10%	
Forming / sheet metal	10%	
Extrusion aluminum	10%	
Injection molding - Thermoplastic	15%	
Injection molding - Elastomer	0%	
Copper	32%	Global average
SMC	0%	
Electro sheet	10%	
Others	0%	

Name	CO ₂ e [kg]
Material	473,8143026
Process/Others	298,5702248
Logistics	25,59762889
	797,9821562

Short result summary

Materials	CO ₂ e [kg]
EN AC - AISi9Cu3	129,1482912
forging steel 16MnCr5	64,83167448
25 CrMo 4 / 1.7218	11,50348114

Definition of recycling share for processes

Definition of GWP for SMC material

Electricity premises for different regions

SMC GWP
1,1

Country	System Name	CO ₂ e/kWh	Source
Canada	Canada-Country Average	0,066	Electricity Maps 12 month average: Ontario
China	China-Country Average	0,6192	Sustamize, Abruf 15.08.2023, China
Czech Republic	Czech Republic-Country	0,4601	Sustamize, Abruf 15.08.2023, Czech Republic
Germany	Germany-Country Average	0,3724	Sustamize, Abruf 15.08.2023, Germany
Mexico	Mexico-Country Average	0,48	Sustamize, Abruf 15.08.2023, Mexico
Sweden	Sweden-Country Average	0,03775	Electricity Maps 12 month average: South Sweden
