Translation of project report “RESourcenCHECK für KMUs” (Resource Check for SMEs), 2017

1 Introduction

1.1 Starting point

Rare metals are essential production factors for the manufacturing industry. These raw materials have been used more and more in recent years. In particular with the transition to the age of information and communication technology, but also with the increasing importance of renewable energy production, the need for selected metals (e.g. indium, platinum group metals, rare earths) has exploded.

The secure supply of metals is a key requirement for a functioning and prospering business location. Due to their highly functional and specialized focus, the machine, electrical and metal industry is dependent on the safe and economically viable supply of rare metals or semi-finished products (components, parts) containing them.

While the topic of security of supply of energy systems has long been prominently discussed, for a long time little attention has been paid to this topic in relation to non-energy resources. In recent years, however, the security of supply and dependence on non-energetic raw materials have increasingly moved into the corporate strategic and federal political perspective, particularly with regard to metallic raw materials. This is due to various developments that have been accentuated in recent years, for example:

Increasing scarcity: Comparatively, many metals are geochemically scarce and their recoverable quantities are limited.

Coupled production: Many rare metals that are used in high-technology applications and future technologies are so-called coupled products for the extraction and refinement of the quantity-dominating industrial metals such as copper or aluminum. Therefore, their market availability depends on the demand for the "main metals", since this determines how much of a "coupled metal" is obtained at what price.

Geographical concentration: The extraction and production of non-metallic raw materials is relatively often concentrated in a few countries (see also Figure 1, what entails significant dependencies on these - at least partially politically and institutionally unstable - countries (e.g. rare earth metals from China)).

Price volatility: Metal prices have been subject to strong fluctuations in recent years. This can be attributed to various causes, e.g. "Mismatch" between production capacities and demand, export taxes from producing countries, speculation in raw material markets.

Rising demand: Due to the increasing demand in existing applications (e.g. photovoltaics), the increasing use in new applications and the economic upswing in emerging countries (e.g. China), the demand for metals is increasing steadily worldwide. Accordingly, competition for these raw materials on the market is increasing, with potentially negative effects on their complete and inexpensive supply.

Added to this is the fact that the mining and refining of metallic raw materials due to the decreasing average metal mass proportions in the deposits (ores) are associated with increasingly extensive impairments of people and the environment. This is due to the fact that ever larger quantities of ore have to be extracted and refined in a complex manner in order to extract a certain amount of a metal. From a social perspective, the focus is increasingly on the fact that certain metals are mined in conflict regions (e.g. tantalum) and the mining of these raw materials often takes place in countries with relatively high levels of corruption. In addition to the business or economic risk of a potential undersupply of rare metals, the negative effects on people and the environment, which are becoming more and more public, are therefore critical for companies.

Until now, small and medium-sized companies have been little aware of their dependence on rare metals or the corresponding business risks and the effects on people and the world that go hand in hand with the mining and refining of metals. The resource check project presented here (short: RESCHECK) is intended to close this gap - at least in part - by developing a tool for SMEs with which they can assess their resource dependency and develop prevention and innovation strategies related to rare metals.

1.2 Objectives of the work

The RESCHECK project basically follows two main directions. On the one hand, a methodology for recording the risks and effects of the use of rare metals in SMEs, including recommendations for action, is to be developed and used in a pilot with selected SMEs. On the other hand, the knowledge gained should be synthesized with the development of an electronic tool and generalized for the application.

The related objectives are as follows:

- Analysis of how a resource footprint for SMEs can be created and application in selected pilot SMEs. Thereby:
    - A methodology is developed which allows the resource footprint with manageable effort, considering supply risks, susceptibility of companies to supply shortages as well as ecological and social effects.
    - A questionnaire will be developed which can be used to collect the necessary data and information from the MEM companies.
    - The resource footprint for the selected pilot SMEs are quantified.
- Development of options for SMEs to deal with potential supply shortages or to improve the supply situation as the basis for the development of an SME resource strategy.

- Development of an electronic SME tool that can be consulted for a rough analysis of the criticality of operational dependencies on rare metals and corresponding recommendations for action to reduce criticality.

1.3 Research framework

1.3.1 Metals

Since the consideration of all metals in the periodic table is neither expedient nor timely, the present project focuses on a selection of metals. The selection was based on the following existing basics:

- All metals were considered which were classified as critical based on a study carried out for the EU member countries (European Commission, 2014).
- This list was specifically supplemented by those metals, which were classified as particularly important in a survey by the industry association Swissmem among companies (Roth, 2013).

The periodic table shown in Figure 1 illustrates the selected 35 metals in the RESCHECK project.

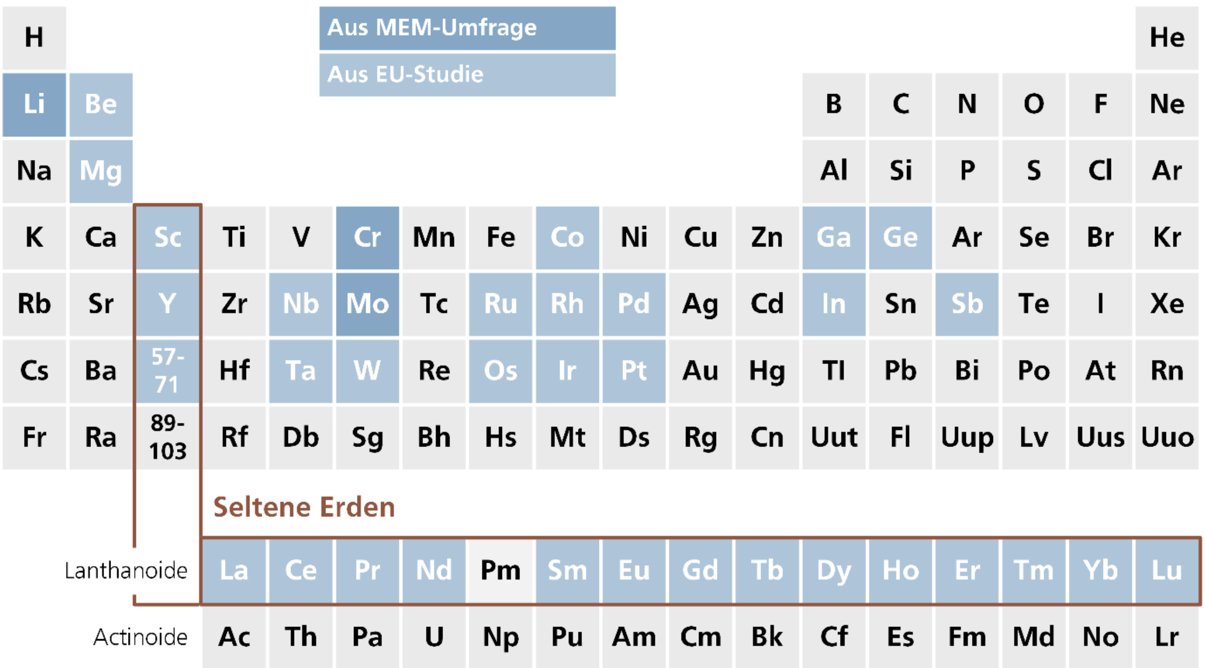

Figure 1: Metals for criticality analysis in the RESCHECK project.

1.3.2 Pilot SMEs

The project was processed based on a case study approach. This means that the development of the methodology for assessing the risks and effects of the use of rare metals and the basis for strategic approaches considers the situation and experience in selected pilot SMEs and is applied and tested on these pilot SMEs.

COMPANY	**PRODUCTS**	**SEMI-FINISHED PRODUCTS**	**METALS**
Pilot-SME 1	Electric drive and control elements	Motor (Magnet)	Neodymium, dysprosium
		Programmable logic controller (PLC)	Niobium, antimony, tantalum, indium, gallium, molybdenum
		Human machine interface (HMI)	
Pilot-SME 2	Bearingless pumps	Motor (Magnet)	Neodymium, dysprosium, samarium, cobalt
Pilot-SME 3	Flexible thin-film solar modules	Copper indium gallium diselenide module (CIGS module)	Gallium, indium

Table 1: Overview of the considered products, semi-finished products and rare metals contained therein.

To this end, three exemplary pilot SMEs were selected in cooperation with the Swissmem industry association (see Table 1).

1.4 Project processing and structure of the report

The project was processed in four modules and corresponding work packages (see Figure 2). The module and the operational situation around the selected rare metals in the three pilot SMEs are surveyed. On the one hand, this serves as the basis for the development of a method for the rough assessment of the risks and scope (criticality assessment) of the use of rare metals in companies (module 2). On the other hand, module 1 also collects foundations for the development of recommendations for action as building blocks for the development of a resource strategy to reduce criticality. The knowledge and outputs developed in the first three modules are then summarized in the fourth module in a practical electronic tool, which enables companies to carry out «criticality screenings» for rare metals with little effort.

