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By Hyve

The impact of a potential tighter energy performance regulation for power distribution transformers

International Copper Association Europe

UNIVERSITÀ DEGLI STUDI DI BERGAMO

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Agenda

Ecodesign regulation for power transformers under revision

Potential introduction of Tier 3 energy performance requirements

What will be the impact on:

- **Energy savings**
- **Material use**
- **Impact on volume**
- **Investment and life cycle cost**
- **Life Cycle Assessment**

Conclusions and recommendations

Ecodesign regulation

Requirements for three-phase medium power transformers with rated power ≤ 3 150 kVA

	Tier 1 (from 1 July 2015)		Tier 2 (from 1 July 2021)	
Rated Power (kVA)	Maximum load losses P_k (W) (*)	Maximum no-load losses P_o (W) (*)	Maximum load losses P_k (W) (*)	Maximum no-load losses P_o (W) (*)
≤ 25	C_k (900)	A_o (70)	A_k (600)	A_o – 10 % (63)
50	C_k (1 100)	A_o (90)	A_k (750)	A_o – 10 % (81)
250	C_k (3 250)	A_o (300)	A_k (2 350)	A_o – 10 % (270)
315	C_k (3 900)	A_o (360)	A_k (2 800)	A_o – 10 % (324)
400	C_k (4 600)	A_o (430)	A_k (3 250)	A_o – 10 % (387)
500	C_k (5 500)	A_o (510)	A_k (3 900)	A_o – 10 % (459)
630	C_k (6 500)	A_o (600)	A_k (4 600)	A_o – 10 % (540)
2 000	B_k (18 000)	A_o (1 450)	A_k (15 000)	A_o – 10 % (1 305)
2 500	B_k (22 000)	A_o (1 750)	A_k (18 500)	A_o – 10 % (1 575)
3 150	B_k (27 500)	A_o (2 200)	A_k (23 000)	A_o – 10 % (1 980)

Ecodesign regulation

Requirements for three-phase medium power transformers with rated power ≤ 3 150 kVA

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2 000	B_k (18 000)	A_o (1 450)	A_k (15 000)	A_o – 10 % (1 305)
2 500	B_k (22 000)	A_o (1 750)	A_k (18 500)	A_o – 10 % (1 575)
3 150	B_k (27 500)	A_o (2 200)	A_k (23 000)	A_o – 10 % (1 980)

Would TIER 3 make sense?

Modelling exercise for a 630 kVA unit

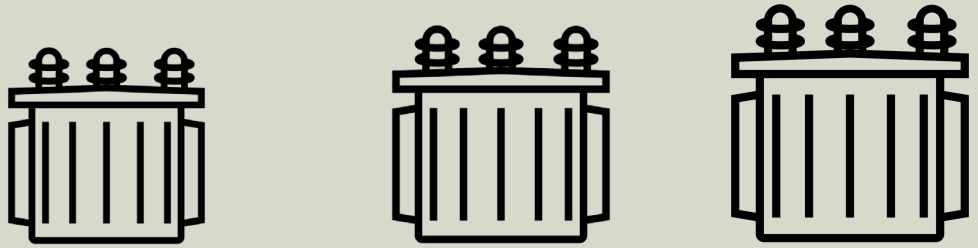
Rated power	630 kVA
Rated frequency	50 Hz
Number of phases	3
Short circuit impedance	4%
MV winding Um	Um ≤ 24 kV
LV winding Um	Um ≤ 1.1 kV
Type	liquid-immersed

Material	**Cost per kg**
Aluminium	€6.00
Copper	€12.00
Magnetic sheet (quality M070 = 0.70 W/kg at 1.7 T)	€5.50
Oil	€2.00
Tank + cover	€4.50

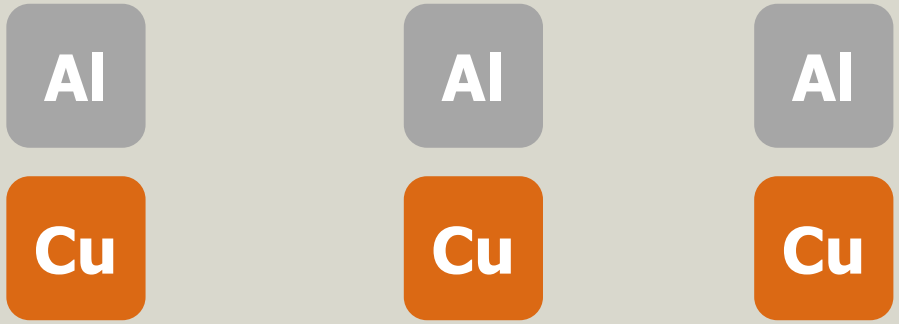
Other parameters	
Root Mean Square load	20% to 40% (30% base case)
Lifetime	40 years
Electricity price	0.10 to 0.16 €/kWh (0.13 base case)
Annual interest rate	2%

Modelling exercise for a 630 kVA unit

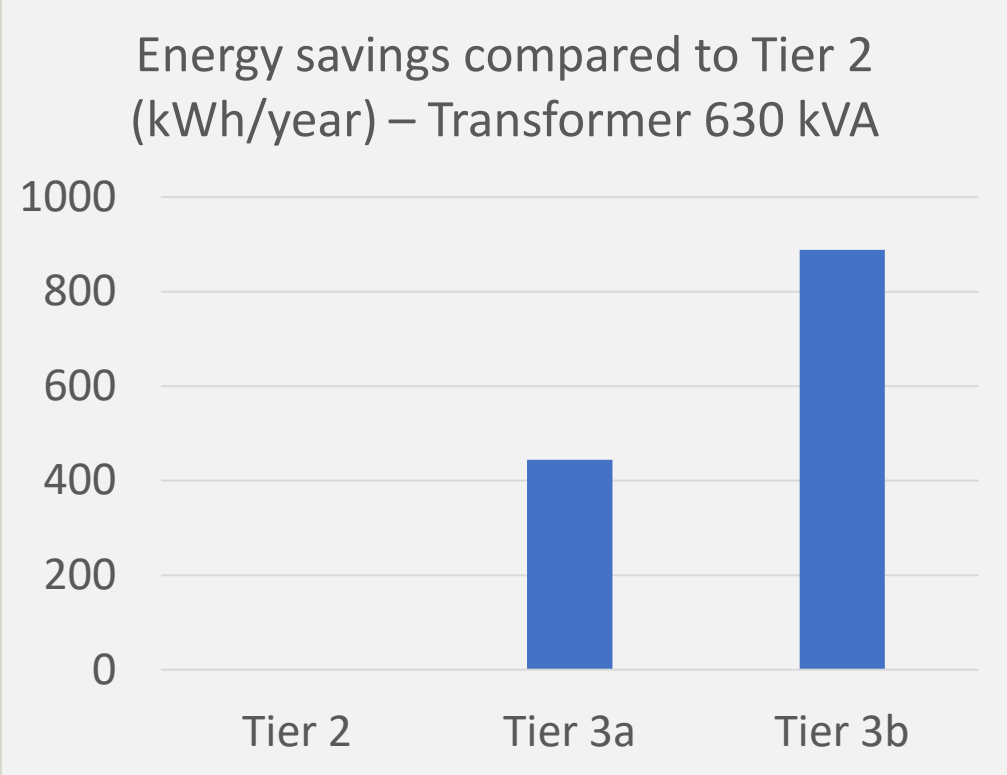
		Load losses		
		Ak	Ak-5%	Ak-10%
No-load losses	A0-10%	Tier 2		
	A0-15%		**Tier 3a**	
	A0-20%			**Tier 3b**



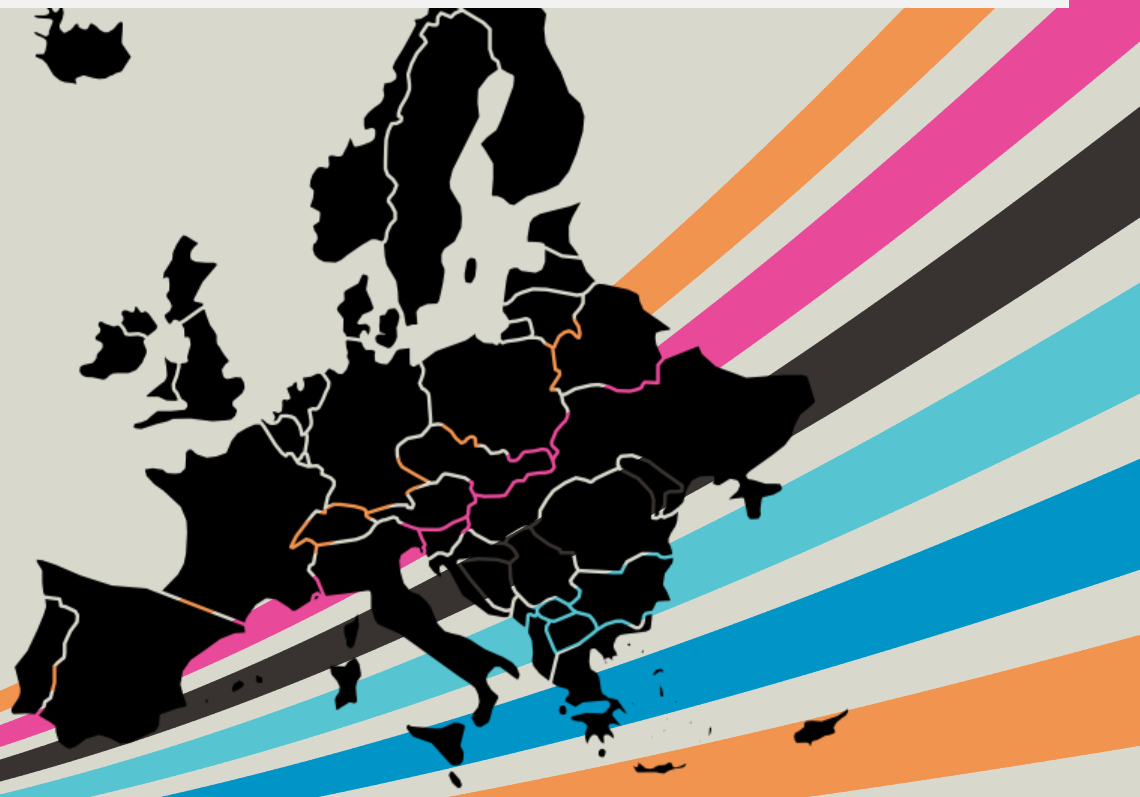
Two options
Aluminium windings
Copper windings



Energy savings potential

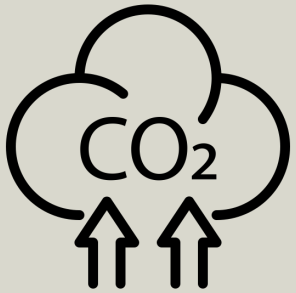


In the EU-27, potential electricity savings of Tier 3b are estimated at 1.8 TWh/year.



