International Conference on Resource Chemistry
March 08-09, 2021

ICRC International Conference on Resource Chemistry

CRITICALITY OF RAW MATERIALS FOR THE ENERGY TRANSITION

Analysis and Assessment of the Supply Risk of selected Elements for Photovoltaic Technologies in Germany until 2050

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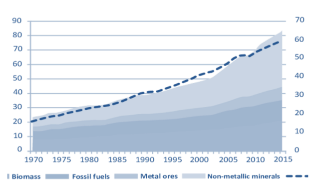
Background

Central problem areas:

Technologie-Shift

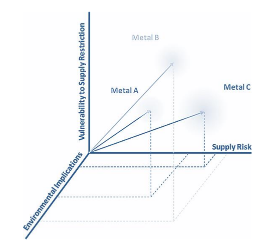
In order to meet national and global climate targets, a transition to a renewable energy system must take place to reduce greenhouse gas emissions in the energy demand sectors.

Material-Demand



This transition requires a responsible use of raw materials, as the consumption of resources has increased significantly over the last decades, and especially for low carbon technologies, the raw material requirements have become more complex.

Element-Criticality



For the long-term use of these raw material-using systems, the elements that have a high criticality for the reference system must be identified in order to detect future supply risks by assessing the demand and availability of raw materials for specific technologies.

Research Method

SCOPE (raw materials, indicators)

1. Criticality analysis (base year 2017)

Scenario Analysis

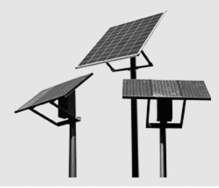
- a. Top-down: Supply side (global, all uses of elements)
  - 2 Parameters: Extrapolation of historical supply trend
  - Global raw material supply in year 2050
- b. Bottom-up: Demand side (Germany, PV use)
  - 3 Parameters: Development paths for demand determining
  - National raw material demand up to year 2050

2. Criticality analysis (target year 2050)

3. Comparison of supply and demand (target year 2050)

SCOPE

- **Tellur (Te)**
- **Cadmium (Cd)**
- **Indium (In)**
- **Gallium (Ga)**
- **Selen (Se)**



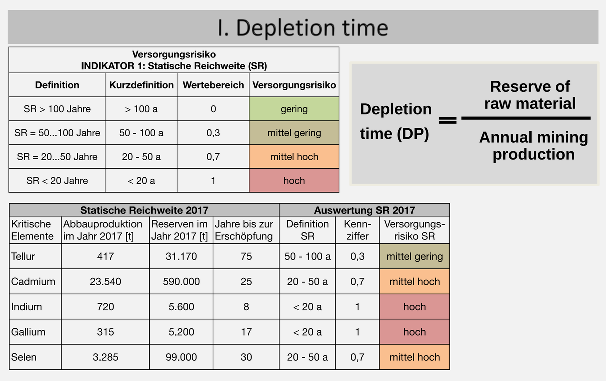
- **Depletion time (DT)**
  Ratio of reserve to annual mining production.
- **By-production (BP)**
  By-production share of critical element extraction.

Results

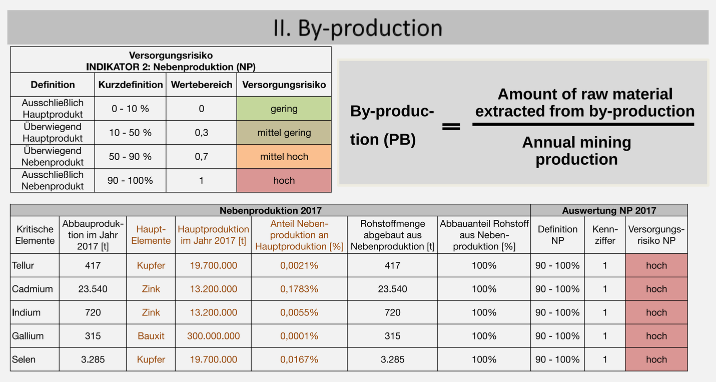
CRITICALITY ANALYSIS:

1. Base year 2017

I. Calculation Indicator DT

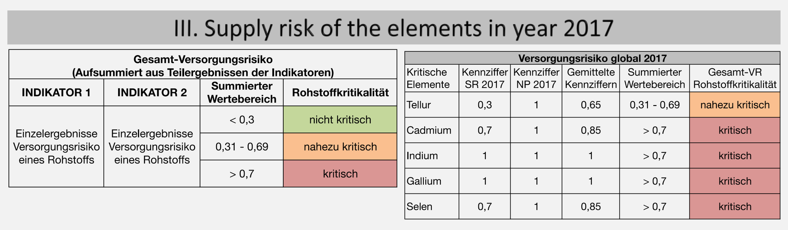


II. Calculation Indicator BP



III. Calculation of supply risk

Supply risk indicates an element is not available or only available to a limited extent.



RESULT: **The analysis categorizes the element tellurium as almost critical and all other four elements as critical.**

2. Target year 2050

RESULT:

The analysis shows the least criticality for tellurium and the most criticality for indium of all raw materials.

Supply risk 2050 – R1P1

Kritische Elemente	SR 50	NP 50	Versorgungsrisiko R1P1	
Tellur	0,3	1	0,3 - 0,7	m. VR
Cadmium	0,7	1	> 0,7	VR
Indium	1	1	> 0,7	VR
Gallium	1	1	> 0,7	VR
Selen	0,7	1	> 0,7	VR

Supply risk 2050 – R1P2

Kritische Elemente	SR 50	NP 50	Versorgungsrisiko R1P2	
Tellur	0,7	1	> 0,7	VR
Cadmium	1	1	> 0,7	VR
Indium	1	1	> 0,7	VR
Gallium	1	1	> 0,7	VR
Selen	0,7	1	> 0,7	VR

Supply risk 2050 – R1P3

Kritische Elemente	SR 50	NP 50	Versorgungsrisiko R1P3	
Tellur	0,7	0,3	0,3 - 0,7	m. VR
Cadmium	1	0,3	0,3 - 0,7	m. VR
Indium	1	0,7	> 0,7	VR
Gallium	1	1	> 0,7	VR
Selen	0,7	0,7	> 0,7	VR

Supply risk 2050 – R2P1

Kritische Elemente	SR 50	NP 50	Versorgungsrisiko R2P1	
Tellur	0	1	0,3 - 0,7	m. VR
Cadmium	0,7	1	> 0,7	VR
Indium	0,3	1	0,3 - 0,7	m. VR
Gallium	0,3	1	0,3 - 0,7	m. VR
Selen	0,3	1	0,3 - 0,7	m. VR

Supply risk 2050 – R2P2

Kritische Elemente	SR 50	NP 50	Versorgungsrisiko R2P2	
Tellur	0,3	1	0,3 - 0,7	m. VR
Cadmium	0,7	1	> 0,7	VR
Indium	0,7	1	> 0,7	VR
Gallium	0,3	1	0,3 - 0,7	m. VR
Selen	0,3	1	0,3 - 0,7	m. VR

Supply risk 2050 – R2P3

Kritische Elemente	SR 50	NP 50	Versorgungsrisiko R2P3	
Tellur	0,3	0,3	< 0,3	kein VR
Cadmium	0,7	0,3	0,3 - 0,7	m. VR
Indium	0,7	0,7	> 0,7	VR
Gallium	0,3	1	0,3 - 0,7	m. VR
Selen	0,3	0,7	0,3 - 0,7	m. VR

Supply risk 2050 – R3P1

Kritische Elemente	SR 50	NP 50	Versorgungsrisiko R3P1	
Tellur	0	1	0,3 - 0,7	m. VR
Cadmium	0	1	0,3 - 0,7	m. VR
Indium	0	1	0,3 - 0,7	m. VR
Gallium	0	1	0,3 - 0,7	m. VR
Selen	0	1	0,3 - 0,7	m. VR