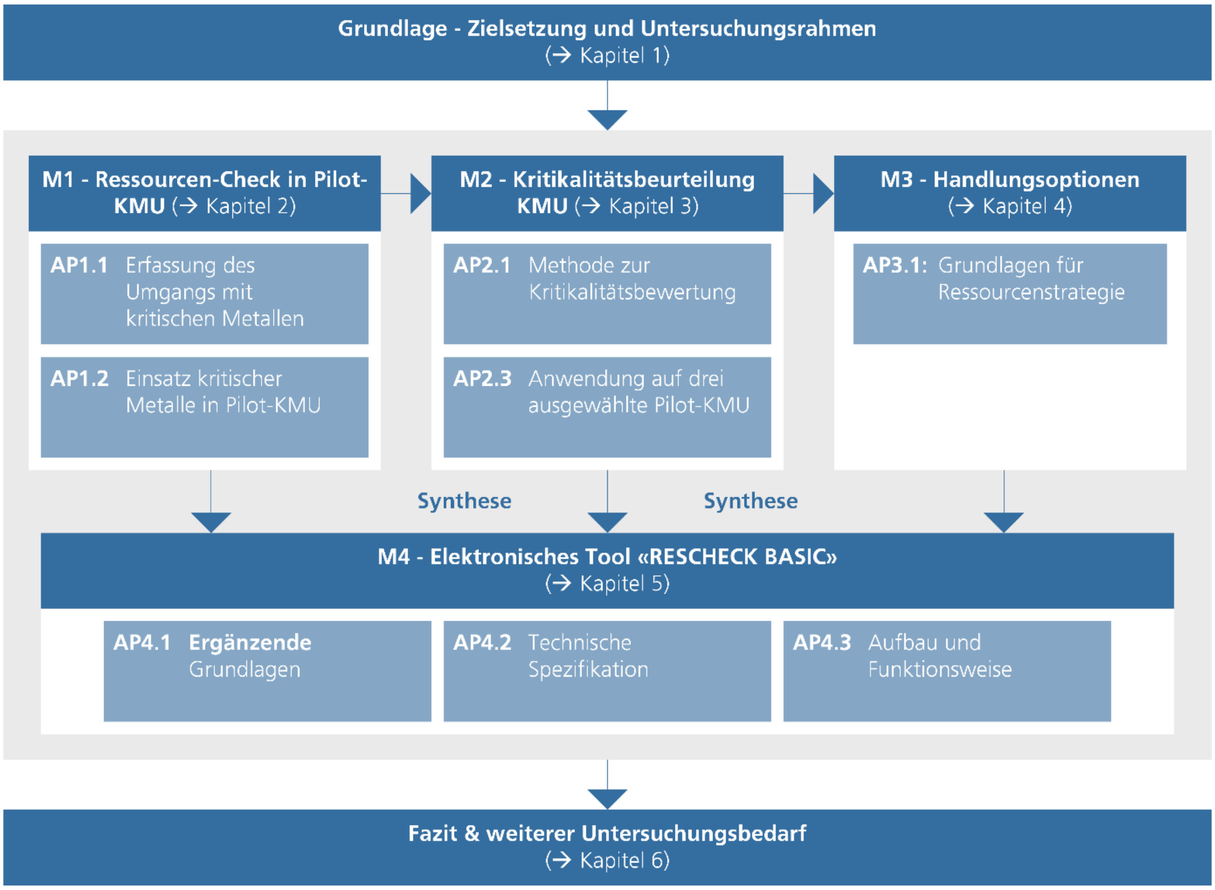

Figure 2: Structure of the project processing and the present report.

2 Resource check in pilot SMEs

This chapter develops the conceptual and content-related foundations for the development and application of a methodology for assessing risks and the scope of the use of rare metals in SMEs (i.e. SME resource footprint). First of all, this includes defining the perspectives that should be included in the assessment (assessment framework, cf. 1.1.1). On this basis, standardized questionnaires are developed to specifically collect the information required to assess these perspectives in selected pilot SMEs (cf. 1.1.2). On the one hand, the idea is to be able to use this information to derive tailor-made criteria for the development of the risk and impact assessment methodology. On the other hand, information is also collected that is used for the later application of the developed methodology for assessing the risks and scope of the use of rare metals in the pilot SMEs.

2.1 Detection of the critical metals used

2.1.1 Assessment framework

The underlying perspective of the project to assess the risks and scope of the use of rare metals in SMEs (resource check) is based on various concepts and approaches that are common in science and industry. Each one illuminates different aspects for the assessment of operational (but also economic) supply chains.

On the one hand, the **vulnerability concept** is used, which brings in the perspective of security of supply. Security of supply is given if the operational production activities are guaranteed at all times by the physically uninterrupted availability of operational production factors at affordable prices. In line with the risk-oriented concept developed by the Intergovernmental Panel on Climate Change as part of the climate impact assessment (IPCC, 2007, see Box 1), the dimensions "supply risk" and "sensitivity to supply bottlenecks" are adopted for the resource check and operationalized for the present case.

The former describes those characteristics in the value chain that potentially impair the metal supply in the upstream life cycle phases. That’s why the RESCHECK project strives to consider the entire supply chain from raw material extraction, processing and semi-finished goods production to delivery to SMEs. In terms of a comprehensive supply risk perspective, geological / physical, geopolitical, economic and political-regulatory aspects are analyzed. The second vulnerability dimension complements the supply risk by the sensitivity of SMEs to supply impairments that result from the occurrence of a risk in the supply chain, i.e. how vulnerable an operation is to physical or price supply restrictions. The internal structures and properties of SMEs are recorded, which determine the effects of supply impairments on operational production and value creation. For example, the short-term unavailability of a certain metal is only a problem if it cannot be replaced or if the material reserves for bridging the bottleneck are missing.

For a comprehensive consideration of risks and the scope of the use of rare metals, the two business-oriented security of supply-related dimensions are supplemented by further sustainability dimensions. In addition, the ecological and social impacts and risks upstream of the company are considered, which go hand in hand with the mining of rare metals and are becoming increasingly important for companies in the context of sustainability management.

2.1.2 Questionnaires and entry forms

Based on the previously outlined assessment framework, a procedure is developed here that can be used to collect the relevant information and data relating to the supply situation and the use of rare metals in a standardized manner. For this purpose, a questionnaire was developed, which enables a detailed analysis and recording of the operational situation based on the previously described assessment dimensions in a simple manner (see interview guide and questionnaire in A1). In the following, the structure and the various content blocks are described in summary and the background for inclusion in the survey is explained:

Part A General company information: Contains general questions about SMEs such as number of employees, share of production costs in the total operating costs, or company structure (ownership structure, size, locations, areas of activity, etc.).

Part B Use and handling of rare metals or supply chains: Information on the use or need and operational handling of rare metals form the central basis for the assessment of the three dimensions "supply risk", "environmental effects" and "social effects".

- **B1 Use and handling of critical metals:** the most basic understanding which activities or products of SMEs are dependent on rare metals. A distinction is made between direct use (e.g. neodymium in high-performance magnets of electric motors) and indirect use (e.g. in tools). In addition, information on the recycling of these rare metals from production waste or after use of the products is collected.
- **B2 Supply chain:** As a basis for assessing risks associated with the supply of rare metals, this question block illuminates the company supply chains. The focus is on the spatial location of the supply phases (from raw material extraction to the final supplier) for the identified metals.

Part C Vulnerability: These blocks of questions aim at a comprehensive understanding of operational vulnerability to supply bottlenecks, i.e. they try to find out how badly an SME is affected by a limited supply as a company.

- **C1 Strategic importance or market:** These questions are used to analyze how important products, whose manufacture depends directly or indirectly on rare metals, are for the corporate strategy and the turnover of the SMEs.
- **C2 Substitutability:** Operational vulnerability also depends heavily on the possibilities for substitutability. The better a rare metal can be replaced by alternatives in production, the less vulnerable SMEs are to supply restrictions.

- **C3 Ability to innovate**: This block of questions determines the ability of SMEs to reduce supply risks and the vulnerability of SMEs to supply restrictions through product changes or adjustments in the production process.

Part D Measures to secure raw materials (adaptability): As a basis for the development of a resource strategy and recommendations for action (also for the electronic RESCHECK tool), this block of questions asks about previous experience with raw material shortages and corresponding strategic approaches as well as concrete measures.

2.2 Critical metals in pilot SMEs

2.2.1 Pilot SMEs 1

General information

The company was founded in 1964 and is part of a company group. The company is a Swiss family business with a total of 110 employees and is active worldwide in the graphics industry. The product portfolio ranges from rotary offset presses for printing a wide range of products to mailroom solutions for the newspaper market.

The company is a producer and supplier of electrical equipment and electronic products for the company group as well as for a small part of external customers (3-5%). The company operates in the following areas:

- Engineering
- Industrial automation
- Wiring technology
- Electronics
- Services

Design and production consulting and training account for around two thirds of the operative business and one third accounts for the effective manufacture of electronics. The manufacture of electronic equipment consists on the one hand of the manufacture of components that are otherwise not available on the market in this form, and on the other hand of the functional composition of purchased components.

Innovation ability

The company uses 20-30% of its turnover for engineering. The ability to innovate is therefore relatively high (60 points, on a scale of 0-100). One staff section is responsible for research and development, although the number of registered patents is rather small.

Regular supervision of diploma theses in cooperation with universities exists and is also appreciated. However, cooperation is sought with practice-oriented universities of applied sciences rather than with universities or ETH.

Raw material situation and value chain

The raw material situation of the company is complex (approx. 32,000 materials in stock) and in the supply chain the company is rather far behind or far away from the actual raw material metal. For this reason, the company risk must be assessed for individual components.

The material costs make up 60-70% of the total costs. Since the company is a subcontractor to the corporation, price increases can theoretically be passed on to the corporation. However, the graphics industry is under great pressure, which is why the company is unable to pass on higher prices to customers. It is not the price that tends to be the risk, but the quantity available.

Due to the complexity of the raw material situation, the company risk for individual components must be determined. Three components were selected that are of great importance to the company:

Component 1: Motor

The motor is purchased and installed in a certain business area of the corporation together with the control in electronic equipment (see Figure 3). A total of 200-300 different motors are used. A distinction is made between main and secondary motors.