With a 40-year average distribution transformer capacity in EU-27 of 1,250 GVA.

Why each kWh saved matters?



2030: -55%

2040: -90%

2050: carbon neutral

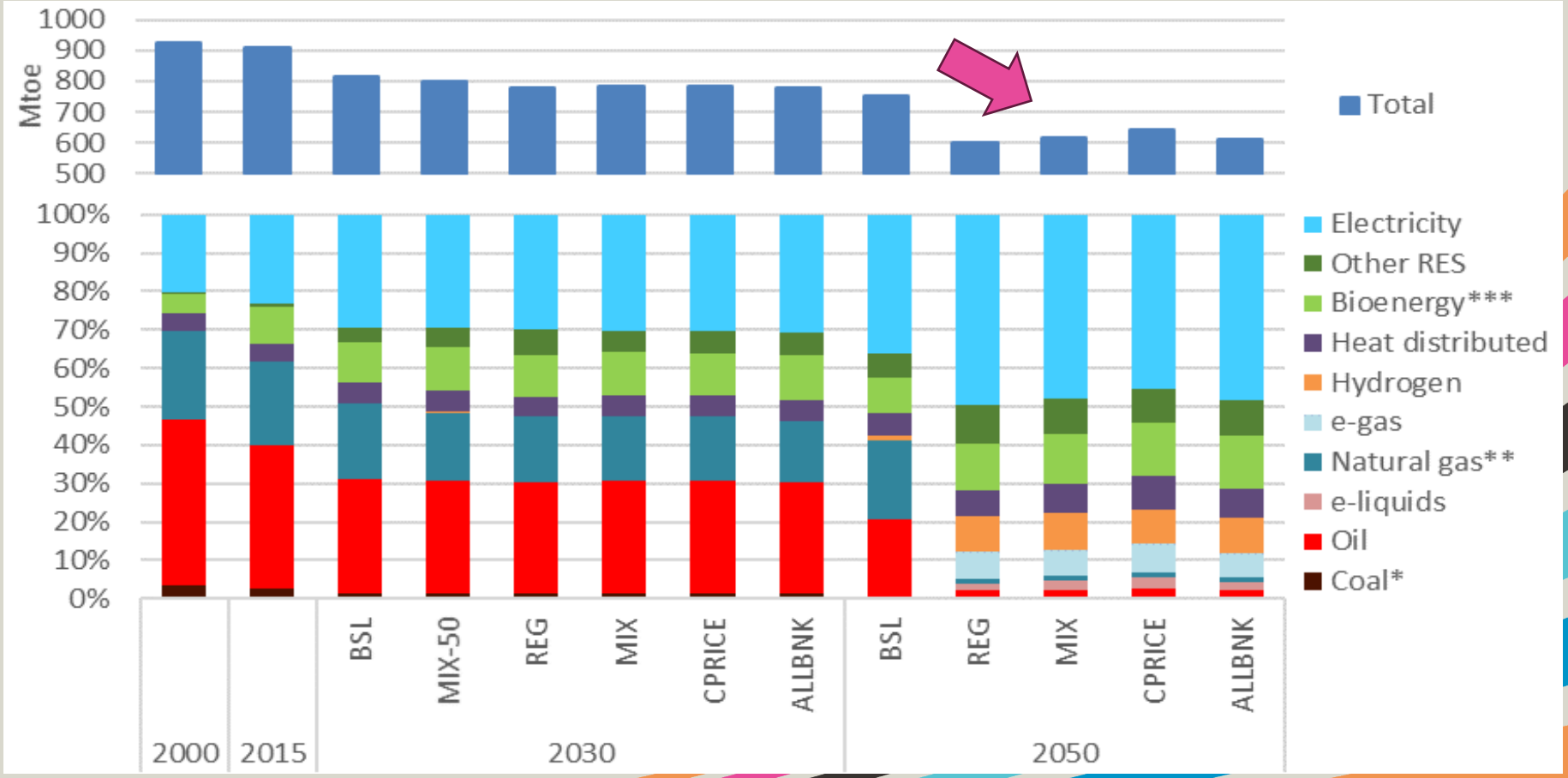
2030 final energy consumption is CAPPED to 763 Mtoe

For reference, final energy consumption was **940 Mtoe in 2022**

→ Needs a reduction equivalent to the whole consumption of Germany, to be implemented in just 8 years

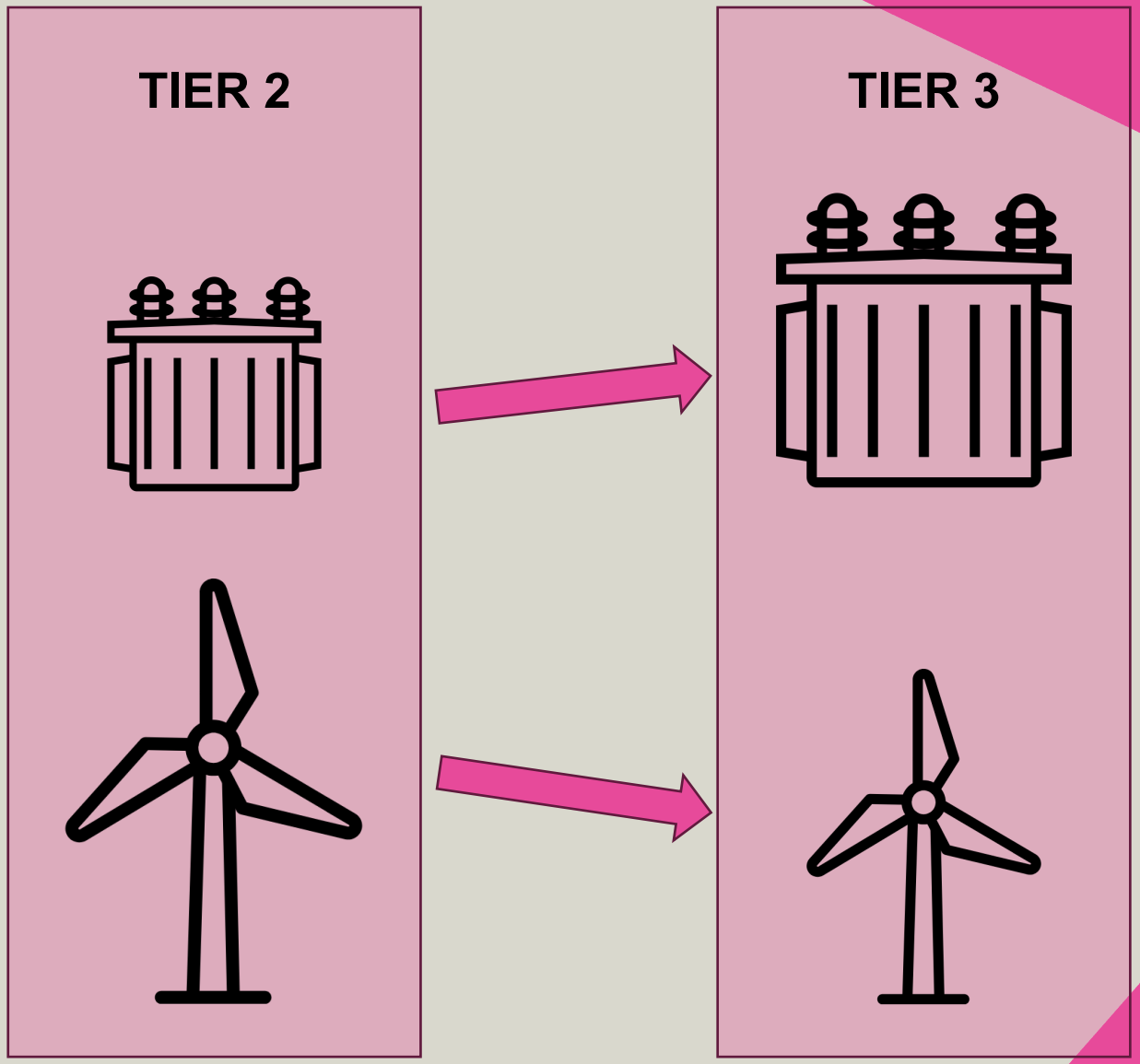
Why each kWh saved matters?

