Environmental benefits of coatings based on sintered nano-tungsten-carbide cobalt ceramics

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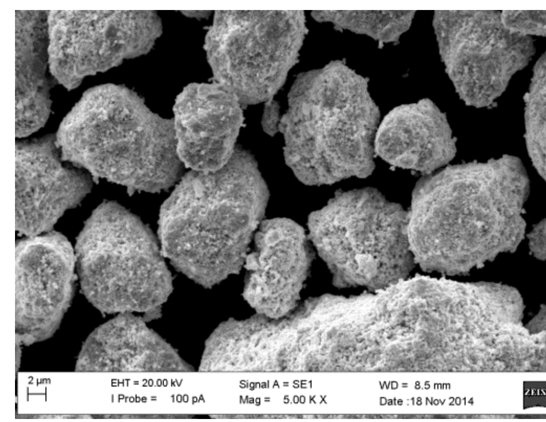
Sustainable Nanotechnologies

Background

- **Tungsten-carbide**
  - High density (15.6 g/cm3)
  - Melting temperature: 2870 °C
  - High hardness (only diamond is harder)

- **Cobalt improves material properties (Cermets)**

- **Nano-Tungsten-Carbide Cobalt (nano-WC-Co)**
  - sintered ceramic
  - potential substitute for chromium
    - hexavalent chromium is known to be carcinogenic
  - higher wear resistance
  - ten-times longer service life

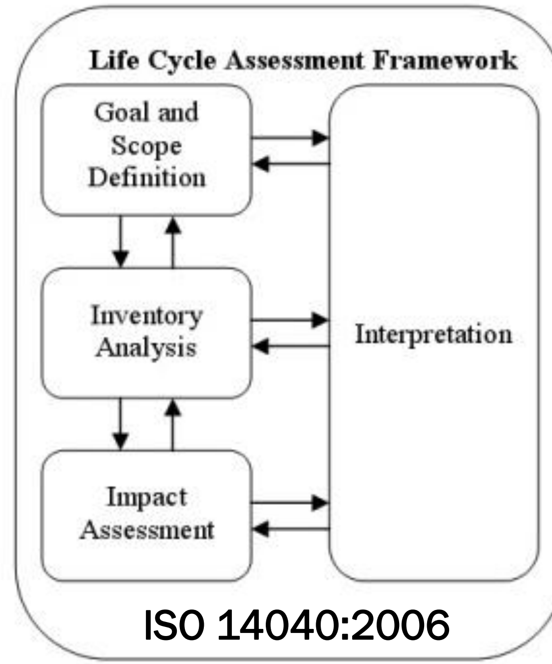


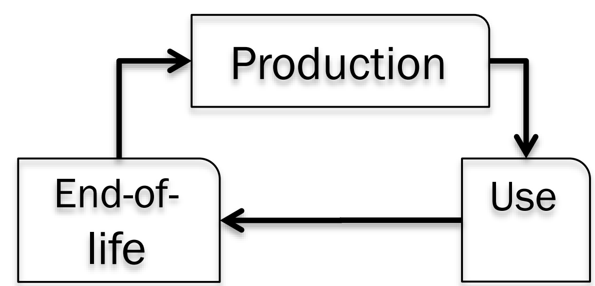
→ <u>Environmental performance?</u>

Approach and Objective

- Life cycle assessment (LCA)
  - only a few LCA studies on ENMs have been conducted
  - most studies focus on the production of ENMs

- Objective of the applied LCA
  - focus on the whole product life cycle
  - assessment of environmental performance
  - identification of the most relevant processes
  - comparison to conventional applications (chromium)





Functional unit, basic assumptions and modeling

Surface area

1 m^2

System boundary

Europe

Coating thickness

300 µm

Electricity mix (ENTSO-E)

Europe

Service life

10 times longer

Impact assessment

ReCiPe midpoint indicator

(not nano-specific)