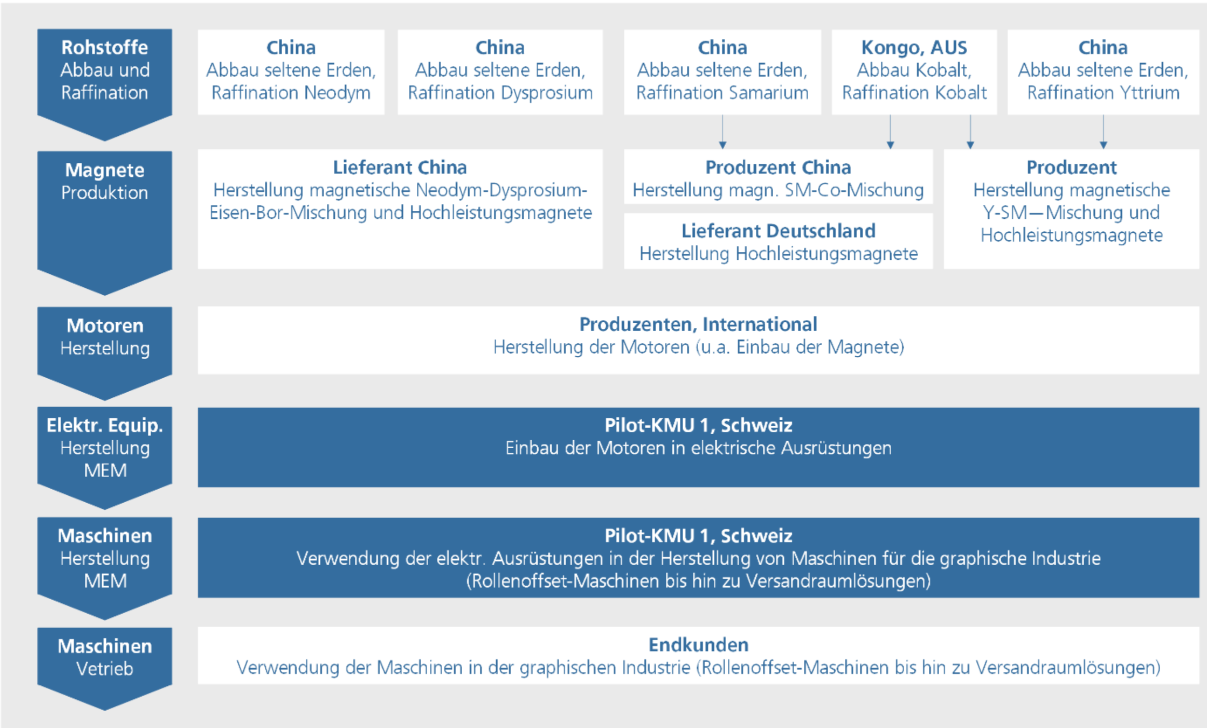

Figure 3: Simplified value chain for the "motor" product component.

The motors are essential for the corporation because they drive the machines (80 points, on a scale of 0-100). If there is a delivery problem, it is possible to use old motors as a replacement.

The motors are purchased from several suppliers (e.g. Bosch Rexroth). On the one hand, standard motors are purchased and on the other hand motors are specially drawn with CAD. A change of supplier in case of shortage of rare earths does not make sense, since all suppliers are affected. Manufacturing the motors themselves is not an option. The substitutability depends on the type of engine and functionality and is particularly a question of price.

Component 2: PLC - Programmable Logic Controller (PLC)

The PLC is the control box and thus the connection to the motor. It gives impulses to the drive boxes and can be described as the "brain" of the drive. The company buys the PLC from various manufacturers and installs it in the electronic equipment (see Figure 4). The raw material situation of the PLC is comparable to that of the HMI.

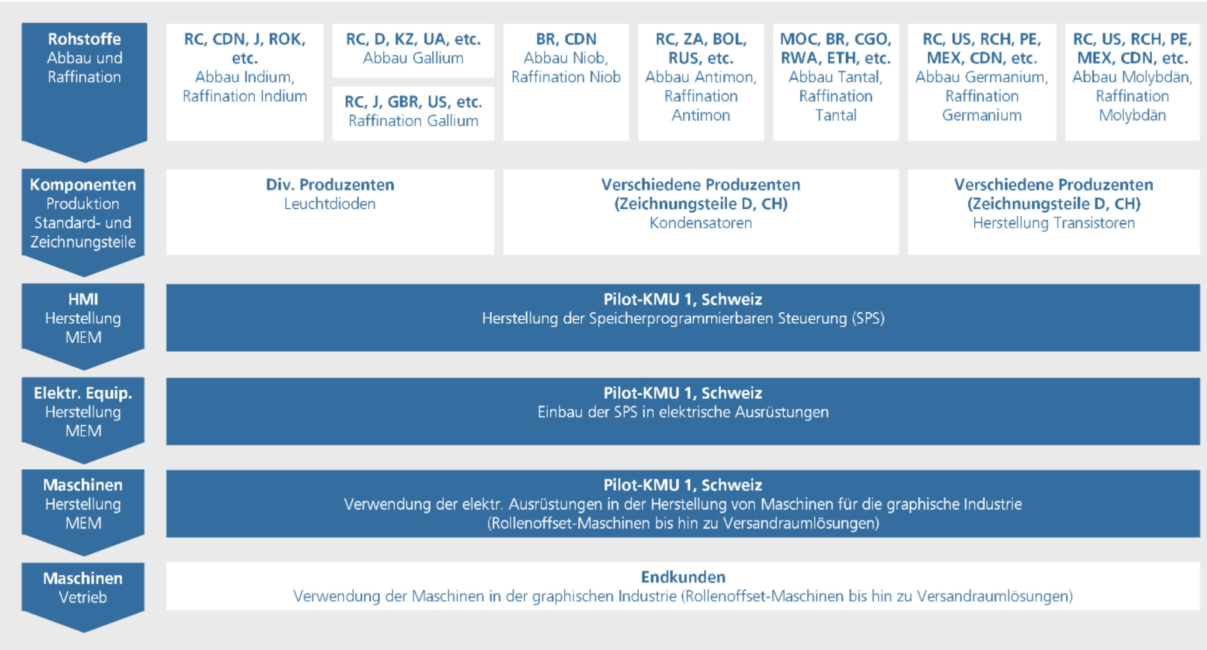

Figure 4: Simplified value chain for product component "Programmable Logic Controller (PLC)".

Component 3: HMI - Human Machine Interface (HMI)

The HMI is a component that the company manufactures itself and incorporates into the electronic equipment. It enables the user to interact with the drive control and is roughly composed of an LC display with a touchscreen and two prints. Approx. 2,500 HMIs are manufactured each year and the share of turnover is approx. 15%, which varies depending on the size of the HMI. The importance of the HMI for corporate strategy is very high (80 points, on a scale of 0-100).

The parts required for the manufacture of the HMI are divided into standard and drawing parts. The standard parts are obtained from various foreign distributors, while the drawing parts are specially made for the company. The manufacturers of the drawing parts are located in Switzerland and Germany (see Figure 5).

A change of supplier for drawing parts is associated with high costs. The substitutability depends very much on the respective component.

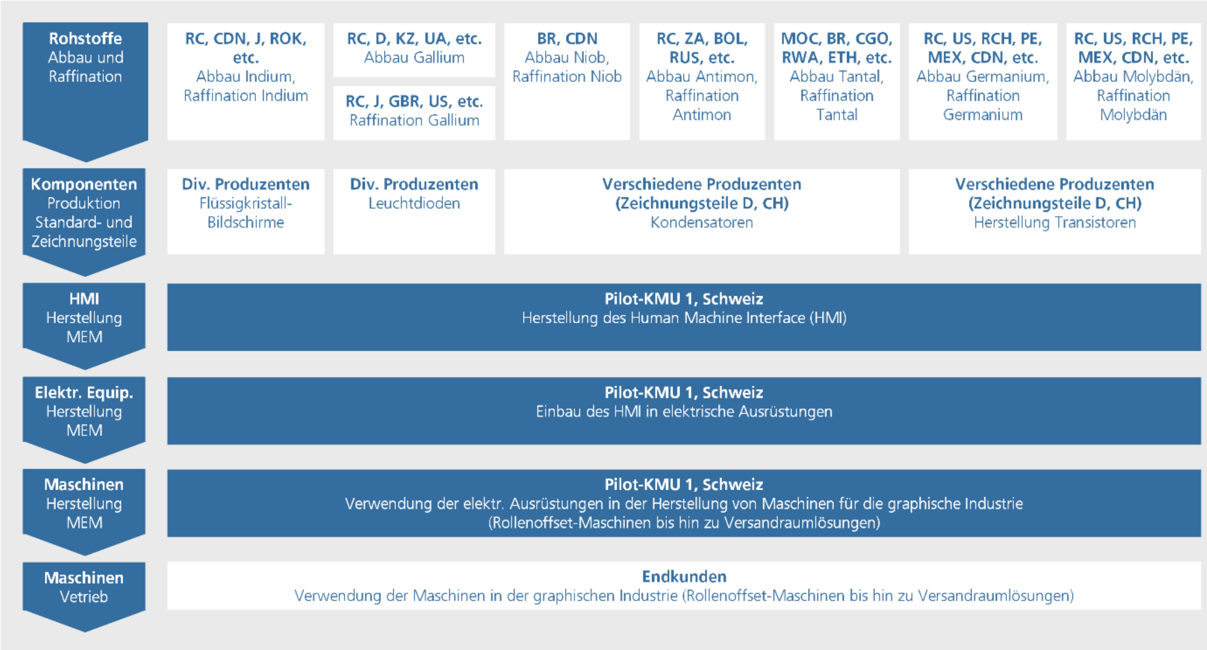

Figure 5: Simplified value chain for product component "Human Machine Interface (HMI)".

Experience with shortage of raw materials

The company has already experienced shortages of raw materials and the resulting difficulties in procuring certain components. Three events should be highlighted:

- Bosch Rexroth surcharges for motors due to rare earths
- An earthquake has led to a shortage of tantalum supplies (affected supplier with market share 70-80% has failed), whereupon IC manufacturers reacted with less use of raw materials in production.
- The Fukushima earthquake has caused problems with the purity of metals, causing restrictions on the delivery of certain components. The company immediately secured the annual requirement.

Every event triggered adjustments that were not previously expected in this form. The type of reaction is therefore always difficult to estimate and strongly depends on which component is affected by the procurement difficulties.

Strategies for securing raw materials or components

The strategies for reducing the procurement risk depend on the component concerned. The following strategies play a central role in the company:

- Long-term planning ahead (planning horizon: approx. 1 year)
- Long-term supplier contracts (sometimes over two years)
- Gather experience and information
- In the event of unforeseeable events: react quickly and secure delivery

- Warehousing (special problem with soldering tin HMI: have an expiry date and therefore cannot be stored without restriction)

Gathering experience and developing a “gut feeling” about which components are critical and how to respond to an acute procurement bottleneck are very important. It is often not possible to change suppliers because some of the components have very specific functions and must comply with safety-relevant standards. In addition, a shortage of raw materials usually affects all suppliers, which makes it even more difficult to switch.

Framework

The use of certain hazardous substances in electrical and electronic equipment is restricted by the RoHS directive (Restriction of the Use of Certain Hazardous Substances) of the EU. In Switzerland, the implementation of the REACH regulation (Registration, Evaluation, Authorization and Restriction of Chemicals) is being monitored. REACH regulates the safe production and use of chemical substances in the EU and in the EEA countries.