United States	United States-Country A	0,500	Electricity Maps 12 month average: Midcontinent Independent Transmission System Operator, Inc.

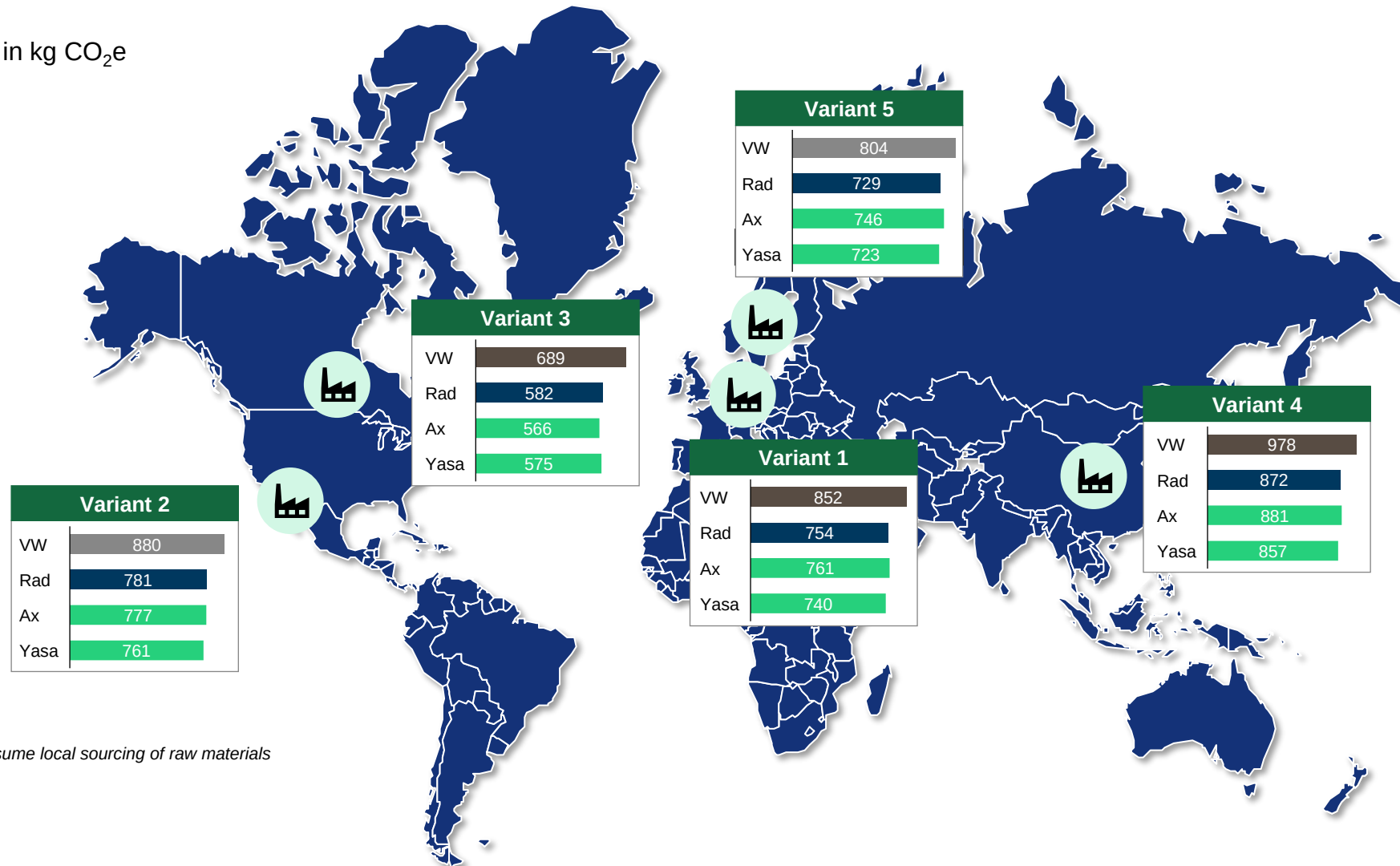
Start	Target	Route	CO ₂ e/€ Logistics
Canada	Canada	Canada - Canada	1,482
China	Canada	China - Canada	4,493
Czech Republic	China	Czech Republic - China	4,431
Germany	Czech Republic	Germany - Czech Republic	1,185
Mexico	Germany	Mexico - Germany	2,051
United States	Mexico	United States - Mexico	1,482
Canada	United States	Canada - United States	1,482
China	China	China - China	2,223
Czech Republic	Canada	Czech Republic - Canada	2,643
Germany	China	Germany - China	4,579
Mexico	Czech Republic	Mexico - Czech Republic	4,041
United States	Germany	United States - Germany	2,273
Canada	Mexico	Canada - Mexico	
China	United States	China - United States	
Czech Republic	Czech Republic	Czech Republic - Czech Republic	
Germany	Canada	Germany - Canada	
Mexico	China	Mexico - China	
United States	Czech Republic	United States - Czech Republic	2,643
Canada	Germany	Canada - Germany	2,273