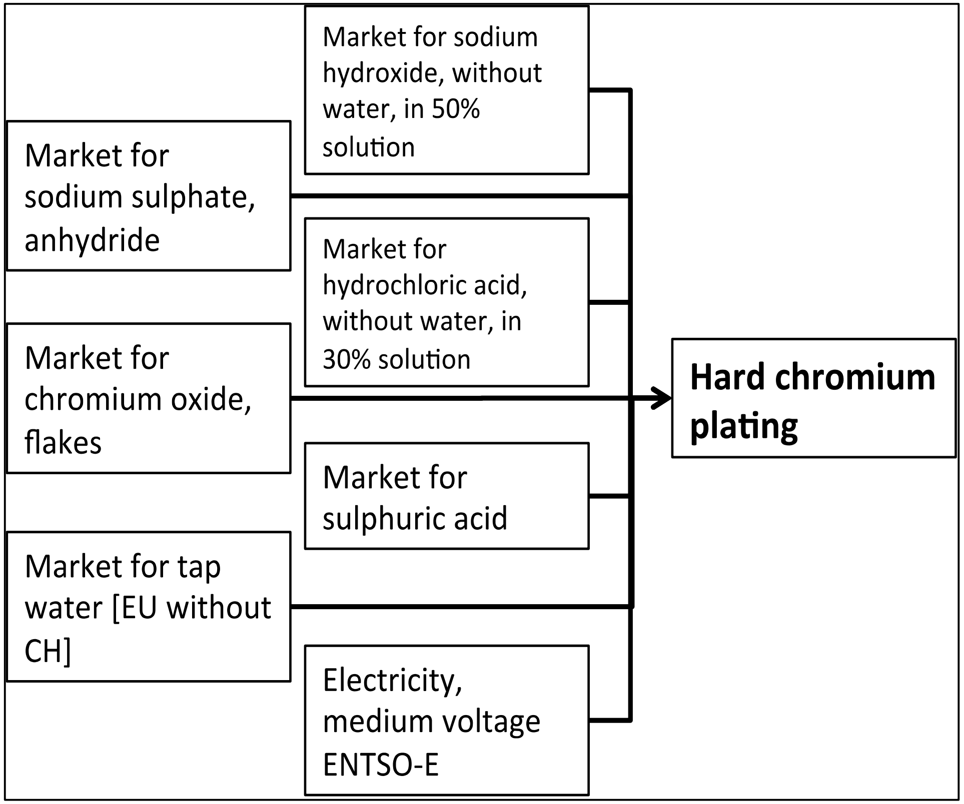
Software & Database

Umberto NXT LCA & ecoinvent 3.2

http://www.smaltiriva.com/paper-and-cardboard-industries.php

Model structure and inventory data

Convential hard chromium coatings



Coating of chromium onto a substrate

- electroplating

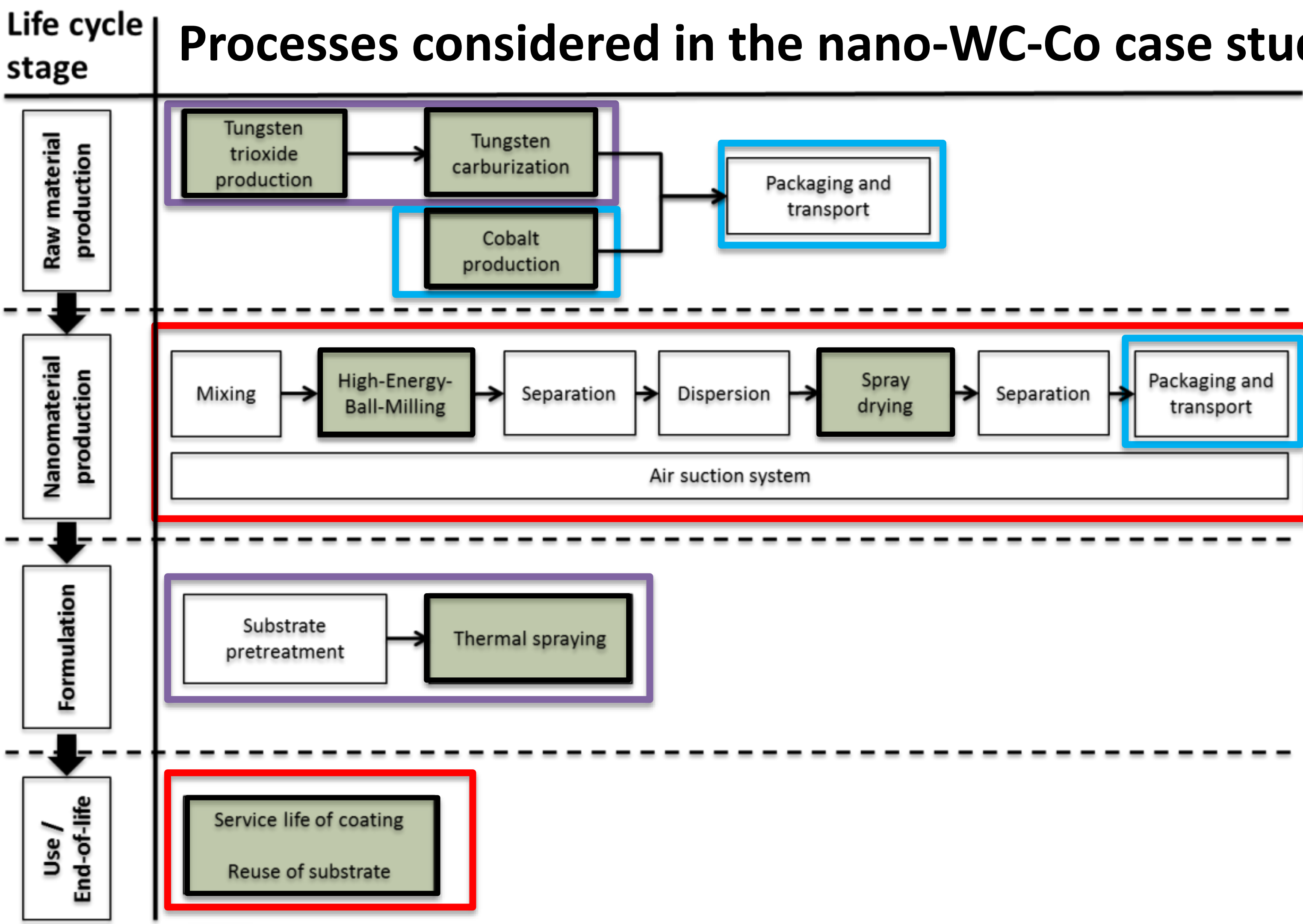
Assumption

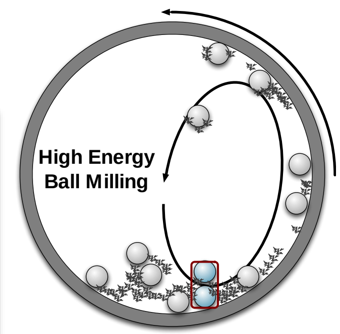