Supply risk 2050 – R3P2

Kritische Elemente	SR 50	NP 50	Versorgungsrisiko R3P2	
Tellur	0	1	0,3 - 0,7	m. VR
Cadmium	0,3	1	0,3 - 0,7	m. VR
Indium	0,3	1	0,3 - 0,7	m. VR
Gallium	0	1	0,3 - 0,7	m. VR
Selen	0	1	0,3 - 0,7	m. VR

Supply risk 2050 – R3P3

Kritische Elemente	SR 50	NP 50	Versorgungsrisiko R3P3	
Tellur	0	0,3	< 0,3	kein VR
Cadmium	0,3	0,3	< 0,3	kein VR
Indium	0,3	0,7	0,3 - 0,7	m. VR
Gallium	0	1	0,3 - 0,7	m. VR
Selen	0	0,7	0,3 - 0,7	m. VR

SCENARIO ANALYSIS:

a. Top-down: Supply side results

Rohstoffangebot im Jahr 2050 [t]

Kritische Elemente	geringe Reichweite (R1) min. (P1) / max. (P2) Produktion			mittlere Reichweite (R2) min. (P1) / max. (P2) Produktion			größte Reichweite (R3) min. (P1) / max. (P2) Produktion		
	2050 - P1	2050 - P2	2050 - R1	2050 - P1	2050 - P2	2050 - R2	2050 - P1	2050 - P2	2050 - R3
Tellur	388	860	31.170	388	860	48.000	388	860	98.000
Cadmium	24.848	50.913	590.000	24.848	50.913	1.200.000	24.848	50.913	2.630.000
Indium	760	1.276	5.600	760	1.276	47.100	760	1.276	112.000
Gallium	748	728	5.200	748	728	42.000	748	728	1.000.000
Selen	3.057	3.407	99.000	3.057	3.407	172.000	3.057	3.407	600.000

Parameters:

Annual mining production (P)
Determining future values using historical growth rates

Reserve (R)
Determining future values based on static and dynamic development of the reserve

Development Paths Assumptions:

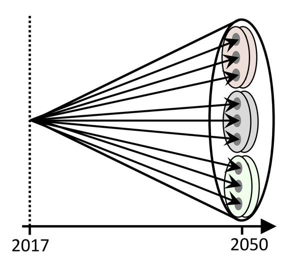
P1: Not reaching expected values of Te, Cd, In, Se
P2: Achieving expected values with better extraction techniques
P3: Achieving expected values through own mining production

R1: Current reserve (static approach)
R2: Current reserve base (dynamic approach)
R3: Ultimately Recoverable Resources (URR) (dynamic approach)

b. Bottom-up: Demand side results

Rohstoffnachfrage im Jahr 2050 [t]

Kritische Elemente	2050 - Hoch		2050 - Trend		2050 - Niedrig	2050 - Mittel
	2050 - Dünnschicht		2050 - Dünnschicht		2050 - Kontinuität	
	2050 - L.E.	2050 - D.	2050 - L.E.	2050 - D.	2050 - L.E.	2050 - D.
	Bedarf A	Bedarf B	Bedarf C	Bedarf D	Bedarf E	Bedarf F
Tellur	563,91	296,33	230,38	121,83	50,28	34,25
Cadmium	644,39	411,11	266,15	171,51	59,38	43,50
Indium	524,66	474,19	223,35	202,64	39,92	32,81
Gallium	49,17	34,26	20,38	14,21	3,57	2,70
Selen	420,68	219,17	174,61	92,02	30,99	20,41