Material efficiency and recycling

The company strives to always be at the cutting edge of technology. However, the material efficiency depends heavily on the component under consideration. Basically there is potential for savings. For example, simpler parts can be combined into a more complex component, which means that less material is used overall. However, there is sometimes a trade-off between more efficiency and less risk.

Electronic manufacturing waste (mainly cable waste) and machines returned by customers are given to a company that sorts and disposes the waste. Individual components are recovered.

2.2.2 Pilot SMEs 2

Company description

The company with headquarters in Zurich and the USA is a global company in bearingless engine technology. The basic principle of a bearingless electric motor was developed between 1987 and 1994 by a research project by ETH Zurich. As a result, the company was founded in 2001 as a spin-off. Based on the principle of magnetic levitation, the company has developed a bearingless centrifugal pump for

- the semiconductor industry, for pumping very pure, sometimes aggressive liquids (semiconductor pumps);
- the medical and pharmaceutical industry (disposable pumps)

In total, the company employs around 80 people, including from the fields of electrical engineering, physics and mechatronics, with around 50 working in Zurich. More than 50% of the employees work in research and development, followed by 20% in production, 10% in sales and the rest in logistics and administration.

Capacity for innovation

Due to the high level of commitment to research and development (23% of turnover), the company has a high level of innovation (80-100 points, on a scale of 0-100). In the past five years, the company has created 14 patent families with 50-60 individual patents. Cooperation with universities is very central and goes beyond the Swiss borders. A total of six universities work together (e.g. ETH Zurich, ZHW, University of Linz), with most projects arising in connection with a doctoral thesis. This connection with research is of great importance for the company, because it can maintain contact with students and potential employees and the universities also have important infrastructures (laboratory, equipment, etc.).

Value chain and raw material situation

The company manufactures two main classes of pumps - semiconductor and disposable pumps. The average material cost is 30-40%, which varies depending on the product. The value of a pump is also very different and ranges from CHF 2,000 to CHF 15,000. Semiconductor pumps account for approximately 85% of turnover and are therefore of greater importance to the company than life science pumps (semiconductors: 100 points; life science: 50 points, on a scale of 0-100).

Value chain

Figure 6 illustrates the company's simplified value chain.

The metals neodymium, dysprosium, samarium and cobalt are used in the imported magnets to manufacture the pumps. The composition differs depending on the temperature of the liquids for which the pumps are used. The usual proportion of a magnet is 32% neodymium, 3% dysprosium, 0.5% boron and the rest consists of iron. A total of 2.2 t of neodymium, 200 kg of dysprosium, 20 kg of samarium and 15 kg of cobalt are used per year.

Figure 6: Simplified value chain of pilot SME 2.

The magnets are purchased from two suppliers based in Germany and China. China has a market share of approx. 90% as a supplier of magnets, which gives the country great market power. Other components, such as the engine and plastics are supplied by Swiss companies, but most of their materials are also sourced from China.

Pilot-KMU 2 produces the impellers of the pumps, develops the necessary software, finally assembles the pumps and tests them. The pumps are manufactured exclusively in Switzerland. The pumps are then used as a standard product or are customized, in the semiconductor industry as well as in the medical and pharmaceutical industries.

Experience with shortage of raw materials

China's high market power poses a supply risk for the company. In 2011, China took advantage of its monopoly position, which led to a sharp increase in the price of neodymium. The price of a magnet has increased six-fold within six months. After that, the price bubble collapsed and the magnet price dropped back to normal levels. Neodymium is usually only about 1-2% of the company's cost. In the peak phase, however, these rose to around 6%.

This example shows that the problem of scarcity is not only due to a physical shortage of metals, but is also largely political and economic. The company estimates the risk due to geopolitical and economic conditions to be much higher than the risk of resource-related scarcity. Semiconductor pumps are less sensitive to fluctuations in the magnet price compared to disposable pumps.

Strategies for securing raw materials

The company is very innovative and can react well to changing framework conditions. A problem mainly arises when the change in the raw material situation occurs very quickly and adjustment options are not possible in time. The company uses three main strategies to secure the magnet inventory:

- Warehousing (with a range of approx. 1.5 years)
- Ongoing clarifications and obtaining information about the raw material situation
- Research to optimize and redesign the pumps: A project is currently being run with a university that is trying to manufacture disposable pumps without magnets.

Framework

There are two main problems with the current framework:

- Switzerland provides little help in securing raw materials for industry compared to other countries. The direction is there, but there is a lack of concrete action. The company is considering a long-term relocation of production to improve the raw material situation for the company.
- A second problem is the legal obligation to provide proof of origin in the form of certificates that confirm where and under what conditions the raw materials used are mined. This political pressure is very difficult for a small company like the pilot SME 2 to transfer to their suppliers and access to this information is very time-consuming. This problem exists particularly for cobalt.

Material efficiency and recycling

Defective and old pumps can be returned to the company by customers. There, they are checked and then disposed together with the production waste. A recycling system is currently not an issue for two reasons. On the one hand because the raw material price is too low and recycling is not economically worthwhile, and on the other hand because the recovery of the raw materials from the pumps is industrially very complex. Life science pumps can only be used once for hygiene reasons and must be disposed afterwards. Cleaning these pumps would involve a great deal of effort and the fear of “biohazards” is too great.

However, saving material during production is an ongoing topic that is particularly subject to cooperation with universities.

Particularities about the corporate risk

Since the company faces no direct competition, it has the advantage that short-term price fluctuations of the magnets can be passed on to customers (80 points, on a scale of 0-100). In the long term, however, there is a risk that customers will switch to other technologies and thus be lost completely. In addition, the company has two other special features that increase the company risk due to the scarcity of raw materials:

- The company relies on the production of the bearingless pumps and thus on the use of magnets (meaning 100 points, on a scale of 0-100). The loss of a delivery loss in sales would be 100% in the long term and the company could not remain in its current form. Costs as high as in 2011 would not be bearable in the long term.
- The magnets used can only be substituted with difficulty (5 points, on a scale of 0-100), since other magnets have a lower energy density and are therefore not suitable for use in bearingless pumps.

2.2.3 Pilot SME 3

Company description

Pilot-KMU 3 was founded in 2005 as a spin-off company from the Laboratory for Solid State Physics at the Swiss Federal Institute of Technology in Zurich (ETH Zurich). It produces flexible thin-film solar modules using CIGS thin-film technology and employs 20 people.

The production process enables a tailor-made design of the photovoltaic modules in various sizes and electrical performance features for the following areas of application:

- Building-integrated photovoltaics (BIPV) for roofs and facades
- Mobile devices such as mobile phones, laptops, bags and other devices
- Vehicles such as cars and ships

The solar modules are manufactured using a roll-to-roll coating process. The deposition of the light-absorbing CIGS compound semiconductor (CIGS: copper gallium indium selenide) is a key criterion of the coating technology.

Capacity for innovation

The company's ability to innovate is rated relatively high at around 90 points (on a scale of 0-100). Since the company is in development, 100% of turnover are also used in research and development. Cooperation with universities supports this.

Value chain and raw material situation

The value chain of pilot SME 3 is illustrated in a simplified form in Figure 7.

Figure 7: Simplified value chain of pilot SME 3.

The critical metals indium and gallium are used in the production of flexible solar modules. The annual requirement of these metals is approximately 3000 kg per year. These metals are used directly in production. Indirectly (e.g. contained in aids), no rare metals are used.

The company's suppliers come from all over the world. According to USGS (2010), China is currently the world's largest provider of primarily refined indium with around 300 tons or 51 percent of the world market, followed by South Korea, Japan, Canada, Belgium, Peru, Russia and other countries such as the USA, Germany, and the Netherlands or Great Britain.

The production of flexible solar modules is the company's core business and is therefore of great importance for the company's strategy (100 points on a scale of 0-100). The loss on production downtime is 100%.

The material costs make up about 75% of the production costs (for mass production).

The company supplies wholesalers of solar panels (B2B shops, OEM) internationally. End customers are in the areas of building construction, electronics and transport. The solar energy market has been in a difficult situation since 2011 due to global overcapacity. The company's direct competitors (mainly from the USA and Germany) are trying to cover niche markets or are going bankrupt.

There is currently no recycling system. Technically speaking, the products can be introduced into the recycling system of flat screens.

Particularities about the corporate risk

In connection with the business risk due to the shortage of rare metals, the pilot SME 3 has the following special features:

- The possibility of substituting the manufactured product or individual elements is hardly available (2 points on a scale from 0-100) and is hardly suitable (also 2 points). There are no substitutes immediately available.
- Price increases of rare metals can be completely passed on to the customer (100 points, on a scale from 0-100). The rare metals used make up only a small share of approx. 5% of the product costs of flexible solar modules or approx. 2.5% based on the installed product costs.
- So far, the company has no experience with shortages of metals. Accordingly, no strategies for securing raw materials are currently being pursued (also no warehousing). There are no special legal framework conditions.
- No material saving measures have been implemented so far. There is still potential for material efficiency.

If the criticality was assessed for a specific year, this would have to be done for 2017.

2.2.4 Summary and implication for the electronic tool

Following the description of the three case studies, there is an overview of the data inventories collected, which form the basis for the following criticality assessment (see Table 2). In addition, we summarize the key findings for the later development of the electronic tool in an interim conclusion. This mainly relates to the knowledge base gained (data basis), but also to suggestions from companies on the structure and content of the tool.

WHAT		PILOT-SME 1		PILOT-SME 2		PILOT-SME 3	
METAL USE IN SME		**Metal**	**Quantity (kg/a)**	**Metal**	**Quantity (kg/a)**	**Metal**	**Quantity (kg/a)**
		Neodymium	-	Neodymium	2‘200	Indium	1‘500
		Dysprosium	-	Dysprosium	200	Gallium	1‘500
		Samarium	-	Samarium	20		
		Cobalt	-	Cobalt	15		
		Niobium	-				
		Antimony	-				
		Tantalum	-				
		Indium	-				
		Gallium	-				
SUPPLY RISK		The companies hardly have any information on supply chains for the metals used (countries / regions / companies from extraction to delivery of raw materials and semi-finished products). Accordingly, the methodology will be limited to those areas for which it is possible to make a statement based on robustly available data sources.					
SUSCEPTIBILITY SME							
Strategic Importance	Adverse effect on turnover	80/100		100/100 85/100 (SC-pump) 15/100 (Disposable-pump)		100/100	

	Transfer of additional costs to customers	0/100 (big competition and cost pressure)	80/100	100/100
	Importance business	80/100	SC-pumps: 100/100 Disposable-pumps: 50/100	100/100
Substitutability	Availability substitutes	100/100	100/100	2/100
	Functionality substitutes	50/100	5/100	2/100
	Procurement costs substitutes			
Capacity for innovation	Measures material savings	60/100	80/100	90/100
	Potential material savings	0/100	5/100	20/100

Table 2: Resource inventories for the three pilot SMEs (the data and information from the companies are shown, which are used as input values in the criticality assessment.