Logistics definition in kg CO₂e / € logistic cost

Remark: The calculation of the CO₂e footprint builds on the cost calculation of the different drive units. Nevertheless the calculated cost values are not linked to this dashboard and should not be used as reference value for cost. For cost calculation please see the corresponding calculations.

Supply chain variants worldwide

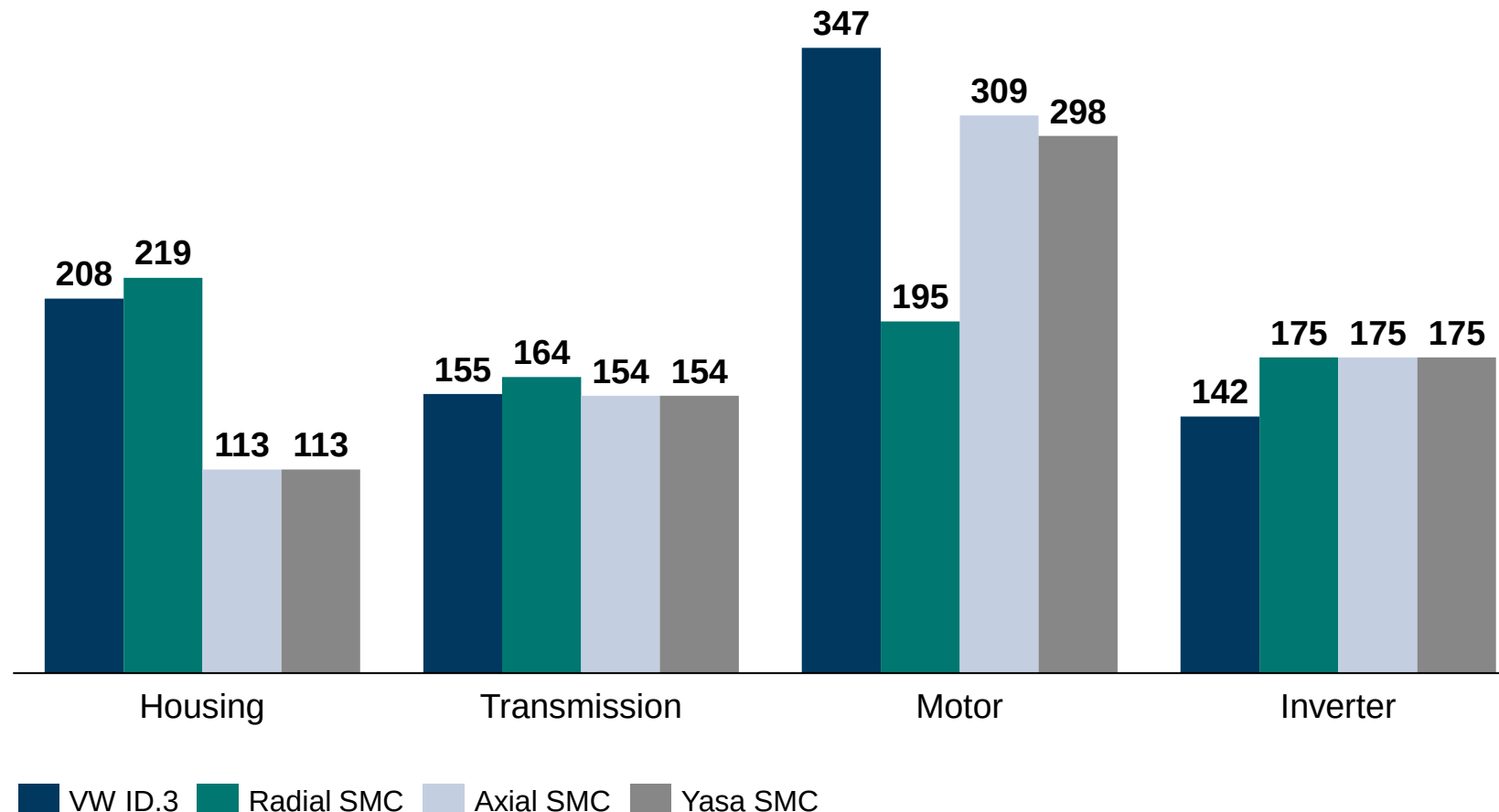
All values in kg CO₂e



All variants assume local sourcing of raw materials

The main CO₂e differences can be found in the housing and the motor

All values in kg CO₂e



- The radial drive unit has its main advantage in the motor
- The axial and Yasa drive unit have its main advantage in the housing, but loses it in the motor
- The use of SMC brings a relevant advantage
- Main driver of emissions between Radial and Axial/Yasa motor are the magnets

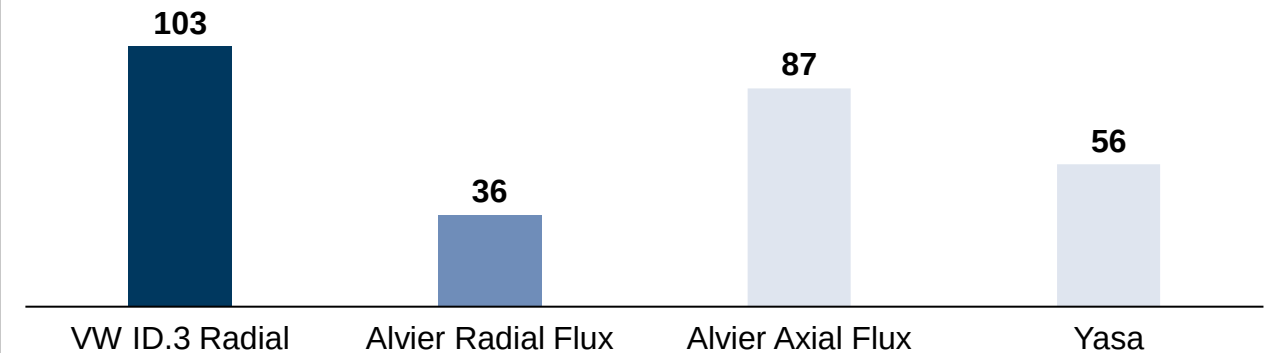
Main driver for stator emissions is the amount and technology for the lamination