- electroplating process is similar to ecoinvent database set "black chromium selective coating " for solar absorbers

Modification of the dataset

- according to coating thickness
- shorter service life compared to nano-WC-Co

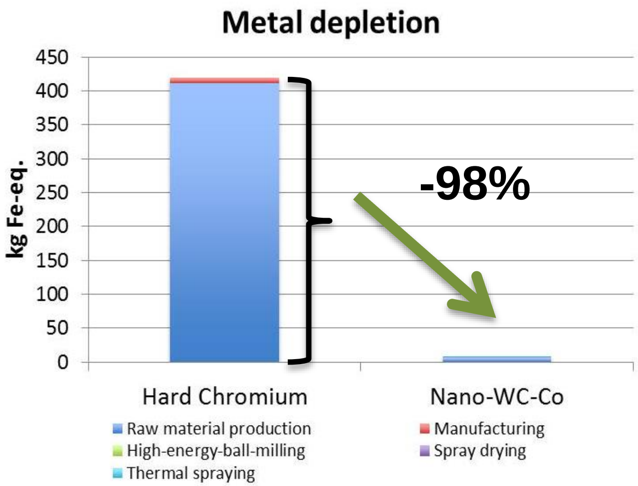
Model structure and inventory data

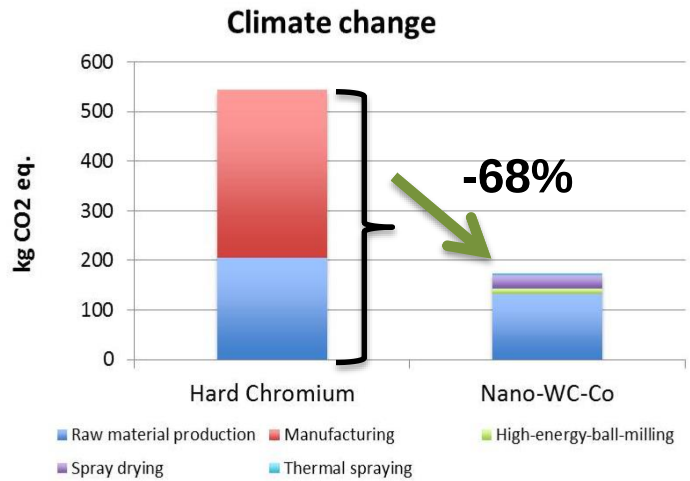




Primary data   Reasonable assumptions   Database

Results





Results:

- reduced environmental impact in almost all categories (from 51% to 98%)