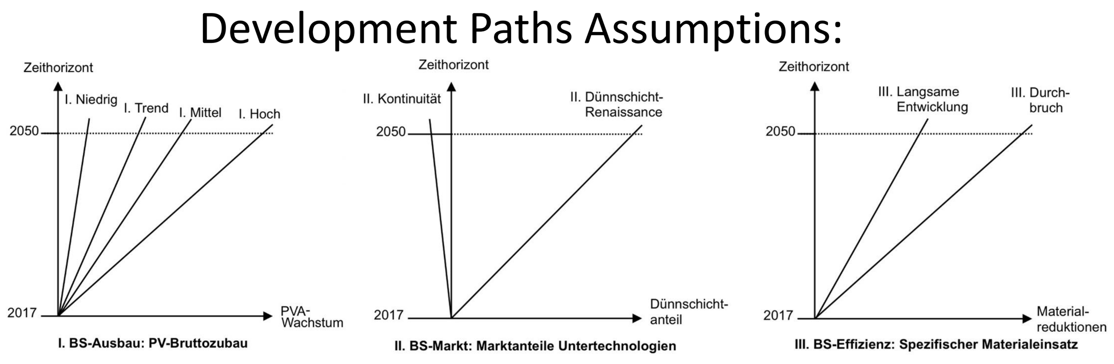
Parameters:

PV installation
4 paths until 2050 (low, medium, high, trend)

Market shares
2 paths (continuity, thin-film renaissance)

Specific material demand
2 paths until 2050 (slow development, breakthrough)

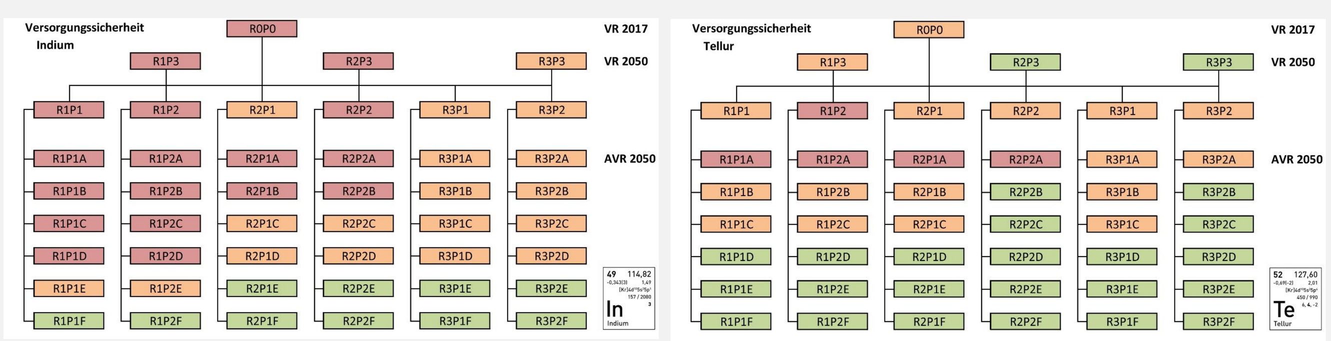
Development Paths Assumptions:



3. COMPARISON SUPPLY AND DEMAND:

From six supply and six demand scenarios, a wide range of results emerges for different worst-case and best-case conditions in year 2050. For all five elements exist scenarios for which there is a possibility of a medium supply risk in the future. On the other hand, future developments can also occur for which no future supply risk can be assumed.

RESULT: Only for the elements indium and tellurium can a high supply risk arise from the future demand. The decisive factor for the high probability of a shortage of raw materials is the small ratio of required quantities to raw material reserves.



Conclusion

The results of the criticality assessment lead to these statements:

1. In relation to the overall results, tellurium and indium show a high criticality. Indium causes the lowest supply security of all elements. As a result, problems can arise in the manufacture of all thin-film PV cells.
2. The elements cadmium, gallium and selenium show only low criticality. Therefore it is highly unlikely that security of supply will be impaired for these elements.
3. Only the results obtained from the quantity values of the worst-case scenarios indicate criticality of all five elements and therefore low security of supply.
4. The best-case scenarios show that, with the exception of indium, none of the other elements considered can lead to problematic security of supply.
5. This underscores the previous first thesis that indium is the element with the highest criticality and thus has the lowest overall security of supply.