Component data

	VW ID.3	Alvier Radial Flux	Alvier Axial Flux	Yasa
Tech. design:	Radial	Radial	Axial	Axial
Material:	Electrical Steel	SMC	SMC	SMC
Net mass lamination:	16.11 kg (Steel)	11.05 kg (SMC)	4.8 kg (SMC)	5.90 kg (SMC)
Net mass copper:	7.10 kg	3.67 kg	4.08 kg	3.82 kg
Electrical Steel:	1.92 kg CO ₂ e / kg			
SMC*:	1.10 kg CO ₂ e / kg			

Bottom-up

All values in kg CO₂e



Main deltas

- Stator lamination
 - ID.3: 75 kg CO₂e
 - Al Rad: 17 kg CO₂e
 - Al Ax: 26 kg CO₂e
 - Yasa: 24 kg CO₂e
- Different supply chains assumed for tooth for Al Ax /Yasa
- Additional housing/cages for Al Ax vs. Al Rad + 52 kg CO₂e

Comparison of SMC and electrical steel

Scrap



- The use of SMC for the stator significantly reduces the scrap in production of the stator-/rotor-package
- ~50% less scrap than only electrical steel for Stator + Rotor
- Scrap can have a very high impact on the product carbon footprint

Process



- The SMC process is less efficient in terms of energy consumption, but easily optimized:
 - Reduction of energy usage by optimizing batch sizes and cavities
 - Process can be easily conquered by using green energy

CO₂



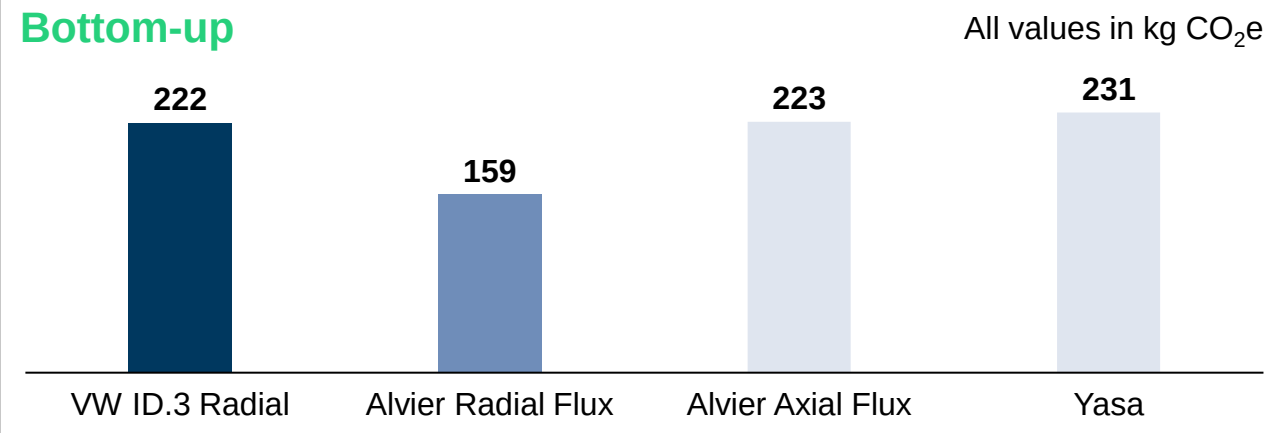
- Good recyclability for electrical steel (~30% carbon footprint reduction for material)
- SMC (i.e. Somaloy) already has a better carbon footprint than recycled electrical steel

Rotor

Component data

	VW ID.3	Alvier Radial Flux	Alvier Axial Flux	Yasa
Tech. design:	Radial	Radial	Axial	Axial
Material:	Electro Steel	Electro Steel	Electro Steel	Electro Steel
Net mass laminati on:	15.31 kg (Steel)	6.98 kg (Steel)	3.56 kg (Steel)	2.76 kg (Steel)
Net mass magnet:	2.43 kg	1.33 kg	1.92 kg	2.48 kg
Rotor:	Shaft	Shaft	Disc	Disc