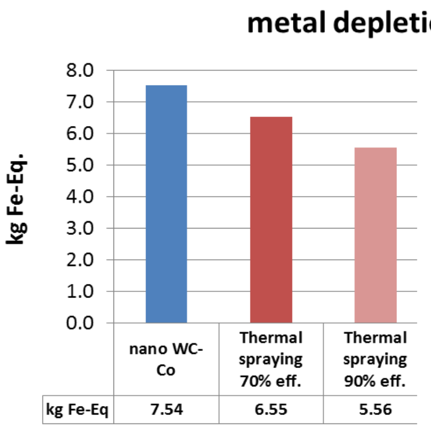
Relevant processes:

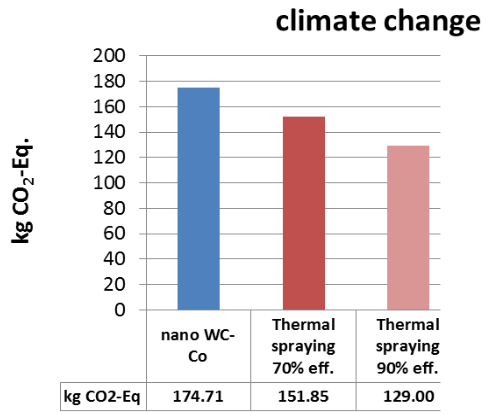
- raw material production
- Manufacturing
    - electricity

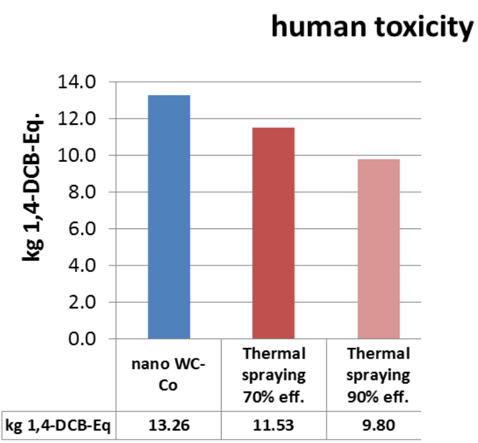
Sensitivity analysis

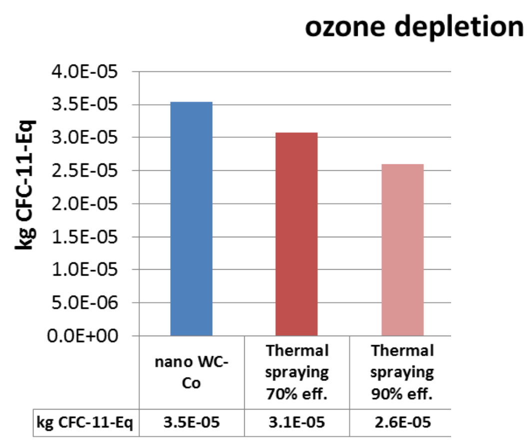
- Five scenarios considered:
  - increased efficiency in thermal spraying (50->**70%**)
  - increased efficiency in thermal spraying (50->**90%**)
  - thermal spraying (HVOF) conducted by the **HVAF** process (replacement of oxygen/kerosene by air/natural gas mix)
  - use of recycled tungsten carbide (**20%**)
  - service life reduction (**50%**)