The key findings from the analysis of the pilot SMEs for the electronic tool to be developed are briefly summarized below:

Knowledge about the use of rare metals	Knowledge within the SMEs of the used rare metals is limited. As soon as the metals are not purchased in their elementary form (e.g. gallium and indium in pilot SMEs 3) but as part of semi-finished products or finished products, the companies can provide little or no information about the type and amount of rare metals (cf. Pilot SME 1). IMPLICATION FOR ELECTRONIC TOOL: For a resource check tool to be used broadly and effectively in the corporate landscape, it must be possible to derive a statement on the rare metals used based on operating information on related semi-finished products (building parts, components, sub-components) or products.
Transparency value chain	As the analysis of pilot SMEs 1 and 2 have shown, the value chains are not or little transparent: • Location of raw material extraction: It is difficult or impossible to draw any conclusions about the country and region of the excavation site for raw material extraction. • Geographical and company-specific information on the intermediate stages (raw material refinement, manufacture of subcomponents, components, components; trade / intermediate trade) is, if at all, only incomplete (i.e. mostly only for the direct supplier). IMPLICATIONS FOR ELECTRONIC TOOL: The integration of supply and value chain characteristics in the resource check seems difficult due to the lack of information in the companies and the lack of data bases. Partially however, e.g. for the extraction of raw materials, there is reliable data that can be used for the electronic tool (e.g. information on world annual production in different countries, on natural frequencies, on by-products in mining, on demand development).

3 Criticality rating

Metals are vital for modern society. The number of metals used in products and services has increased steadily in recent years as a result of technological innovations. Many (geochemically) rare metals[1]) are indispensable for future technologies such as information and communication technology or renewable energy production, which is why a significant increase in the mining, processing and use of these metals is expected. Accordingly, questions about availability and sustainability in dealing with these metals have come to the fore.

In 2006, the U.S. National Research Council conducted a study to identify "critical" minerals and highlighted the importance of these minerals for the U.S.A. (National Research Council 2008). Since then, many more studies on the criticality[2]) of raw materials have been carried out, which differ from each other both in the area of investigation and in the methodology

[1] Metals, whose average mass fraction in the earth's crust is less than 0.01 mass% (Skinner, 1979).
[2] According to EC (2010), a raw material is considered "critical" if the supply risk and the potential effects of a supply shortage are higher than those for other raw materials.

(Erdmann and Graedel 2011). A study commissioned by the European Commission "Enterprise and Environment" identified 14 out of 41 raw material (groups) examined as critical for the European economy (European Commission 2010). In the study updated in 2014, 20 out of 54 raw material (groups) examined were identified as critical (European Commission 2014).

Only a few of these studies have so far related to the company level. One of them is the study by General Electric (GE) (Duclos, Otto et al. 2010), whose main aim was to identify materials that are at risk of supply shortages or price increases. For this purpose, the method for assessing criticality, which had been developed by the National Research Council, was specified for the specific case. The GE study covers a subset of 11 from a total of 24 elements selected based on the purchase value; the specific risks (sub-risks in the study) are determined both quantitatively and qualitatively.

Tom Graedel's research group at Yale University is currently developing a generic, predominantly quantitative method for assessing criticality on three levels: global, national and corporate. The method for assessing criticality at company level contains a large number of indicators, which have not yet been tested for any specific case. It is data-intensive and requires extensive background research.

3.1 Method of criticality assessment

The development of the method for assessing the risks and scope of the use (criticality) of rare metals in companies was based - in addition to the findings from the analysis of the pilot SMEs (see Chapter 2.2) - on existing approaches to criticality assessment of raw materials in companies, in particular Duclos et al. (2010). The two valuation approaches by General Electrics (Duclos et al., 2010) and the aforementioned research group at Yale University (Graedel et al., 2012) were combined in such a way that an assessment can be implemented and interpreted with a reasonable effort for companies and at the same time, the criticality is recorded as comprehensively and quantitatively as possible.

The resulting method of criticality assessment is described below. Subsection 3.1.1 illustrates the assessment framework, i.e. the question of what is valued, while subsection 3.1.2 illustrates the operationalization for valuation, i.e. the question of how to evaluate.

3.1.1 Assessment framework

The criticality was differentiated using a multi-criteria approach and operationalized for the evaluation. The resulting assessment framework consisting of dimensions, corresponding aspects and indicators is shown in Table 4.

A total of four dimensions are distinguished in the assessment. In line with all current approaches to assessing the criticality of raw materials (at company and also economic level), these are on the one hand the two dimensions "supply risk" and "vulnerability of the company to supply shortages". The former describes the risk of physical (i.e. quantity-related) as well as price-related supply restrictions of a certain metal, while the latter includes the sensitivity of the company to the occurrence of supply restrictions. These dimensions, which are directly related to the operation turnover, are supplemented by the (sustainability) dimensions of "environmental pollution" and "social effects", which as "reputational risks" are also important from a business perspective. While the environmental impacts are taken into account in the Yale University method as the third dimension, the social impacts were added as the fourth dimension due to the project specifications, but also the relevance of this dimension in the RESCHECK project.

All four dimensions are differentiated and described on the basis of so-called criticality aspects, which in turn can be operationalized or assessed using indicators. The evaluation method comprises a total of ten different criticality aspects or 19 indicators for evaluating the aspects across all four dimensions.

DIMENSION	ASPECT	INDICATOR
Supply risk (D1)	Natural frequency (A1.1)	Mass fraction earth crust (I1.1.1)
	Country dependency (A1.2)	Mining Concentration (I1.2.2)
		Policy Potential Index (I1.2.3)
	Coupled production (A1.3)	Main- vs. co-product/ by-product (I1.3.4)
		Economic Importance of co-product (I1.3.5)
	Demand (A1.4)	Global demand trend (I1.4.6)
	Price volatility (A1.5)	Relative price fluctuations (I1.5.7)
Business susceptibility(D2)	Strategic importance (A2.6)	Adverse effect on turnover (I2.6.8)
		Transferability of additional costs (I.2.6.9)
		Importance to the business (I2.6.10)
	Substitutability (A2.7)	Availability of substitutes (I2.7.11)
		Functionality of substitutes (I2.7.12)
		Procurement costs of substitutes (I2.7.13)
	Capacity for innovation(A2.8)	Importance of making savings in the use of materials (I2.8.14)
		The potential for making savings in the use of materials(I2.8.15)
Environmental impact (D3)	Environmental impact (A3.9)	Ecosystems (I3.9.16)
		Human health (I3.9.17)
Social impact (D4)	Social conflict potential (A4.10)	Conflict mineral (I4.10.18)
		Corruption (I4.10.19)

Table 3: Framework of the multi-criteria method for criticality assessment in companies (assessment dimensions with corresponding aspects and indicators).

3.1.2 Description of the valuation approach

When evaluating a metal, the underlying indicators for each criticality aspect are quantified and then transferred to a five-level ordinal scale, which represents different risk categories. At the one end of the scale, the value 1 stands for "uncritical" and at the other end the value 5 stands for "highly critical". The risk assessment is based on an assessment of the SMEs concerned (for context-dependent measures) as well as on publicly available data (for context-independent measures).

Detailed explanations of the indicators and their transfer into the five risk categories of the relevant criticality aspect can be found in the following subchapters on the individual criticality dimensions.

Supply risk (D1)

As can be seen from Table 4, the supply risk is depicted via five criticality aspects, which are operationalized using a total of seven indicators for the assessment. These are exclusively dependent on the metal to be assessed and not on company-specific characteristics. Accordingly, the determination of the risk categories is based on publicly available information and data bases.

Natural Frequency (A1.1)	Geological frequency of the metal in the earth crust				
INDICATORS					
Concentration in the earth's crust (I1.1.1)	Average concentration of the metal in the earth's crust (in ppm)				
RISK-CATEGORIES	**1**	**2**	**3**	**4**	**5**
	> 10'000	100–10'000	1–100	0.01–1	< 0.01
BASICS	Wedepohl (1995)				
CRITICALITY REFERENCE	The rarer a metal is present in the earth's crust, the higher the risk of supply restrictions[3].				

Dependence on certain countries (A1.2)	Dependence on the supply of the metal from producer countries
INDICATORS	
Mining Concentration (I1.2.2)	Distribution of global annual production across individual producing countries (in %)
Policy Potential Index (I1.2.3)	The extent to which the general political conditions in mining countries are attractive to investment in metal production (0-100)

[3] The geological frequency of a metal in the earth's crust is only of limited use as an indicator for assessing the availability of a metal (see e.g. Graedel & Reck, 2015), but was provisionally used due to the lack of a viable alternative.

RISK-CATEGORIES	**1**	**2**	**3**	**4**	**5**
	< 20% Mining in countries with PPI < 50	20–40% Mining in countries with PPI < 50	40–60% Mining in countries with PPI < 50	60–80% Mining in countries with PPI < 50	> 80% Mining in countries with PPI < 50

BASICS

Du et al. (2011), European Commission (2014), Nassar et al. (2015), United States Geological Survey (USGS, 2012a)

Annual Survey of Mining Companies des Fraser Institute (Fraser Institute, 2013)

CRITICALITY REFERENCE

The fewer countries that mines a metal or the more unstable the political framework conditions in the producing countries, the higher the likelihood of physical and price-related supply restrictions.