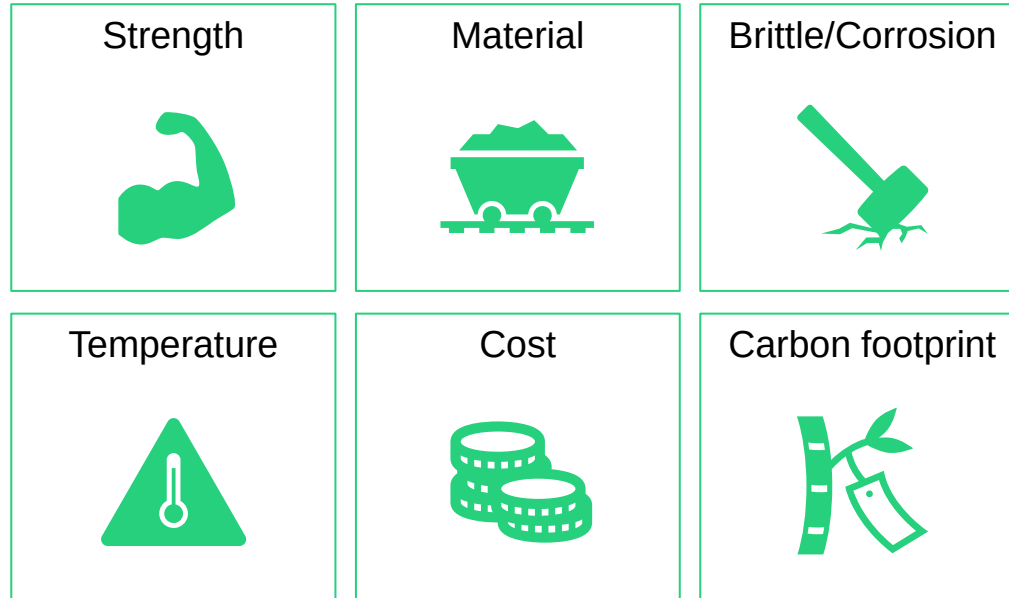
Bottom-up



Main deltas

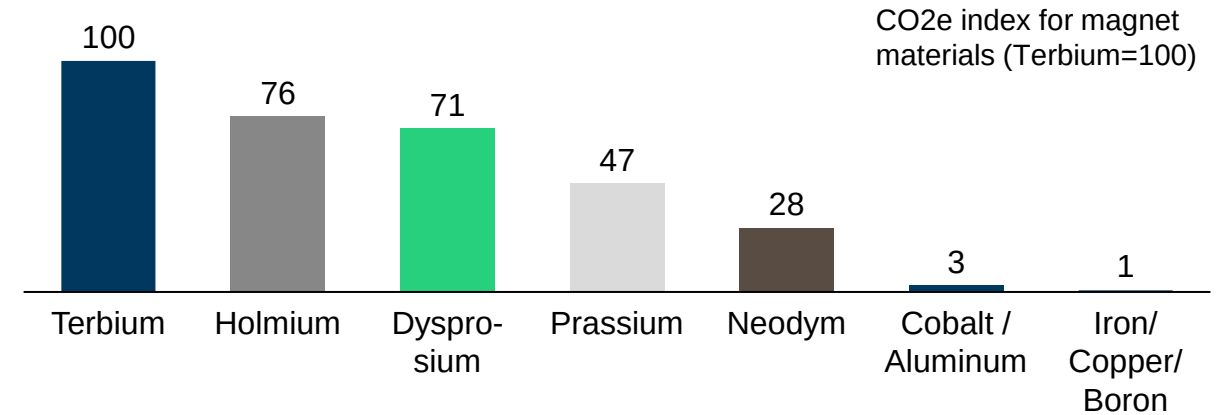
- Magnets
 - ID.3: 32+64 magnets: 161 kg CO₂e
 - Al Rad: 32+64 magnets: 92 kg CO₂e
 - Al Ax: 40*4 magnets: 169 kg CO₂e
 - Yasa: 8*8 magnets: 181 kg CO₂e

Properties and carbon footprint of magnets - NdFeB (Neodymium-Iron-Boron)