By 2050 the situation is to get even tougher,
with final energy consumption further capped to ~600 Mtoe

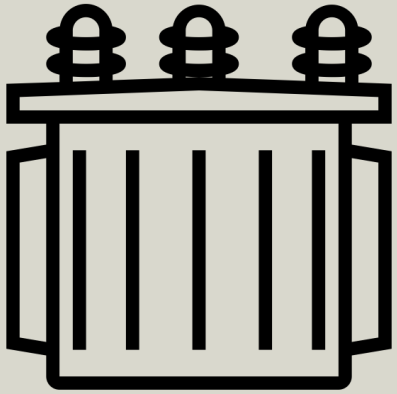


Source: Impact Assessment EU Green Deal – Part 2, Figure 37
https://eur-lex.europa.eu/legal-content/EN/TXT/DOC/?uri=CELEX:52020SC0176

Materials use



The increased material use for transformer manufacturing is compensated by a lower need for power generation assets (thanks to lower energy losses)

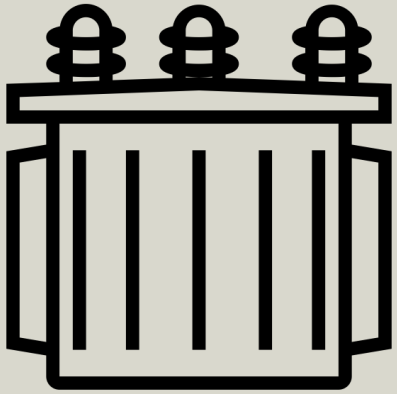


Transformer: bill of materials

Al/Al windings	Tier 2 A_0-10% A_k	Tier 3a A_0-15% A_k-5%	Tier 3b A_0-20% A_k-10%
Aluminium (kg)	426	489	465
Magnetic steel (kg)	1106	1280	1370
Oil (kg)	366	387	435
Tank + cover (kg)	298	285	345
Mass of metals (kg)	2,004	2,203	2,295
Total mass (kg)	2,370	2,590	2,730

Cu/Cu windings	Tier 2 A_0-10% A_k	Tier 3a A_0-15% A_k-5%	Tier 3b A_0-20% A_k-10%
Copper (kg)	631	698	735
Magnetic steel (kg)	633	746	1020
Oil (kg)	262	280	300
Tank + cover (kg)	264	251	270
Mass of metals (kg)	1,679	1,851	2,125
Total mass (kg)	1,941	2,131	2,425

Bill of materials as per International Copper Association Europe modelling exercise

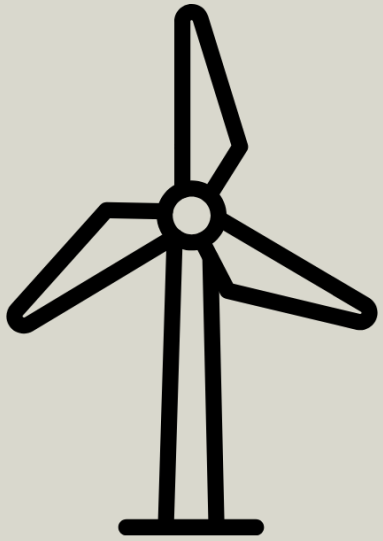


Transformer: bill of materials

Al/Al windings	Tier 2 A_0-10% A_k	Tier 3a A_0-15% A_k-5%	Tier 3b A_0-20% A_k-10%
Aluminium (kg)	100%	115%	109%
Magnetic steel (kg)	100%	116%	124%
Oil (kg)	100%	106%	119%
Tank + cover (kg)	100%	96%	116%
Mass of metals (kg)	100%	110%	115%
Total mass (kg)	100%	109%	115%

Cu/Cu windings	Tier 2 A_0-10% A_k	Tier 3a A_0-15% A_k-5%	Tier 3b A_0-20% A_k-10%
Copper (kg)	100%	111%	116%
Magnetic steel (kg)	100%	118%	161%
Oil (kg)	100%	107%	115%
Tank + cover (kg)	100%	95%	102%
Mass of metals (kg)	100%	110%	127%
Total mass (kg)	100%	110%	125%

Bill of materials as per International Copper Association Europe modelling exercise

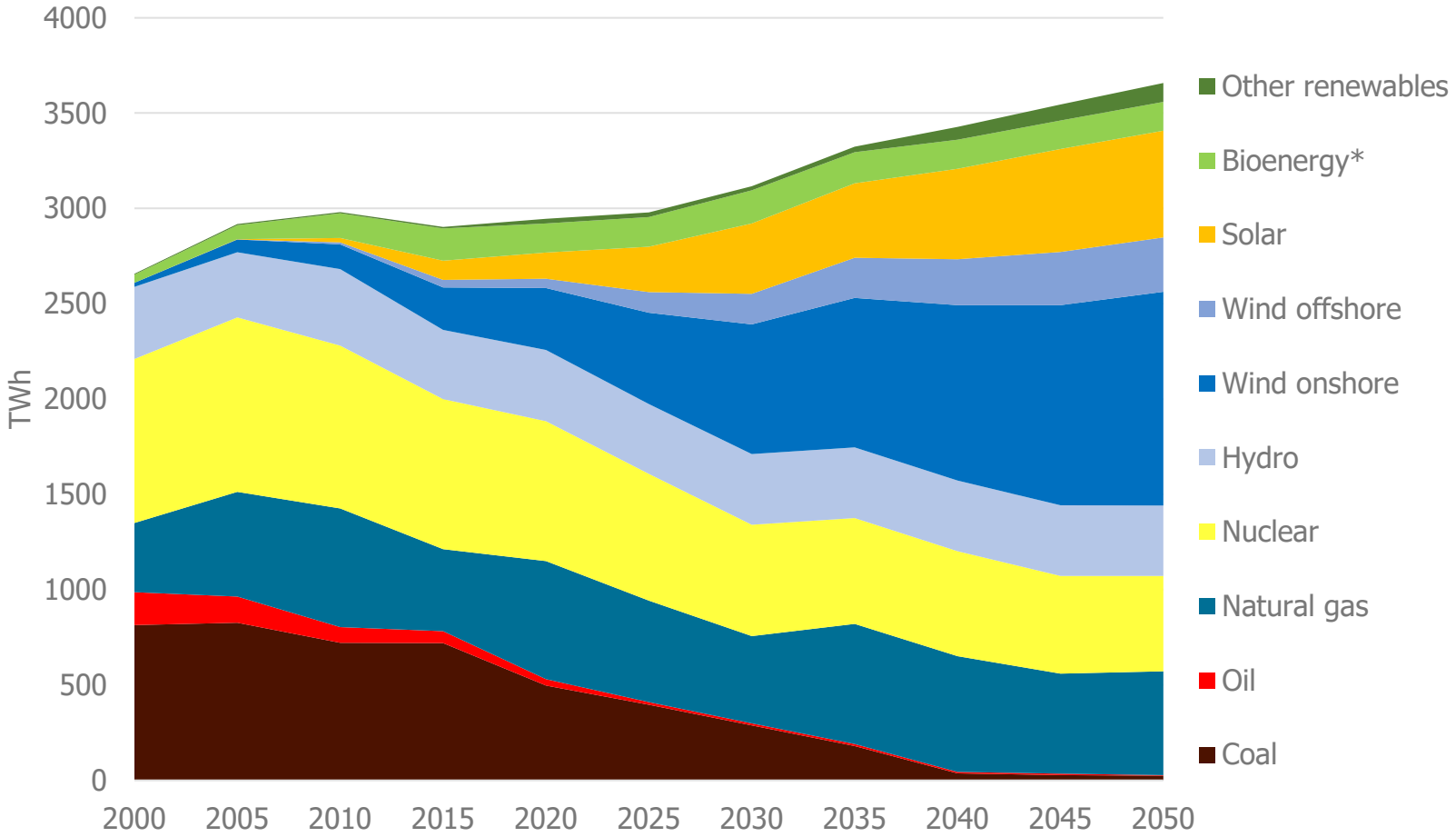


Onshore wind: bill of materials

Material	Kg / kW onshore wind
Steel	143
Cast iron	12
Composites and polymers	29
Other metals and alloys	19
Concrete	404
Road aggregate	613
Other materials	3
Total	1,223

The U.S. Department of Energy (DOE) Renewable Energy Materials Properties Database (REMDP). Available online: https://www.nrel.gov/wind/materials-database.html (accessed on 2 April 2024).

EU Electricity generation mix as modelled in the EU Green Deal



New capacity is fully dominated by wind (onshore and offshore) and solar

Electricity mix as modelled in the Green Deal impact assessment
https://climate.ec.europa.eu/document/download/ec1acac9-10fe-4eeb-915f-cad388990e0f_en?filename=2030_climate_target_plan_figures_en.xlsx

How much material is saved when we spare 1 kWh?

Renewable Energy Materials Properties Database: Summary

Aubryn Cooperman, Annika Eberle, Dylan Hettinger, Melinda Marquis, Brittany Smith, Richard F. Tusing, and Julien Walzberg