Co-production (A1.3) Mining of metal as the main product, co-product or by-product in the mining of other metals

INDICATORS

Main- vs. co-product/ by-product (I1.3.4) — Dependency of the mining of the metal on the supply of other metals (% co-production)

Economic Importance of co-product (I1.3.5) — The economic importance of the co-produced metal compared to other metals contained in the ore (price ratio co- vs. main product)

RISK-CATEGORIES	**1**	**2**	**3**	**4**	**5**
	Rare metal as main product (0% co-production)	0–10% co-production	10–50% co-production	> 90% co-production and price ratio > 1 or 50-90% co-production	> 90% co-production und price ratio < 1

BASICS

Nassar et al. (2015)

United States Geological Survey (USGS, 2010 und 2011)

CRITICALITY REFERENCE

The more the mining of a rare metal depends on the mining of other metals as the main product or the more marginal the economic importance of the co-mined metal, the higher the supply risk for it due to economic dependencies.

Demand (A1.4) The trend of global demand for the metal

INDICATORS

Trend in global demand (I1.4.6) — Expected change in demand for the metal due to increased production of existing applications and / or new applications (increase in production in the last 5 years in%)

RISK-CATEGORIES	**1**	**2**	**3**	**4**	**5**
	< 0%	0–1%	1–5%	5–10%	> 10%

BASICS

Du et al. (2011), European Commission (2014), Nassar et al. (2015), United States Geological Survey (USGS, 2012b)

CRITICALITY REFERENCE	The higher the future demand for a rare metal (in existing and also new applications), the higher the risk of a physical and / or price restriction for the company due to the increasing competition.

Price volatility (A1.5)	Volatility of the world market price of the metal				
INDICATORS					
Relative price fluctuations (I1.5.7)	The range of relative fluctuations in the price of the metal over the past 5 years (in %)				
RISK-CATEGORIES	**1**	**2**	**3**	**4**	**5**
	< 50%	50–100%	100–200%	200–500%	> 500%
BASICS	United States Geological Survey (USGS, 2010, 2011)				
CRITICALITY REFERENCE	The more volatile the metal prices, the higher the risk of a price restriction for the company.				

SME sensitivity (D2)

The sensitivity of SMEs to supply restrictions is recorded using three criticality aspects, which are operationalized using a total of eight indicators for the assessment (see Table 3). In comparison to the other three dimensions, these criticality aspects depend on the specific operational characteristics or structures. Accordingly, the determination of the risk categories is based on information and assessments of the respective company.

Strategic Importance (A2.6)	Importance of the availability of the metal in relation to the corporate strategy				
INDICATORS					
Adverse effect on turnover (I2.6.8)	Adverse effect on turnover due to a restricted supply of the metal (in%)				
RISK-CATEGORIES	**1**	**2**	**3**	**4**	**5**
	Insignificant	Viable	Barely viable	Significant	Very significant
The ability to pass on additional costs (I2.6.9)	The possibility to pass on increased procurement costs of the metal to customers				
RISK-CATEGORIES	**1**	**2**	**3**	**4**	**5**
	Yes, also medium term	Yes, but only short term	Limited, also medium term	Limited, only short term	No, neither short term
The importance to the business (I2.6.10)	The Importance of the metal in relation to the corporate strategy				
RISK-CATEGORIES	**1**	**2**	**3**	**4**	**5**
	Insignificant	Little significance	Medium significance	Significant	Very significant
BASICS	Information and assessments of the respective company				

CRITICALITY REFERENCE The more important a metal is for a company from a turnover-related and strategic point of view, the more vulnerable the company is when supply restrictions occur.

Substitutability (A2.7) Possibility to replace the critical metal or semi-finished product which contains this metal by an alternative raw material or semi-finished product.

INDICATORS

Availability of a substitute (I2.7.11) The presence of an alternative raw material or semi-finished product to replace the critical metal or semi-finished product containing it.

RISK-CATEGORIES

1	2	3	4	5
Yes, no problem	Yes, usually	Yes, but limited	Only in exceptional cases	No, not at all

The substitute's functionality (I2.7.12) Suitability of the alternative metal or semi-finished product for product manufacture

RISK-CATEGORIES

1	2	3	4	5
Significantly better	Slightly better	Comparable	Slightly worse	Significantly worse

The substitute's procurement costs (I2.7.13) The cost of procuring the alternative metal or semi-finished product compared i the original

RISK-CATEGORIES

1	2	3	4	5
Significantly lower	Slightly lower	Comparable	Slightly higher	Significantly higher

BASICS Information and assessments of the respective company

CRITICALITY REFERENCE The worse a rare metal can be replaced by an alternative (metallic) raw material for a use, the more critical the supply restriction becomes for the company or the more extensive the negative effects are.

Capacity for innovation(A2.8) Operational adaptability to reduce metal dependency

INDICATORS

Importance of making savings in the use of materials (I2.8.14) Significance of measures to reduce the dependence of the critical metal through material savings (e.g. alternative product design, minimization of production waste).

RISK-CATEGORIES

1	2	3	4	5
Very central	Significant	Yes, but limited	Subordinate	No significance at all

The potential for making savings in the use of materials(I2.8.15) Operational potential for savings in the need for critical metal or semi-finished products containing it.

RISK-CATEGORIES

1	2	3	4	5
Very extensive	Extensive	Significant	Moderate	Very little

BASICS Information and assessments of the respective company

CRITICALITY REFERENCE	The more innovative a company deals with material savings or the greater the potential for material savings, the lower the dependency on raw materials and thus the susceptibility to the occurrence of a supply restriction.

Environmental impact (D3)

The environmental impact is described using a criticality aspect, the risk category of which is determined taking two indicators into account (see Table 3). This depends exclusively on the metal to be assessed and not on company-specific characteristics. Accordingly, the determination of the risk categories is based on publicly available information and data bases.

Total environmental impact (A3.9)	Environmental impact of the production of critical metals (cradle-to-gate perspective), without the two midpoints «Mineral resources» and «Fossil resources» or the endpoint «Damage to resource availability, because this is considered in the dimension« supply risk ».				
INDICATORS					
Ecosystems (I3.9.16)	The adverse effect on ecosystems due to the extraction of the metal (endpoint of the LCIA method ReCiPe 2008, V1.10)				
Resource Consumption	The risk of resources of metals becoming scarce				
Human health (I3.9.17)	The adverse effect on human health by the extraction of the metal (endpoint of the LCIA method ReCiPe 2008, V1.10)				
RISK-CATEGORIES	**1**	**2**	**3**	**4**	**5**
	< 20 points	20–39 points	40–59 points	60–79 points	> 80 points
BASICS	Graedel et al. (2015)[4]				
CRITICALITY REFERENCE	The greater the environmental damage associated with metal extraction, the higher the company's reputational risk.				

Social impact (D4)

The social impact is described via a criticality aspect, the risk category of which is determined taking two indicators into account (see Table 3). This depends exclusively on the metal to be assessed and not on company-specific characteristics. Accordingly, the determination of the risk categories is based on publicly available information and data bases.

The potential for conflict l (A3.9)	The potential for societal conflicts due to extracting the metal
INDICATORS	
Conflict mineral (I4.10.18)	Extraction of the metal in conflict regions or not in conflict regions
Corruption (I4.10.19)	Perceived corruption in metal-producing countries (Corruption Perception Index)

[4] The inventories for rare metals contained in the ecoinvent database (www.ecoinvent.ch), on which Graedel et al. (2015) are currently undergoing a comprehensive revision by Empa on behalf of the FOEN.

RISKO-KATEGORIEN	**1**	**2**	**3**	**4**	**5**
	0–20% in corrupt countries (CPI < 50)	20–40% in corrupt countries (CPI < 50)	40–60% in corrupt countries (CPI < 50)	60–80% in corrupt countries (CPI < 50)	> 80% in corrupt countries (CPI < 50) or conflict mineral
BASICS	Du et al. (2011), European Commission (2014), Nassar et al. (2015), United States Geological Survey (USGS, 2012a) Corruption Perception Index (CPI) by Transparency International (2013)				
CRITICALITY REFERENCE	The contribution to social conflicts associated with the extraction of metallic raw materials harbors significant reputational risks for companies and can therefore be classified as critical.				

Aggregation of results

To be able to make a statement about the criticality at the level of the four dimensions, the evaluation results (i.e. risk categories) of the individual criticality aspects are aggregated. The risk category of a dimension was determined from the mean of the equally weighted risk categories of the criticality aspects contained in this dimension. In terms of further development, it would be conceivable to have the weighting factors for the individual criticality aspects individually determined by the company in order to incorporate company-specific prioritizations of the various aspects into the evaluation.

From metals to semi-finished products

As mentioned at the beginning of this subchapter, the method is designed for the criticality assessment of a single metal. However, the analysis of the pilot SMEs has shown that Swiss companies often purchase the rare metals as part of semi-finished products and do not know the metals contained therein, or only partially. For this reason, an additional module was developed within the scope of the present project, which allows the application of the developed evaluation method for semi-finished products, so that the practical tool to be developed can be applied to and used by the broad corporate landscape.

On the one hand, this includes an upstream component, which generates information on the metals it contains based on information on semi-finished products. For this purpose, the metallic composition was specified for selected semi-finished products (42 in total) by evaluating various literature bases. The criticality is then calculated for each metal contained in a semi-finished product using the evaluation method. A second additional component aimed to convert the criticality assessment of several metals contained in a semi-finished product into a criticality statement for the entire semi-finished product. For this, the highest risk category is selected for each criticality aspect from all the metals contained in the semi-finished product, i.e. the semi-finished product is as critical as the metal which is most critically assessed in the respective aspect.

3.2 Application to the pilot SMEs

The first application of the presented method for criticality assessment in the three pilot SMEs is based on information that was specifically collected in three companies using the questionnaire developed for the situation analysis (see Chapter 1). The corresponding results for a total of 10 metals or 5 semi-finished products or products containing them are summarized in a table in the following subchapters for each of the four criticality dimensions.

3.2.1 Supply risk

Table 3 shows the supply risk with corresponding criticality aspects for the pilot SMEs examined. At first glance, a relatively similar assessment pattern emerges about the various aspects of the supply risk in the three pilot SMEs examined. It is also noticeable that the overall supply risk for none of the 10 metals was classified as low or very low. In addition, the risk categories of all aspects for all semi-finished products are at least 3.