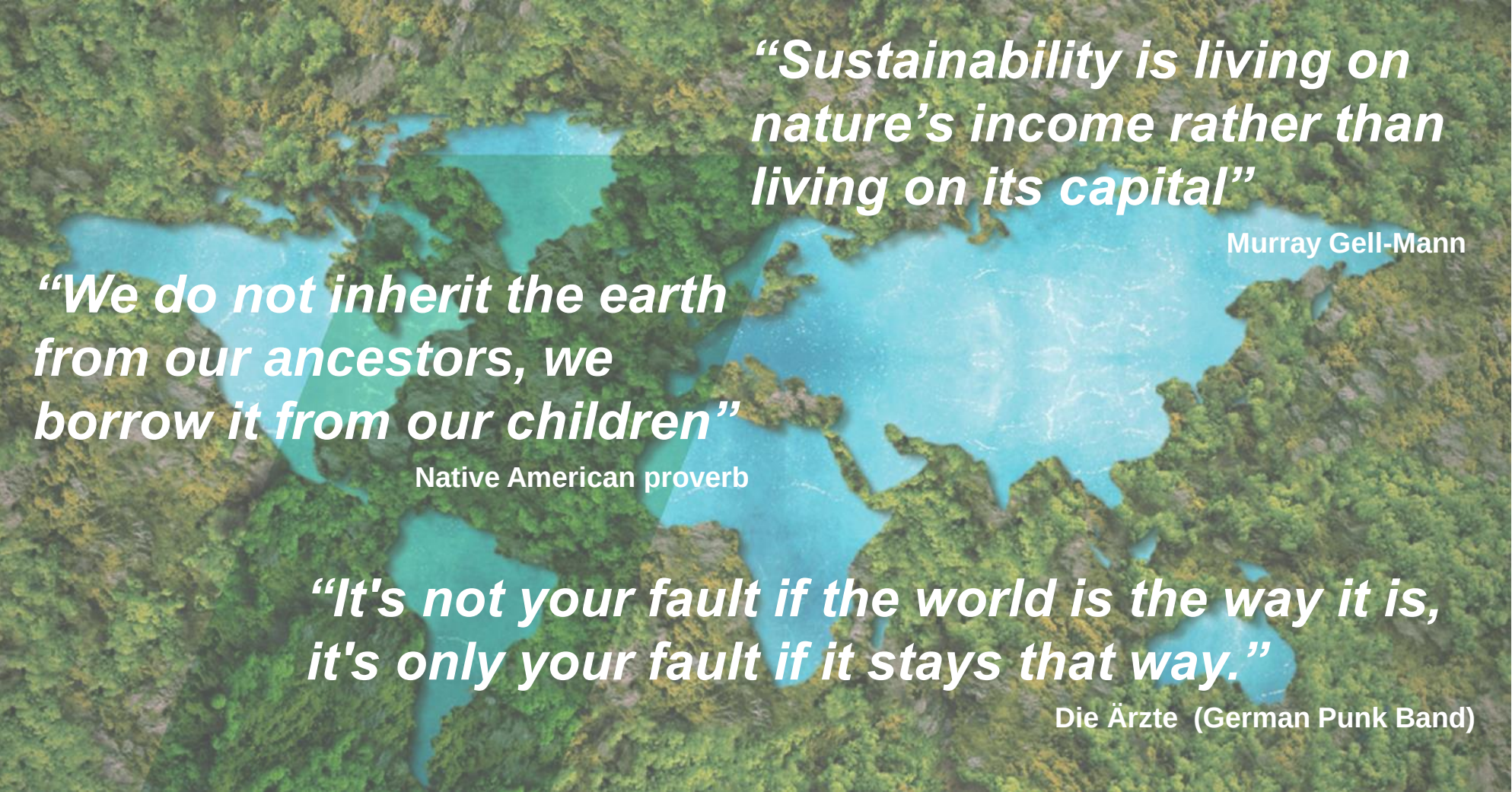
High temperature classes ask for rare metals

- Dysprosium (Medium/High cost)
- Terbium (Very high cost)



Measures

- Recycling of rare earths
- Grain-Boundary-Diffusion
- Reduction of needed heavy rare earths by fine grain process
- Cer-Substitution

An aerial photograph of a lush green forest with a winding river or stream cutting through it. The water is a vibrant blue-green color, contrasting with the dense green foliage. The river meanders from the top left towards the bottom right, with several smaller tributaries branching off.

“Sustainability is living on nature’s income rather than living on its capital”

Murray Gell-Mann

“We do not inherit the earth from our ancestors, we borrow it from our children”

Native American proverb

“It's not your fault if the world is the way it is, it's only your fault if it stays that way.”

Die Ärzte (German Punk Band)