National Renewable Energy Laboratory

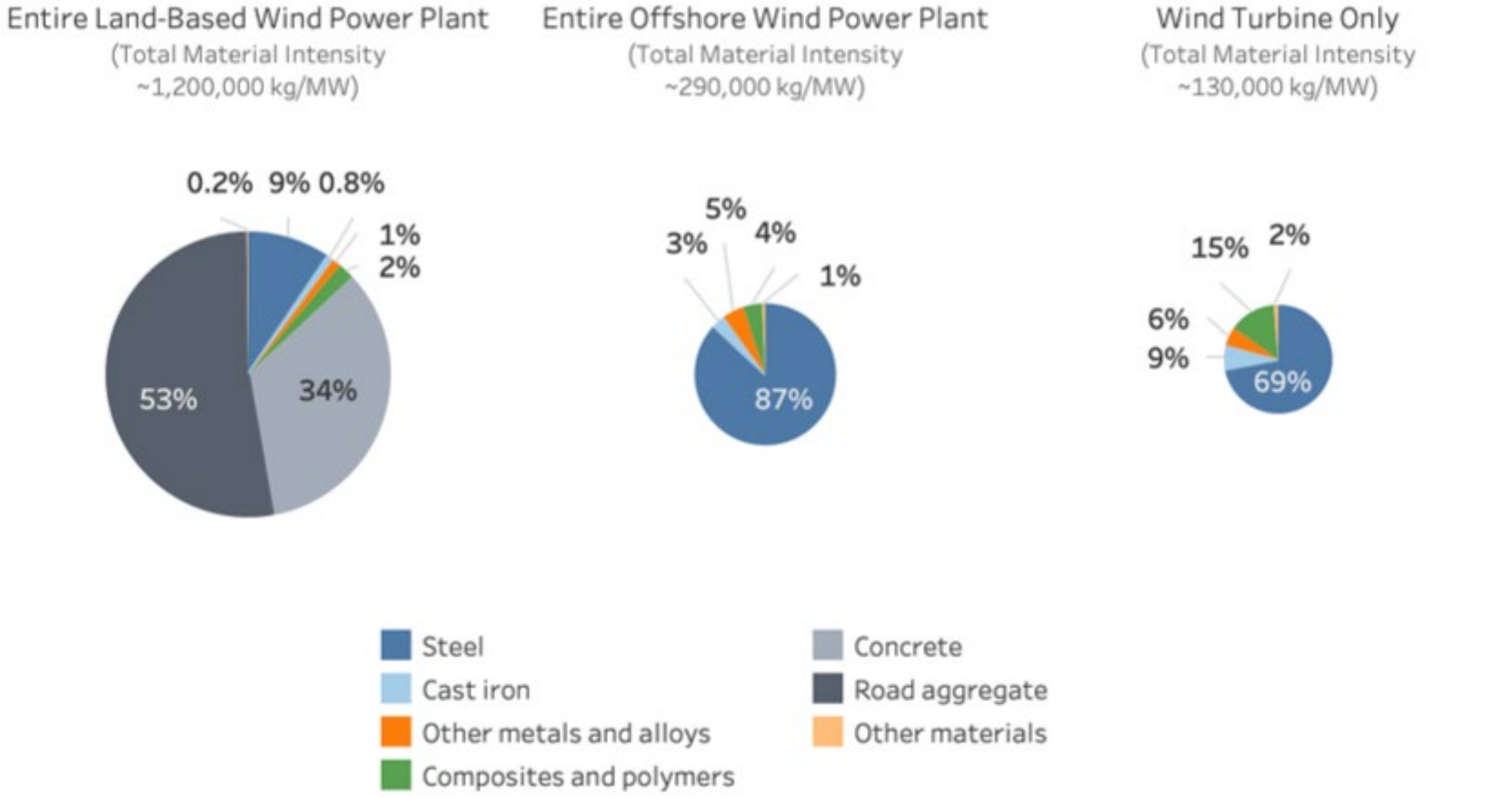


Figure 3. Typical high-level breakdown of wind energy materials by mass as reported in the REMPD

https://www.nrel.gov/wind/materials-database.html

How much material is saved when we spare 1 kWh?

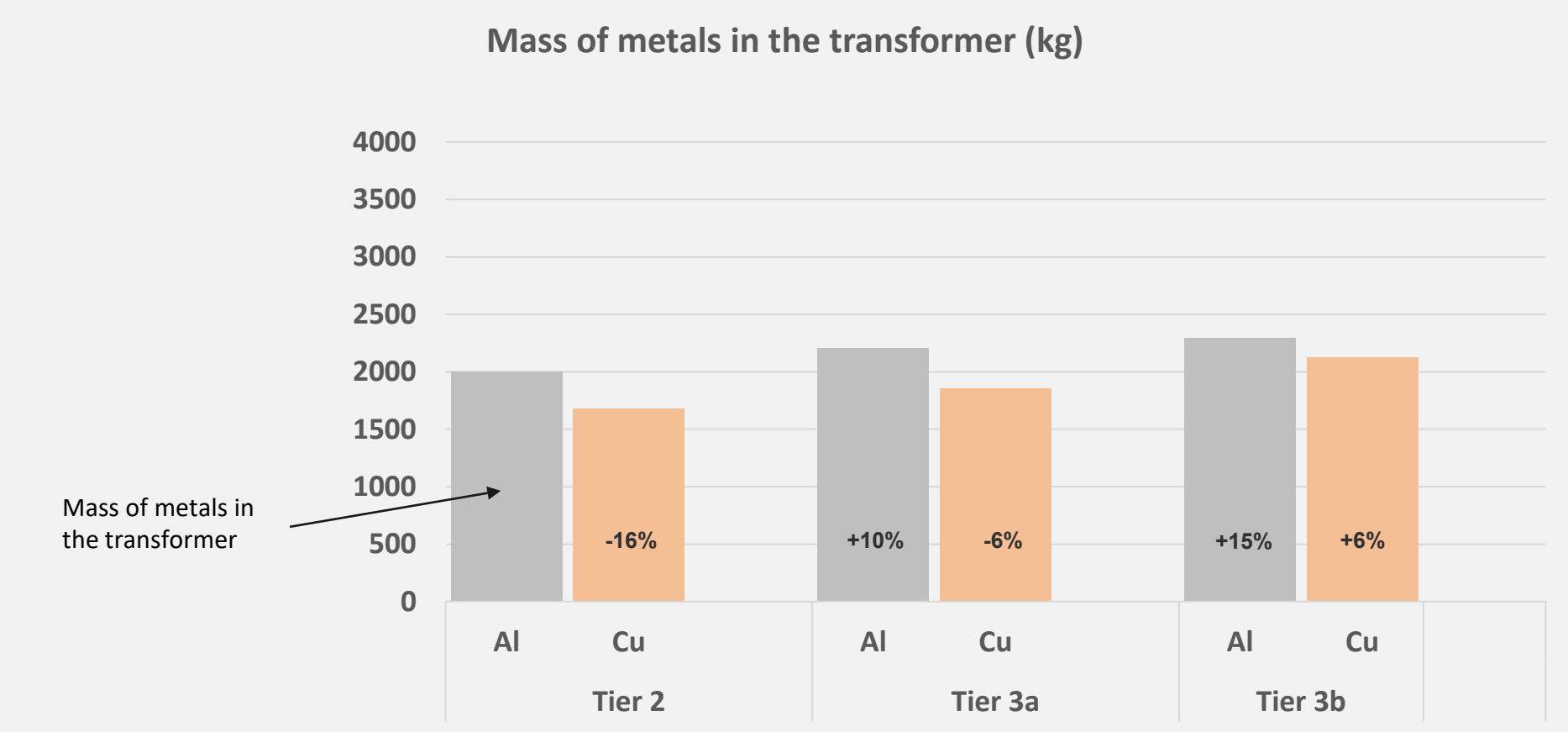
1 kWh/year of electricity losses avoided saves 0.75 kg of materials, of which 0.15 kg of metals

Material Category	Onshore wind (kg/kWh)	Offshore wind (kg/kWh)	PV (kg/kWh)	**EU marginal mix* (kg/kWh)**
Concrete	0,389	0,000	0,032	**0,227**
Road aggregate	0,590	0,000	0,000	**0,331**
Steel	0,138	0,137	0,048	**0,112**
Composites and polymers	0,028	0,009	0,015	**0,021**
Cast iron	0,012	0,005	0,016	**0,012**
Other metals and alloys	0,018	0,011	0,035	**0,022**
Other materials	0,003	0,001	0,090	**0,027**
TOTAL	1,178	0,164	0,236	**0,752**

* Marginal electricity generation capacity additions based on the EU Green Deal Impact Assessment: 56% onshore wind, 15% offshore wind, 28% solar

https://www.nrel.gov/wind/materials-database.html

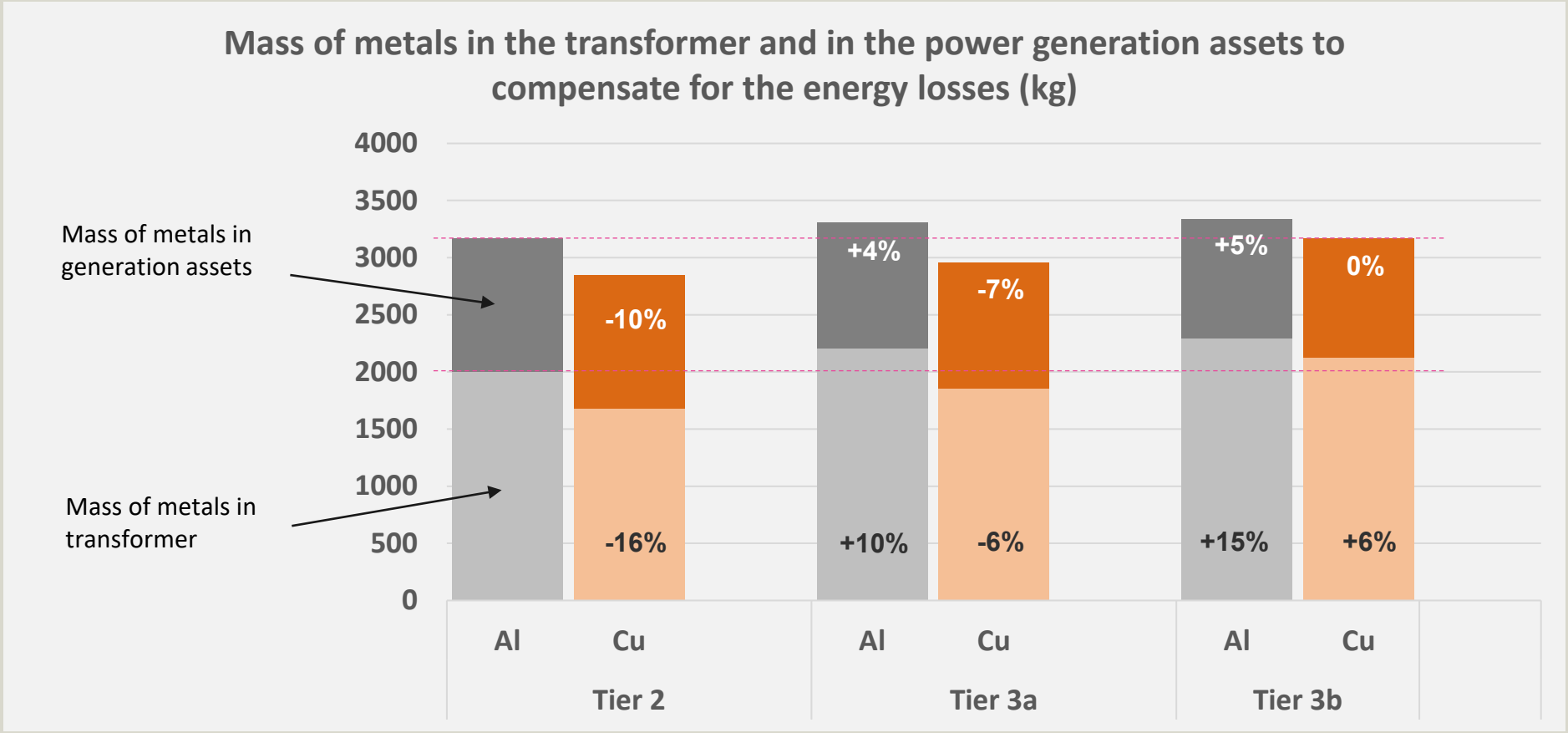
Metals used in transformer



- **More stringent MEPS result in a higher amount of metals used in the transformer.**
- **A design with copper windings is lighter than one with aluminium windings.**