Amatya, Reja; et al. (2015): The Future of Solar Energy – An interdisciplinary MIT Study, MIT Energy Initiative, Massachusetts
Angerer, Gerhard; et al. (2016): Rohstoffe für die Energieversorgung der Zukunft – Geologie Märkte Umwelteinflüsse, in: Schriftenreihe Energiesysteme der Zukunft, München
Candelise, Chiara; et al. (2012): Materials availability for thin film (TF) PV technologies development – A real concern?, in: Renewable and Sustainable Energy Reviews 15, 4972 – 4981
Davidsson, Simon; et al. (2017): Material requirements and availability for multi-terawatt deployment of photovoltaics, in: Energy Policy 108, 574 - 582
Deutsche Rohstoffagentur (2016): Rohstoffe für Zukunftstechnologien 2016 – Auftragsstudie DERA Rohstoffinformationen, Berlin
Fraunhofer (Fraunhofer Institut ISE) (2018A): Aktuelle Fakten zur Photovoltaik in Deutschland, in: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf
Fraunhofer (Fraunhofer Institut ISE) (2018B): Installierte Netto-Leistung zur Stromerzeugung in Deutschland, Energy Charts, in: https://www.energy-charts.de/power_inst_de.htm
Frondel, Manuel; et al. (2007): Trends der Angebots- und Nachfragesituation bei mineralischen Rohstoffen, BMWi Endbericht, ARGE Fraunhofer ISI, BGR und RWI Essen, Forschungsprojekt Nr. 09/05, Essen
Graedel, T. E.; et al. (2012): Methodology of Metal Criticality Determination, in: Environmental Science & Technology 46, 1063 – 1070
Jägermann, Wolfram (2015): Perspectives on Photovoltaic Energy Conversion – Dependency on Material Choices, in: Hartard, Susanne; Liebert Wolfgang (Hrsg.)(2015): Competition and Conflicts on Resource Use, Heidelberg, 273 - 288
Kosow, Hannah; et al. (2008): Methoden der Zukunfts- und Szenarioanalyse – Überblick, Bewertung und Auswahlkriterien, IZT Werkstatt-Bericht Nr. 103, Berlin
Nitsch, Joachim (2017): Erfolgreiche Energiewende – Aktuelle Szenarien 2017 der deutschen Energieversorgung, Stuttgart
Schebek, Liselotte; et al. (2015): Technological Innovation and Anthropogenic Material Flows, in: Hartard, Susanne; Liebert Wolfgang (Hrsg.)(2015): Competition and Conflicts on Resource Use, Heidelberg, 135 – 153
Sverdrup, Harald; et al. (2017): An assessment of metal supply sustainability as an input to policy – security of supply extraction rates, stocks-in-use, recycling, and risk of scarcity, in: Journal of Cleaner Production 140, 359 - 372
USGS (U.S. Geological Survey) (2014): Historical statistic for mineral and material commodities in the United States, USGS Data Series 140, Commodity Chapters Bauxite/Alumina, Cadmium, Copper, Gallium, Indium, Selenium, Tellurium, Zinc, in: https://minerals.usgs.gov/minerals/pubs/historical-statistics/
USGS (U.S. Geological Survey) (2018): Mineral Commodity Summaries 2018, Virginia
VDI (Verein Deutscher Ingenieure) (2018): VDI 4800 Blatt 2 – Bewertung des Rohstoffaufwands, in: ders. (Hrsg.)(2016): VDI-Handbuch Ressourceneffizienz, Düsseldorf
Viebahn, Peter; et al. (2015): Assessing the need for critical minerals to shift the German energy system towards a high proportion of renewables, in: Renewable and Sustainable Energy Reviews 49, 655 - 671
Wuppertal Institut (2014): Abschlussbericht KRESSE – Kritische mineralische Ressourcen und Stoffströme bei der Transformation des deutschen Energieversorgungssystems, Wuppertal
Zuser, Anton; et al. (2011): Considerations of resource availability in technology development strategies – The case study of photovoltaics, in: Resources, Conservation and Recycling 56, 56 - 65