In all three companies, the dependence on countries that produce or produce the metals required for production was consistently the most critically assessed. Eight of the ten metals and all semi-finished products or products are assigned the highest risk category 5. With the exception of indium and molybdenum, which are obtained to a significant extent in politically stable countries (risk category 3), the predominant share of global annual production (> 80%) is promoted in politically unstable countries with a high geographic concentration. For example, in 2012 around 97% of the rare earth metals required for the magnets (neodymium, dysprosium, samarium in pilot SMEs 1 and 2) came from Chinese mines, around 85% of the gallium from China (pilot SMEs 1 and 3) or around 90% of tantalum from Brazil, Burundi, China, Congo, Ethiopia, Mozambique, Nigeria, Rwanda and Somalia (pilot SME 1). These extensive dependencies on unstable extraction countries pose a significant cluster risk, which is reflected negatively in the criticality assessment.

Overall, the forecast increase in demand is also critical for the three pilot SMEs, which is expected to intensify competition and price pressure for purchasing companies in the future and a corresponding decrease in security of supply. Compared to the country dependency, the risk categories vary greatly between the individual elements. For rare earths and cobalt or gallium, annual growth in demand of approximately 10% (neodymium, samarium, cobalt) or more than 10% (dysprosium) is assumed, which is why they are assigned risk categories 4 and 5. In contrast, a negative growth rate is assumed for other metals (antimony, tantalum) (i.e. risk category 1). The evaluation results of the other metals are in risk categories 2 and 3. Due to the fact that the evaluation of the semi-finished or finished products corresponds to the maximum of the evaluation of the metals contained therein, all semi-finished or finished products of the three companies are rated as highly critical from the perspective of foreseeable Demand developments.

SEMI-FINISHED PRODUCTS AND METALS	NAT. FREQUENCY	COUNTRY DEPENDENCY	COUPLED PRODUCTION	DEMAND	PRICE VOLATILITY	D1 AGGREGATED
Pilot SME 1						
MAGNET (MOTOR)	3	5	4	5	4	4
Dysprosium	3	5	4	5	4	4
Neodymium	3	5	4	4	4	4
PLC & HMI	4	5	4	5	3	4
Antimony	4	5	4	1	3	3
Gallium	3	5	4	5	3	4
Indium	4	3	4	3	2	3
Molybdenum	3	3	3	3	2	3
Niobium	3	5	2	2	3	3
Tantalum	3	5	3	1	3	3
Pilot SME 2						
MAGNET (MOTOR)	3	5	4	5	4	4
Dysprosium	3	5	4	5	4	4
Cobalt	3	5	4	4	3	4
Neodymium	3	5	4	4	4	4
Samarium	3	5	4	4	4	4
Pilot SME 3						
FLEXIBLE THIN-LAYER-PV	4	5	4	5	3	4
Gallium	3	5	4	5	3	4
Indium	4	3	4	3	2	3

Table 3: Criticality assessment of the three pilot SMEs for the dimension "supply risk".

The aspect of coupled production is medium critical to critical in relation to all ten metals analyzed in the pilot SMEs. The only exception is niobium (risk category 2), which occurs in various economically important oxide minerals. At the same time, the proportion that is linked to the extraction of other metals is negligible, i.e. niobium is largely obtained as the main product. Although many of the ten metals (i.e. gallium, indium, neodymium, dysprosium, cobalt, antimony, samarium) are extracted to a very high degree as a co-product (at least 85% for cobalt to 100% for example for indium or neodymium), they are in risk category 4 due their high economic importance compared to the respective host metals and not in the highest risk category. This is also due to the fact that the prices of these metals have risen since 2000 due to rapidly increasing applications. In contrast, molybdenum and tantalum are classified as medium critical (risk category 3). Molybdenum is found both as the main metal in deposits and as an associated metal sulfide in copper deposits (USGS 2012) with a comparatively low proportion of co-production, while tantalum is the driver for the mining of a number of important minerals due to its economic importance, or the mining of tantalum less depends on the mining of other metals contained in the ores.

The natural frequency or geological scarcity and price volatility are of medium criticality in the supply risk. None of the 10 metals has the highest risk category 5, i.e. none of the 10 metals used in the three SMEs is neither very rare nor extensive in geological terms. The risk categories range between 3 and 4. At the lower end of the spectrum, metals such as antimony, indium, molybdenum, tantalum and dysprosium (0.1–5 ppm) move, while elements such as cobalt, neodymium and niobium are relatively common (19–27 ppm) and are therefore less critical. Price volatility over the past five years has been in the range of 50–100% (risk category 2), 100–200% (risk category 3) and 200–500% (risk category 4) for all metals. The smallest price differences were found for indium and molybdenum (57% and 53%), the most significant for rare earth metals (367% for neodymium, 370% for dysprosium, 476 for samarium). Accordingly, both companies, which rely on high-performance permanent magnets in their electric drives, are most exposed to price risks.

3.2.2 Company susceptibility

Table 4 shows the results of the criticality assessment for the dimension "company susceptibility". It shows the risk categories for all metals used in the three pilot SMEs and semi-finished products containing these metals. The aspects capture the sensitivity of the company in the event of supply restrictions and the evaluations are based accordingly on the company's estimates (in comparison to the other dimensions, in which the evaluation of the aspects depend purely on the metals used).

SEMI-FINISHED PRODUCTS AND METALS	STRATEGIC IMPORTANCE	SUBSTITUTABITY	CAPACITY FOR INNOVATION	D2 AGGREGATED
Pilot SME 1				
MAGNET (MOTOR)	5	2	4	4
Dysprosium	5	2	4	3
Neodymium	5	2	4	4
PLC & HMI (cf. 1)	5	2	4	4
Antimony	5	2	4	4
Gallium	5	2	4	4
Indium	5	2	4	4
Molybdenum	5	2	4	4
Niobium	5	2	4	4
Tantalum	5	2	4	4

Pilot SME 2				
MAGNET (MOTOR)	4	3	3	3
Dysprosium	4	3	3	3
Cobalt	4	3	3	3
Neodym	4	3	3	3
Samarium	4	3	3	3
Pilot SME 3				
FLEXIBLE THIN-LAYER-PV	4	5	3	4
Gallium	4	5	3	4
Indium	4	5	3	4

Table 4: Criticality assessment of the three pilot SMEs for the dimension "company susceptibility".

At first glance, the assessments of the three criticality aspects differ relatively strongly between the three pilot SMEs. In pilot SMEs 1, the strategic importance of the metals or semi-finished products containing them is rated as highly critical, while in the other two companies (pilot SMEs 2 and 3) they are assigned a risk category of 4. When looking at the indicators on which the aspect is based, it is noticeable that the main difference in ratings between pilot SMEs 1 and the other two companies is due to different product niches. The manufactured technical solutions for the graphic arts industry in pilot SME 1 are exposed to strong competition and accordingly there is no possibility to pass on additional costs in the raw material or semi-finished product procurement to the product prices. In contrast, pilot SMEs 2 and 3 are highly specialized as spin-offs from research institutions and their products are largely unique on the market due to their innovative and highly functional nature, which means that additional costs in raw material procurement can be passed on to customers at least in the short term. Based on the adverse effect on turnover in the event of non-availability and the importance for the corporate strategy, all three or all of the semi-finished products containing these metals were rated as highly critical by all three pilot SMEs.

Significant differences in the ratings can be seen in the possibility of substituting the metals or semi-finished products containing them (risk category 2 for pilot SMEs 1, 3 for pilot SMEs 2 and 5 for pilot SMEs 3). The pilot SME 3 has no possibility of substituting indium or gallium, which are required to produce the copper indium gallium selenide modules (CIGS modules). No alternative materials are currently known for this application. In contrast, substitutes are available for the metals or semi-finished products of the other two companies, which means that substitution is theoretically conceivable. However, the substitutes known today (e.g. magnets for electric drives) do not have the same functional properties. For example, the permanent magnets equipped with rare earths (dysprosium, neodymium, samarium) for the electric drives can be replaced by alternative magnets. However, these have a lower magnetic flux density and would have to be correspondingly larger for the same magnetic properties, which - especially in the case of miniaturized applications such as pilot SME 2 - often involves adjustments to the product or production and the components required for this (e.g. housing) is connected, which cannot be implemented overnight and is difficult for companies due to the far-reaching adjustments required.

Furthermore, all three companies describe themselves as more or less innovative in order to reduce their dependence on critical metals by saving on material requirements. In the two pilot SMEs 2 and 3 such efforts are of great importance, while in pilot SMEs 1 they are only of medium importance, which makes the criticality assessment higher in this aspect. However, all three SMEs rate the open innovation potential as very low.

3.2.3 Environmental and social impacts

Table 5 clearly shows the results of the criticality assessment for the two dimensions "environmental impact" and "social impact". It shows the risk categories for all metals used in the three pilot SMEs and semi-finished products containing these metals.

SEMI-FINISHED PRODUCTS AND METALS	OVERALL ENVIRONMENTAL IMPACT	SOCIAL CONFLICT POTENTIAL
Pilot-SME 1		
MAGNET (MOTOR)	1	5
Dysprosium	1	5
Neodym	1	5
PLC & HMI (cf. 0)	2	5
Antimony	1	5
Gallium	1	5
Indium	2	3
Molybdenum	2	3
Niobium	1	5
Tantalum	2	5
Pilot SME 2		
MAGNET (MOTOR)	1	5
Dysprosium	1	5
Cobalt	1	5
Neodym	1	5
Samarium	1	5
Pilot SME 3		
FLEXIBLE THIN-LAYER-PV	2	5
Gallium	1	5
Indium	2	3

Table 5: Criticality assessment of the three pilot SMEs for the two dimensions "environmental impact" and "social impact".

In the dimensions of "environmental impact" and "social impact", a fundamentally similar picture emerges for all metals or semi-finished products and products used in the three pilot SMEs. While the overall environmental impact turns out to be less critical for all metals (i.e.

risk categories 1 to 2), with a few exceptions (indium, molybdenum) all metals are classified as highly critical.

For many of the metals considered, the main cause of the low environmental pollution is due to the fact that they are obtained as a co-product or even a by-product from the mining of significant industrial metals. Due to the economic allocation used in the life cycle assessment data to distribute the environmental pollution to the main or the co-products and by-products, the metals analyzed in the study are often only charged a comparatively small proportion.

Indium is a co-product of zinc production and the major part of the environmental impact is attributed to zinc and not to indium due to its economic importance (risk category 1).