% relative to a Tier 2 unit with aluminium windings

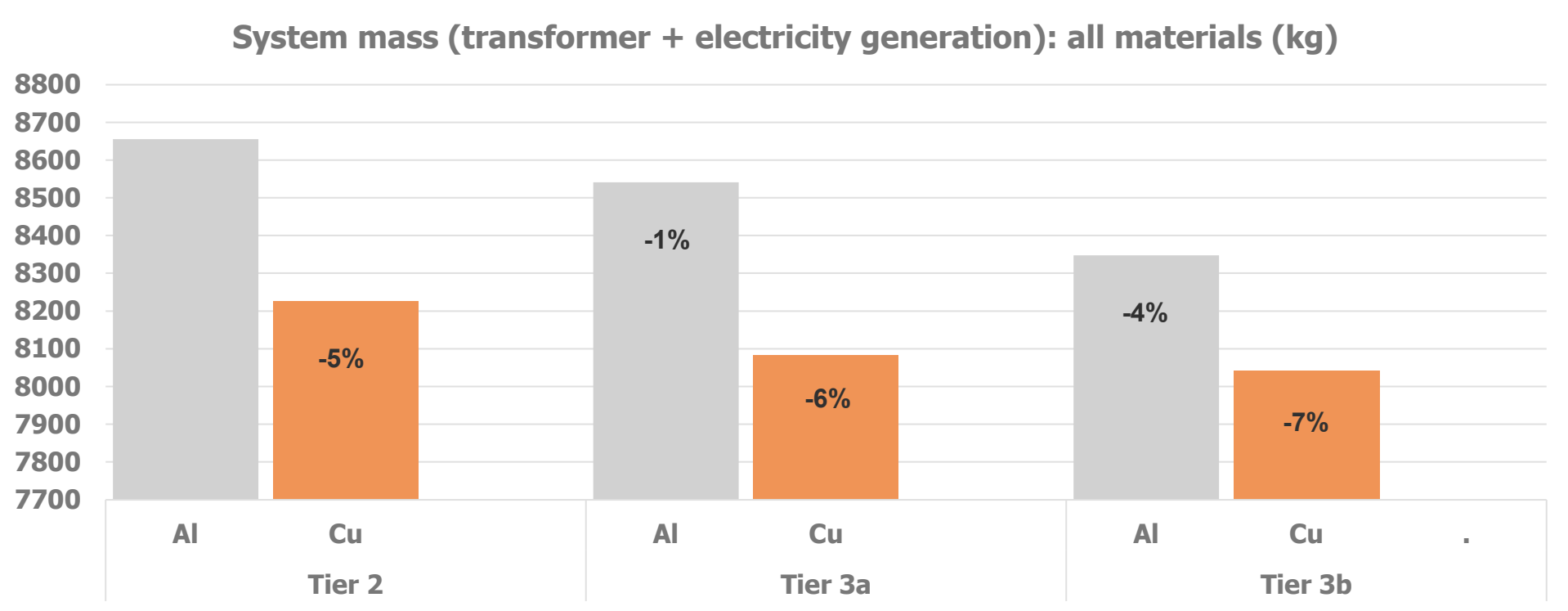
Metals used in system: transformer + electricity generation



- **Metal use increases only slightly for combination of transformer AND associated generation assets.**
- **A design with copper windings is lighter than one with aluminium windings.**

% relative to a Tier 2 unit with aluminium windings

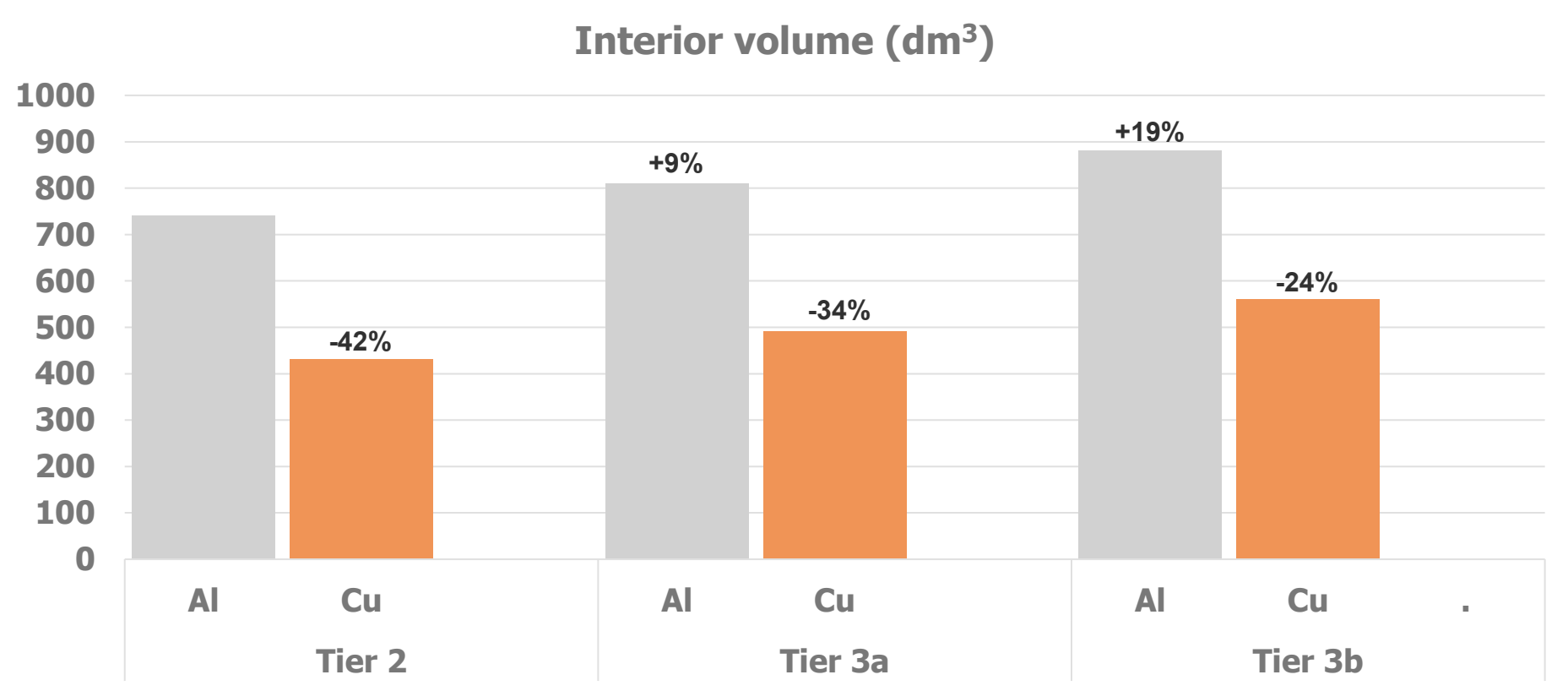
Material use: all materials combined



- The weight of all materials needed in the transformer and in the generation assets compensating for transformer losses (including concrete, road aggregate, etc.) reduces with higher energy performance.
- A design with copper windings saves more material compared to its aluminium counterpart.

% relative to a Tier 2 unit with aluminium windings

Interior volume



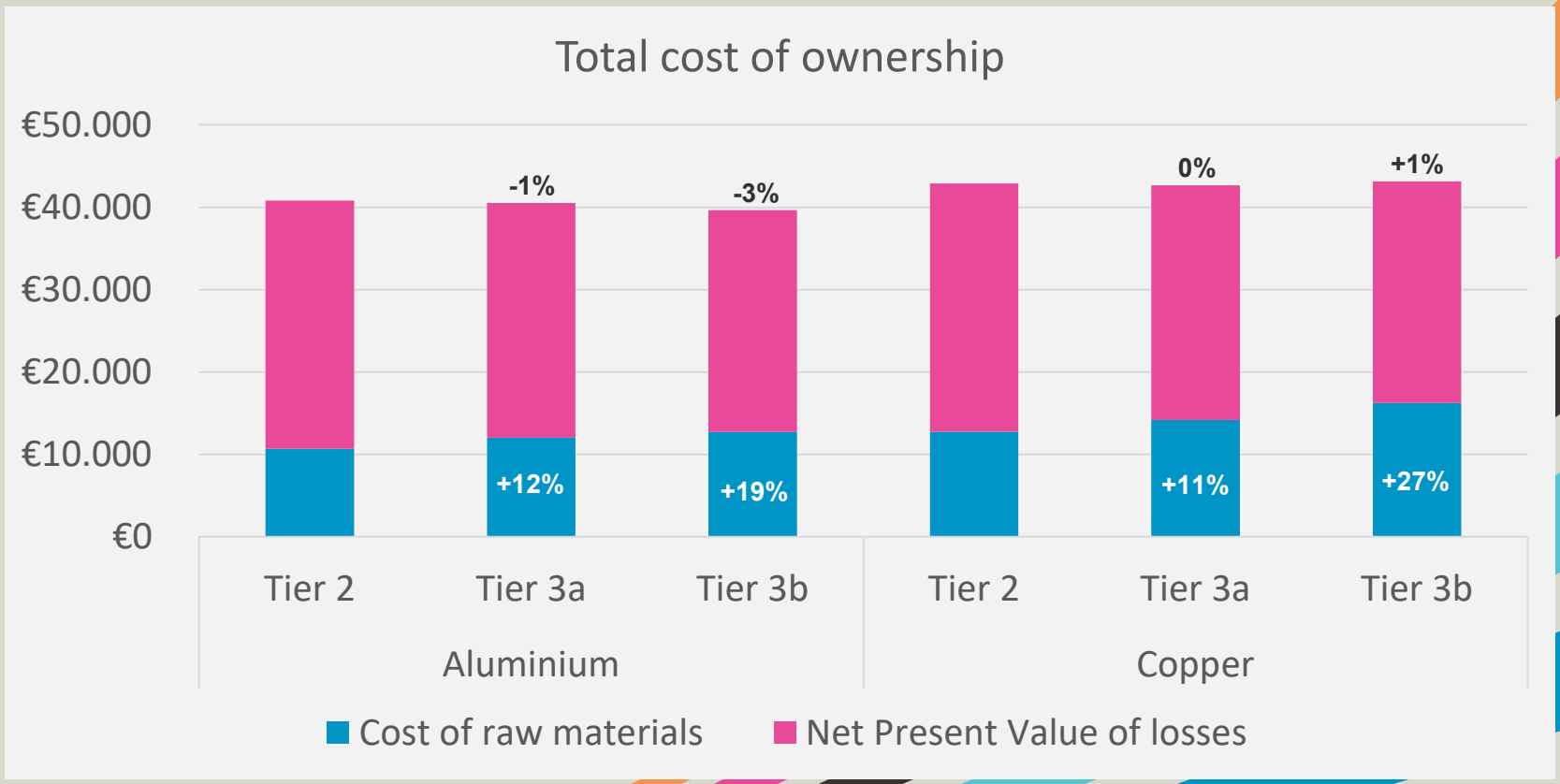
- **The higher the energy performance, the bigger the transformer volume.**
- **In space-constrained applications, the use of copper windings allows for reducing the volume compared to its aluminium counterpart, while increasing the energy performance**