Sensitivity analysis









The thermal spraying process had the highest efficiency impact

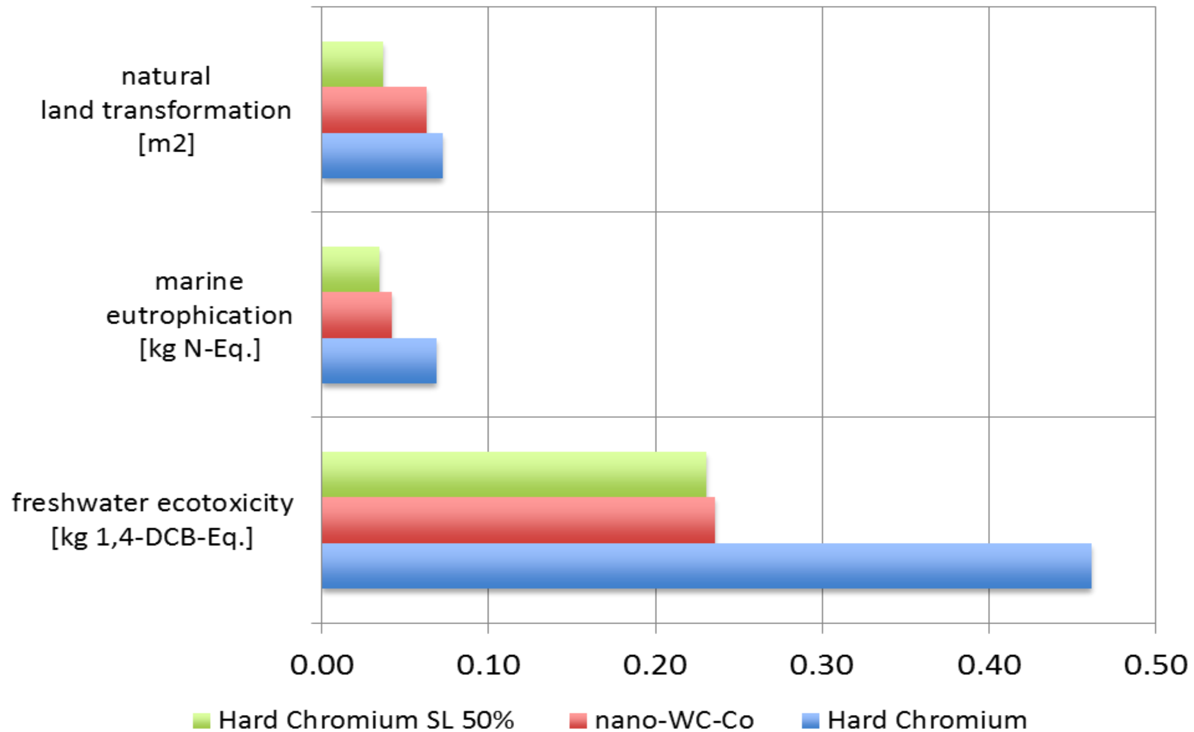
Replacement of the thermal spraying by HVAF did not affect the results

Use of secondary WC can balance the
low efficiency of the coating process

Sensitivity analysis

Reduced service life significantly influences the results

- Highest decreased environmental performance >50% compared to the original assessment



Conclusions

- Processes contributing the most to environmental impacts:
  - production of tungsten and tungsten carbide
  - efficiency of thermal spraying (η=50%)
- Use of recycled WC can decrease the influence of the raw material production stage on the results
- Environmental benefits only prevail if service life is prolonged
- LCIA does not consider nano-specific effects
- nano-WC-Co coatings can significantly improve the environmental performance compared to conventional coatings

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Impact category ReCiPe Midpoint (H) w/o LT	Unit	nano-WC-Co	Hard chromium	Reduction [%]
agricultural land occupation w/o LT, ALOP w/o LT	m^2a	10.9	66.6	83.6
climate change w/o LT, GWP100 w/o LT	kg CO_2-Eq	174.7	543.9	67.8
fossil depletion w/o LT, FDP w/o LT	kg oil-Eq	68.3	140.2	51.3
freshwater ecotoxicity w/o LT, FETPinf w/o LT	kg 1,4-DCB-Eq	0.2	0.4	38.7
freshwater eutrophication w/o LT, FEP w/o LT	kg P-Eq	0.01	0.05	81.3
human toxicity w/o LT, HTPinf w/o LT	kg 1,4-DCB-Eq	13.3	58.0	77.1
ionising radiation w/o LT, IRP_HE w/o LT	kg U235-Eq	18.0	66.0	72.8
marine ecotoxicity w/o LT, METPinf w/o LT	kg 1,4-DCB-Eq	0.2	0.5	51.5
marine eutrophication w/o LT, MEP w/o LT	kg N-Eq	0.04	0.07	37.8
metal depletion w/o LT, MDP w/o LT	kg Fe-Eq	7.5	419.8	98.2
natural land transformation w/o LT, NLTP w/o LT	m^2	0.063	0.060	-5.2
ozone depletion w/o LT, ODPinf w/o LT	kg CFC-11-Eq	0.00004	0.00010	62.8
particulate matter formation w/o LT, PMFP w/o LT	kg PM10-Eq	0.3	1.2	62.3
photochemical oxidant formation w/o LT, POFP w/o LT	kg NMVOC	0.5	1.2	62.3
terrestrial acidification w/o LT, TAP100 w/o LT	kg SO_2-Eq	0.7	2.4	70.7
terrestrial ecotoxicity w/o LT, TETPinf w/o LT	kg 1,4-DCB-Eq	0.01	0.05	77.6
urban land occupation w/o LT, ULOP w/o LT	m^2a	1.7	4.8	65.2
water depletion w/o LT, WDP w/o LT	m^3	0.7	8.4	91.5