% relative to a Tier 2 unit with aluminium windings

Economic impact

The bigger investment cost of a Tier 3 unit is compensated by a lower cost of losses, resulting in a TCO similar to that of a Tier 2 unit.

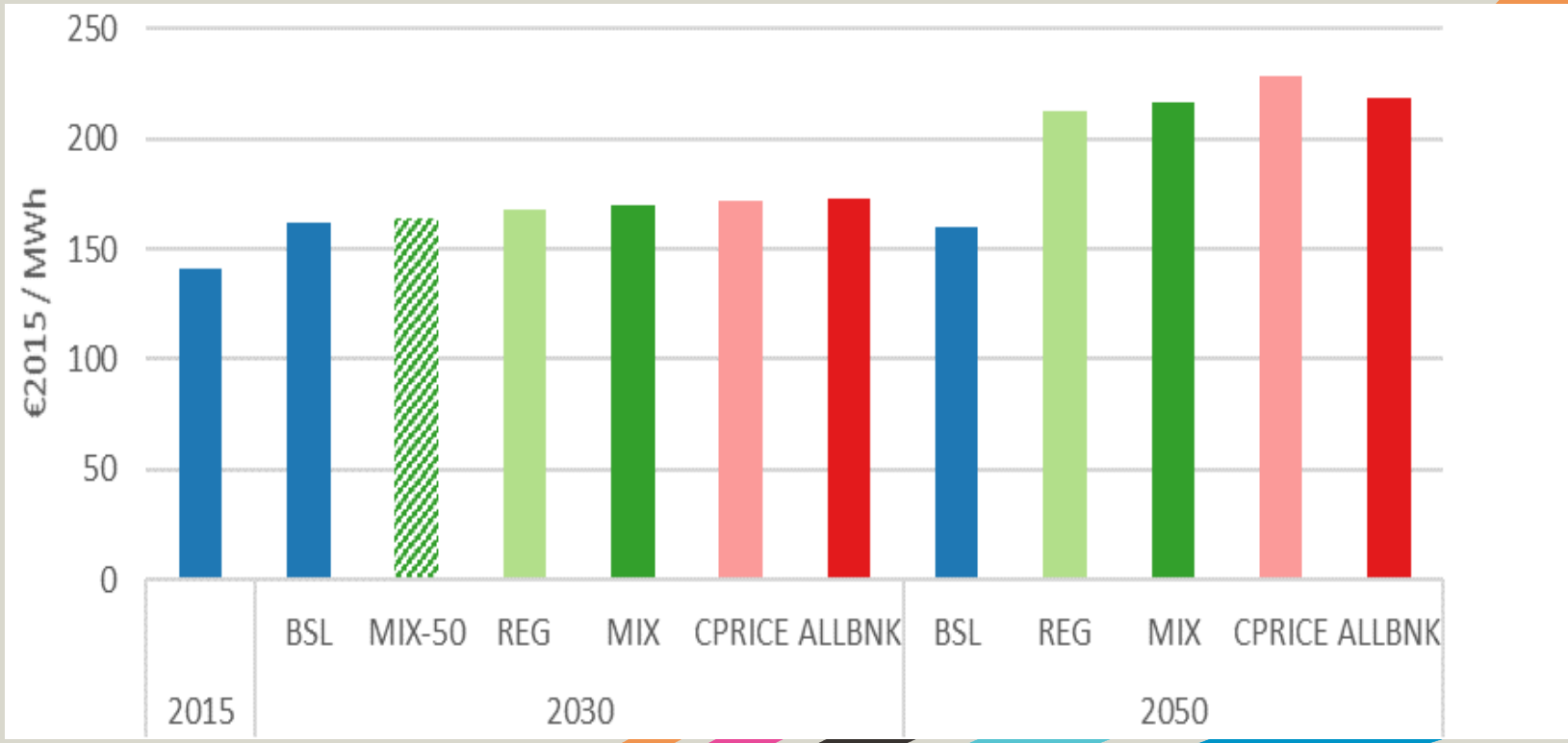
A design with copper windings ends up slightly more expensive than one with aluminium windings but comes with benefits in terms of volume, weight and embedded CO_{2eq} emissions.



% relative to Tier 2

Economic impact: sensitivity to electricity price

Average price of electricity for final consumers (inflation corrected, €2015) ranges between **16c€/kWh** in 2030 and **22 c€/kWh** in 2050.

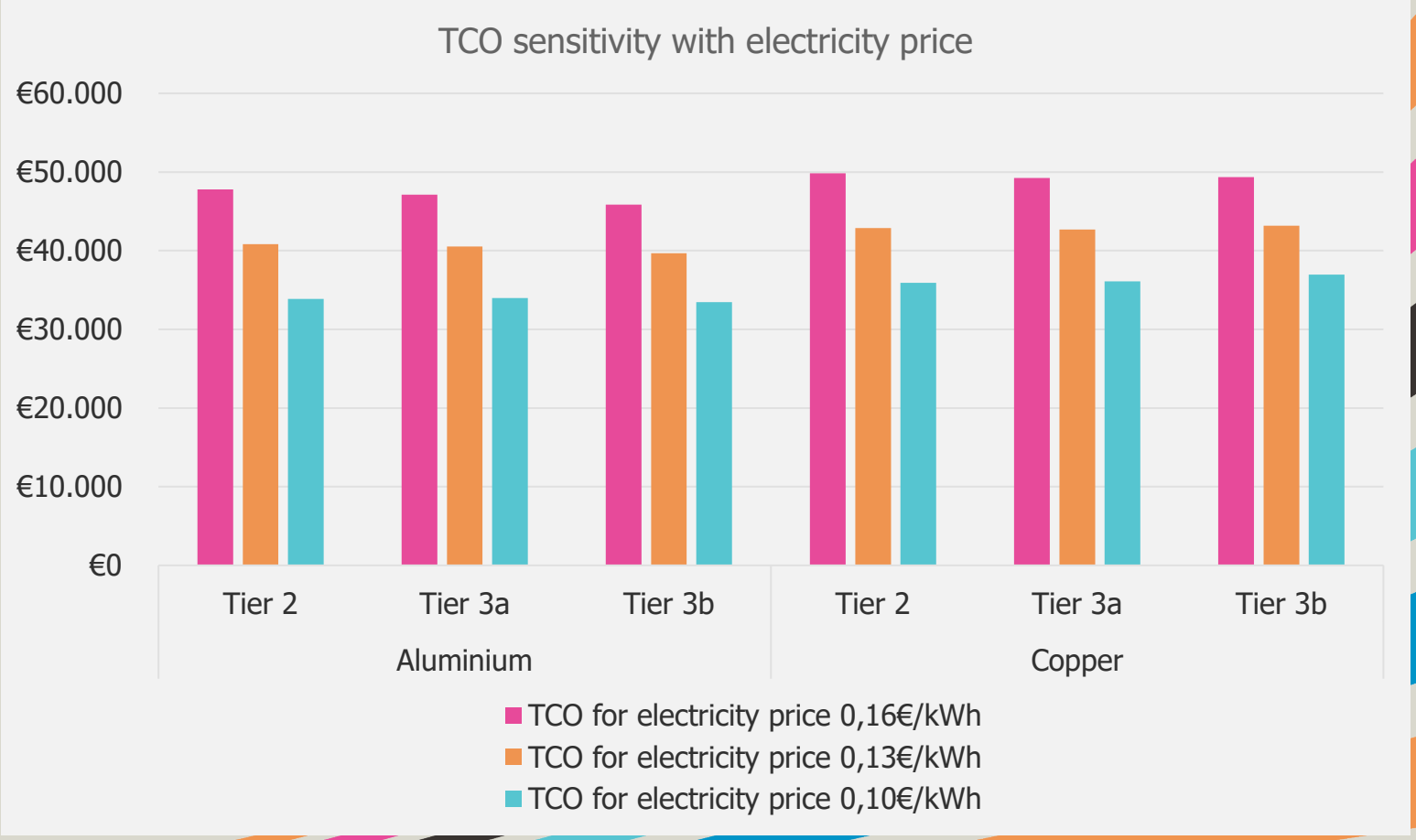


Source: Impact Assessment EU Green Deal – Part 2, Figure 87
https://eur-lex.europa.eu/legal-content/EN/TXT/DOC/?uri=CELEX:52020SC0176

Economic impact: sensitivity to electricity price

The conclusions remain similar with different electricity prices, but:

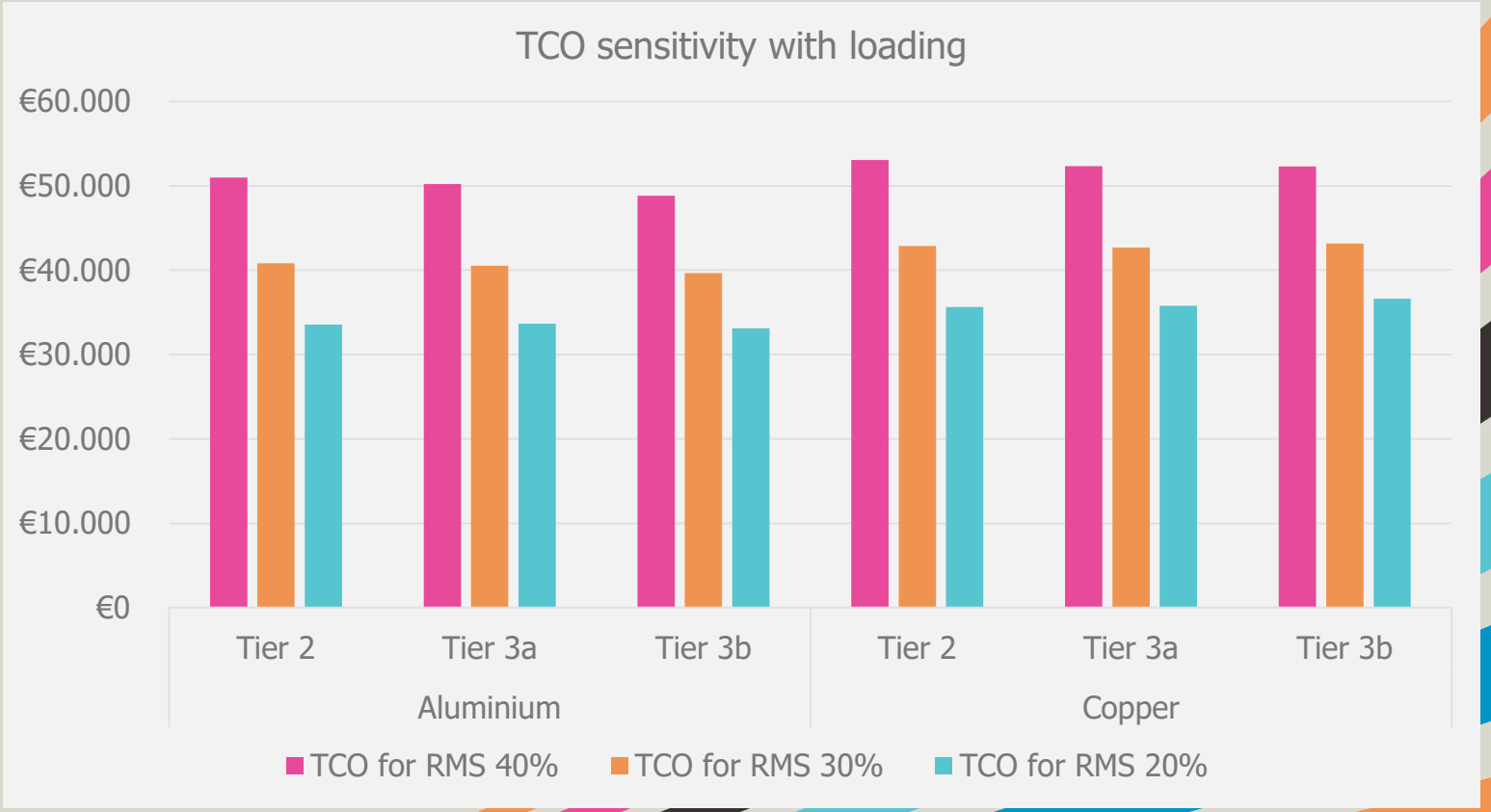
- the TCO slightly increases (3%) at the lowest electricity price
- the **TCO slightly decreases** (up to -4%) at the highest electricity price, which is the **most likely scenario**



Economic impact: sensitivity to transformer loading

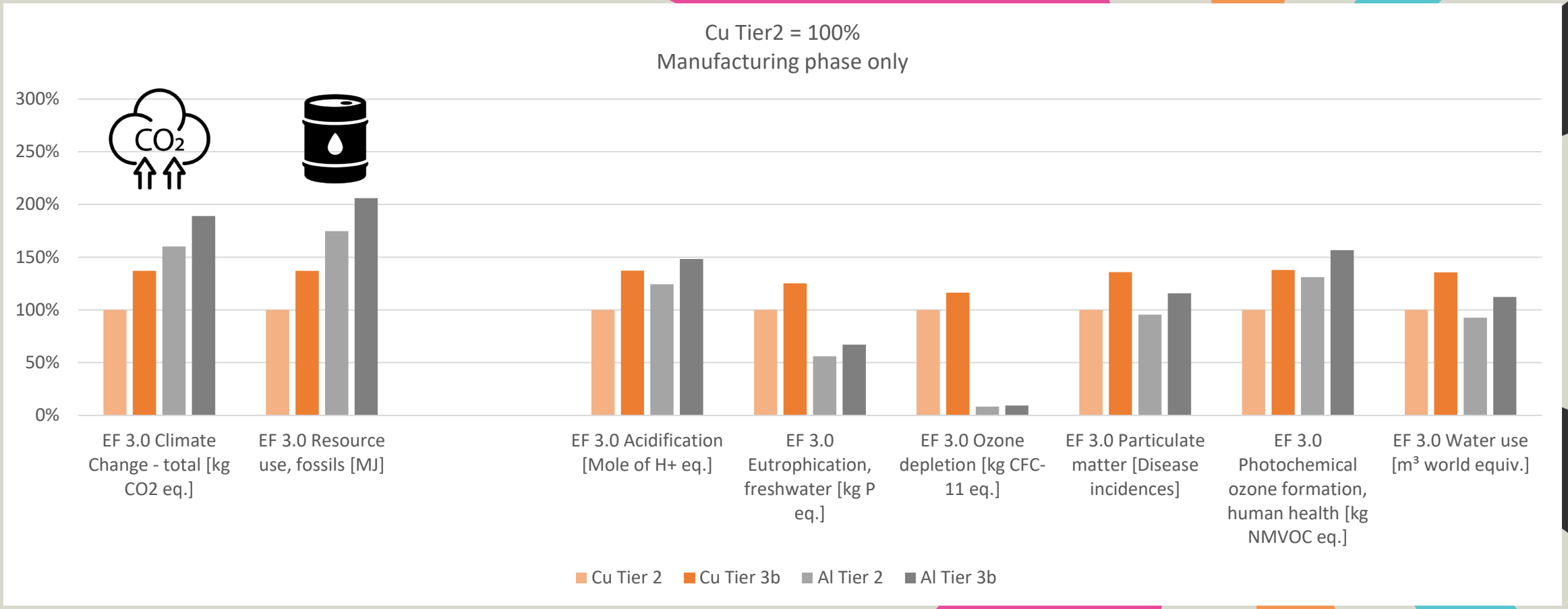
The conclusions remain similar with different transformer loadings, but

- the TCO slightly increases (<3%) at the lowest load profile
- the **TCO slightly decreases** (up to -4%) at the highest load profile, which is the **most likely scenario**



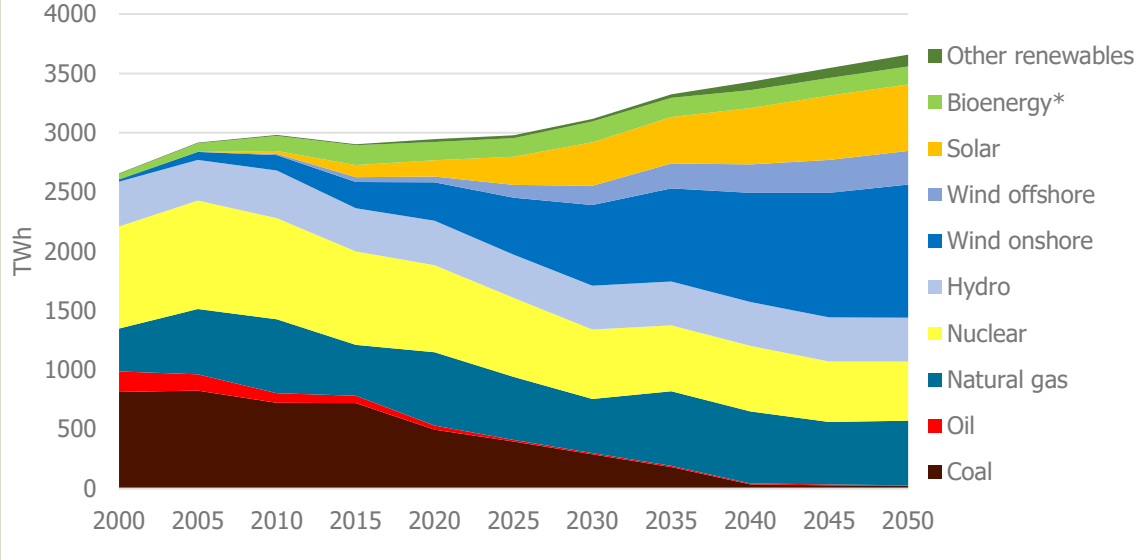
RMS: Root Mean Square of load

Life cycle: manufacturing phase only



- **The higher material use of Tier 3b translates into a 30% to 40% higher impact for the manufacturing phase.**
- **Units with aluminium windings use more material than their copper counterparts, which translates into a higher *Climate Change*, *Energy Use*, *Acidification and Photochemical Ozone.***

LCA impact of future electricity mix

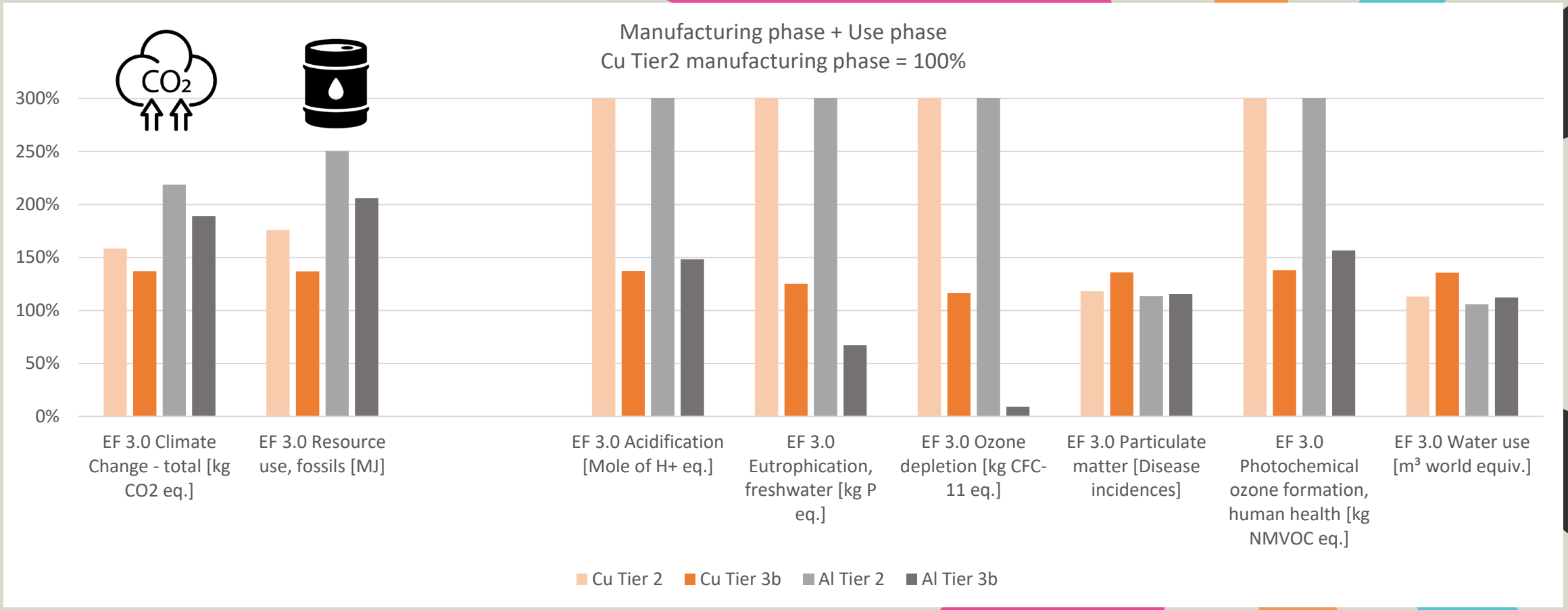


Electricity mix as modelled in the Green Deal impact assessment
https://climate.ec.europa.eu/document/download/ec1acac9-10fe-4eeb-915f-cad388990e0f_en?filename=2030_climate_target_plan_figures_en.xlsx

Impact for 1 kWh electricity produced with		CLIMATE CHANGE TOTAL	FRESHWATER AND TERRESTRIAL ACIDIFICATION	**ETC….**
		[kg CO2-Eq]	[mol H+-Eq]	
Hard coal	PC, without CCS	1,02E+00	1,73E-03	
Hard coal	IGCC, without CCS	8,49E-01	1,05E-03	
Natural gas	NGCC, without CCS	4,34E-01	3,26E-04	
Hard coal	PC, with CCS	3,69E-01	1,80E-03	
Hard coal	IGCC, with CCS	2,79E-01	1,35E-03	
Natural gas	NGCC, with CCS	1,28E-01	6,07E-04	
Hydro	660 MW	1,47E-01	4,15E-04	
Hydro	360 MW	1,07E-02	4,45E-05	
Nuclear	average	5,29E-03	4,28E-05	
CSP	tower	2,17E-02	9,24E-05	
CSP	trough	4,20E-02	1,51E-04	
PV	poly-Si, ground-mounted	3,67E-02	3,01E-04	
PV	CdTe, roof-mounted	1,46E-02	8,82E-05	
PV	CIGS, ground-mounted	1,14E-02	6,11E-05	
PV	CIGS, roof-mounted	1,41E-02	8,64E-05	
Wind	onshore	1,24E-02	5,28E-05	
Wind	offshore, concrete foundation	1,42E-02	1,00E-04	
Wind	offshore, steel foundation	1,33E-02	9,45E-05	

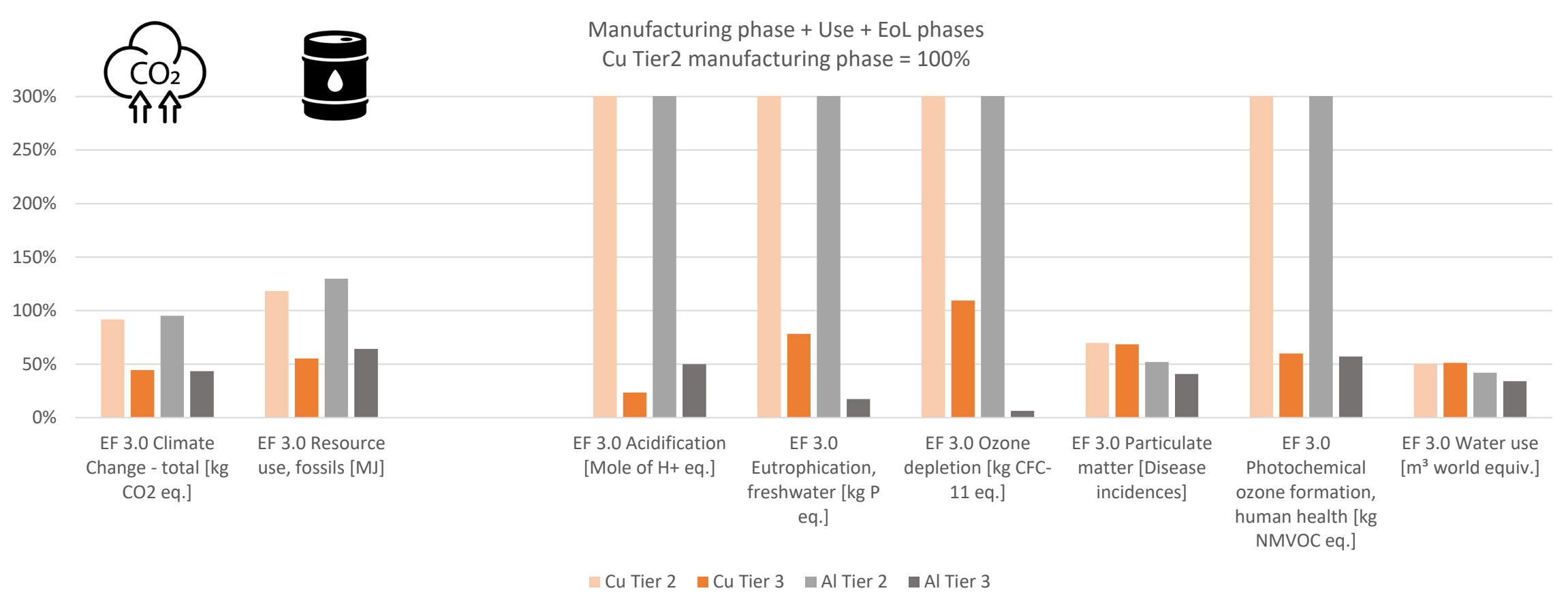
UNECE: Integrated Life-cycle Assessment of Electricity Sources
https://unece.org/documents/2022/08/integrated-life-cycle-assessment-electricity-sources

Life cycle: manufacturing and use phase



- **Thanks to the energy savings, most categories show a lower impact for Tier 3b than for Tier 2.**
- **Copper designs offer better performance in categories that are key for the Green Deal: *Climate Change* and *Energy use*. Also on *Acidification* and *Photochemical Ozone*.**

Life cycle: manufacturing, use phase and recycling credits

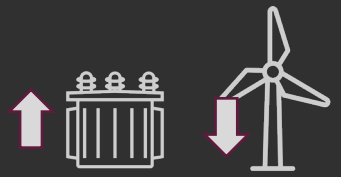


- **Recycling credits significantly reduce the impact in many LCA categories.**
- **Recycling should therefore be further stimulated.**

In a nutshell

EU-27 savings potential of Tier 3 in power distribution transformers is about 1.8 TWh/year

Total cost of ownership of Tier 3 is similar or lower than Tier 2.



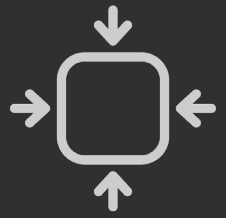
Tier 3 leads to bigger transformers, but the additional material use is moderated by a reduced need for generation, transmission and distribution assets.

When aluminium designs get too bulky / heavy in their Tier 3 versions, a good alternative is to shift to copper, which has a significantly smaller footprint and weight, while their total cost of ownership remains comparable to that of their aluminium counterpart.

Most LCA impact categories improve with Tier 3. The *Climate Change* and *Energy Use* impact categories improve even more when aluminium windings are replaced by copper.

Recommendations for the Ecodesign regulation

Strengthen Minimum Energy Performance Standards (MEPS), as the 2030 energy saving targets require the use of every single opportunity that makes economic sense.



Introduce material efficiency requirements (MMPS), taking into account that an improved energy performance reduces the need for generation, transmission, and distribution assets.

Introduce Design-for-Recycling requirements. Ensure re-utilization of raw materials with minimum downcycling.

Thank you!

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