Gallium is obtained as a by-product of aluminum production from bauxite using the Bayer process. Due to its by-product status, gallium is not assigned any environmental impact from the process in the life cycle assessment (risk category 1).

Cobalt is obtained from the reduction of gray and black cobalt oxide, which is produced during nickel production. Due to its co-product character and the low contribution to turnover compared to nickel, the environmental pollution allocated to cobalt is very low and therefore uncritical (risk category 1).

70% of the molybdenum is mined in the open-cast mine and 30% in the underground mine and then processed together to extract copper or molybdenite in a flotation process. Accordingly, molybdenum is shown in the life cycle assessment data as a co-product from the production of copper and is associated with comparatively low environmental impact (risk category 2).

Antimony is mined industrially mainly from the antimony-rich sulfide mineral stibnite (gray spit gloss) as the main product. Due to the less complex production process, which is mainly the high antimony content of the ores (up to 72% in stibnite and 92% in paradocrasite) also means that the environment is comparatively little affected (risk category 1).

Tantalum is obtained as a main product from tantalite ores and from slag from tin smelting as a by-product. In the present study, the production from tantalite ores was considered using the available life cycle assessment data. Accordingly, the environmental impact is a bit higher than for most of the metals already mentioned, but compared to other metals (e.g. rhodium or platinum group metals) it is still in the non-critical range (risk category 2).

The rare-earth metals (neodymium, dysprosium, samarium) are mined as co-products from bastnasite ores and extracted in the form of oxides. In the subsequent treatment process, the "mixed oxides" (e.g. samarium-europium-gadolinium oxide) are separated from each other and precipitated. The comparatively low environmental impact of rare earth metals (risk category 1) is mainly due to the large number of metals extracted from the ore. As a result, the environmental impacts from mining are distributed among various by-products.

As far as the social impact dimension is concerned, almost all of the metals used in the pilot SMEs are rated risk category 5 or highly critical. The only exceptions are the two metals indium and molybdenum (risk category 3). The reason for both metals is that a 40–60% share is obtained in politically relatively stable countries. For example, at Indium a significant proportion of the world's annual production comes from countries such as South Korea, Belgium, Canada, France and Japan; for molybdenum from countries such as the USA, Chile, or Canada. For the other metals used in the pilot SMEs (antimony, gallium, cobalt, niobium, dysprosium, neodymium, samarium), the world annual production is predominantly dominated by at least 80% of countries (risk category 5) in which the problem of Corruption is relatively common (i.e. CPI <50). For example, in the time horizon considered, over 97% of rare earths or about 85% of gallium extracted worldwide came from China (75%), Kazakhstan, Russia and Ukraine (the significant remainder 10%). In addition to the concentration of global annual production in “corrupt” countries, tantalum is classified as conflict mineral because part of the funding comes from conflict regions in the Democratic Republic of the Congo (risk category 5).

4 Options for action

4.1 Basis for SME resource strategy

In addition to the development of the methodology for evaluating the criticality of rare metals in companies, the next step is to develop the foundations for the development of an SME resource strategy. This is to enable targeted strategic recommendations for action to be derived depending on the evaluation results, so that companies can be shown tailored strategic modules for their resource strategy or the focus for in-depth review of strategies (e.g. supply chain management, increasing resource efficiency) in the electronic tool can be developed.

The development of these options for action was based on various foundations. On the one hand, operational measures to deal with supply risks and operational dependencies were also enquired about during the situation analysis of the use and handling of rare metals in the pilot SMEs. The resulting starting points were supplemented based on a literature search and the involvement of internal EBP experts. They were then structured, compared and described and delimited in terms of content.

This resulted in 18 options for action, which are linked to different points in the value chain and different criticality aspects. These are shown in Table 6, described and related to the different criticality aspects.

OPTIONS FOR ACTION	SUMMARY	ATTACKPOINT
Price hedging	Entering a hedging strategy to protect against uncertain price developments on commodity markets via a premium-based risk transfer, e.g. forward transaction.	A1.4–A1.5
Long-term supply agreements	Conclusion of long-term supply contracts ideally with raw material producing companies to secure the long-term procurement in case of uncertain developments on raw material markets.	A1.3–A1.5
Stockpiling	Expansion of storage capacities and increasing stocks of critical raw materials to bridge temporary supply bottlenecks or unsustainable raw material costs (especially for just-in-time manufacturing companies).	A1.4–A1.5
Supply chain transparency	Expanding the transparency of the supply and value chains of supply-relevant, critical raw materials in order to better anticipate potential supply bottlenecks or price increases or to avoid changes in procurement.	A1.1–A4.1
Supplier diversification	Diversification of suppliers of critical materials in order to avoid delivery bottlenecks or price increases.	A1.3–A1.5
Shorter supply chains	Participation in and conclusion of contracts with raw material-producing companies in order to gain more direct access to critical raw materials.	A1.4–A1.5

Backward-Integration	Participation in and conclusion of contracts with raw material-producing companies in order to gain more direct access to critical raw materials.	A1.2–A1.5, A3.1–A4.1
Horizontal integration (pooling)	Merging with other companies to form purchasing communities to strengthen the negotiating position when concluding supply contracts and influencing political processes.	A1.4–A1.5
Forward integration	Participation in or establishment of post-production recycling plants for production and municipal waste that contain critical raw materials.	A1.4–A1.5, A3.1–A4.1
F+E Dematerialization	Examination of company-internal possibilities and / or participation in research cooperations or knowledge networks to minimize the use of materials in products in order to counter long-term supply bottlenecks or unsustainable price increases.	A1.1–A2.1, A2.3–A4.1
F+E Substitutability	Examination of company-internal possibilities and / or participation in research cooperations or knowledge networks on the substitutability of supply-critical metals in order to counter long-term supply bottlenecks or unsustainable price increases.	A1.1–A2.2, A3.1-A4.1
Substitution measures	Implementation of measures for the substitution of critical raw materials.	A1.1–A2.2, A3.1-A4.1
Less reject material	Encourage efforts within your company to optimize production systems in order to minimize the rejection of long-term supply-critical materials in production.	A1.1–A2.1, A2.3–A4.1
Recycling of production waste	Encourage in-house options for the recycling of critical raw material-containing production waste to reduce the dependency on supply.	A1.1–A1.5, A3.1–A4.1
Alternative product design	Adaptations of products so that their manufacture is no longer or less dependent on the availability of critical metals.	A1.1–A4.1
Design for recycling	Adaptation of products so that critical metals contained therein are better recovered.	A1.1–A1.5, A3.1–A4.1
Product diversification	Development of new business areas through diversification of products in order to reduce the strategic importance of products containing critical materials in the medium term.	A2.1
Recycling municipal waste	Support the development and implementation of recycling solutions for waste containing critical metals.	A1.1–A1.5, A3.1–A4.1

Table 6: Options for companies to reduce the criticality of metals

In principle, operational measures can be applied in three different ways at three points:

- Upstream of production in the supply chain (i.e. from raw material extraction to delivery to the company), e.g. through diversification of suppliers, vertical integration of upstream processes in the company, long-term supply contracts, stock formation at low market prices, etc.
- In the production itself through a more resource-efficient handling of critical raw materials, e.g. reduction of rejects, improved recyclability of products, substitution of critical metals with less critical raw materials, material savings on the product, etc.

- Downstream of the production in the processing of production waste or in the return and processing of disused devices and components.

While certain measures have only a minor influence on the company (e.g. warehouse formation, long-term supply contracts), others demand far-reaching operational adjustments (e.g. substitution often goes hand in hand with product adjustments and changed production systems due to functional differences), which in view of everyday pressure and short-term of trends (e.g. price peaks) is difficult.

By assigning the options for action to the assessment aspects that influence the criticality, recommendations for action can be given automatically and in line with company-specific criticality assessment profiles.

5 Electronic tool "RESCHECK BASIC"

The final fourth module aimed to synthesize the diverse knowledge from the project into an electronic tool, which allows MEM companies to easily evaluate the dependencies and scope of the use of rare metals (criticality screening) and to reach an overview of the corresponding options for reducing criticality.

5.1 Additional basics

As the analysis of the pilot SMEs has shown, among other things, many Swiss companies do not purchase the metals directly as raw materials, but as part of semi-finished products (semi-finished products, parts, components). Since metals contained in these semi-finished products are not always known to companies, it is essential that the web tool also makes it possible to give a statement about the criticality based on semi-finished products.

To date, there is no systematic overview of the critical metals contained in finished and semi-finished products. For this reason, various fragmented information on the use of critical metals in various product applications was collected in the present study and finally stored in a database that was used for the tool. This includes information on the presence of the 35 critical metals considered in a total of 42 semi-finished products or products.

5.2 Technical specification

The electronic tool was implemented as a web tool. The following Table 7 summarizes the main technical characteristics.

WAS	BESCHREIBUNG
URL	The web tool is available at the following four Internet addresses: • www.metalriskcheck.com • www.metalriskcheck.ch • www.metal-risk-check.com • www.metal-risk-check.ch
Browser	The web tool is compatible with the popular web browsers (Internet Explorer, Firefox, Safari, Opera, Chrome).
User types	To be able to track the type of use of the tool as precisely as possible, a distinction is made between different user types. In addition to the main user group "company", four other user types can be selected (i.e. association, administration, media, private person).
User account	The tool offers users the opportunity to register and set up a corresponding user account. Registered users can save their checks and access checks that have already been carried out at any time. This enables the criticality profile to be tracked over time and any conclusions to be drawn about planned or implemented measures.

Export	Checks (completed questionnaire, criticality assessment, recommendations for action) can be exported and made available in the form of a summary PDF using an export function.
Import	The databases stored in the tool (e.g. risk categories for the metals, metals in semi-finished products) can be updated using a CVS import function.
Language	The tool can be loaded in different languages. So far, a German and a French version have been implemented.

Table 7: Technical specification of the web tool "Metal Risk Check BASIC".

5.3 Structure and functionality

The basic structure and functionality of the electronic tool is illustrated in Figure 8. The figure shows the interaction of user interfaces (frontend levels) and databases (backend levels) to convert user input into a clearly presented criticality assessment, including recommendations for action to reduce criticality hotspots. The individual components of the web tool are described in more detail below. The actual tool basically consists of three levels. The information required by the company for the criticality assessment is collected at the input level. In a second level, the information from the questionnaire is linked to the databases and the criticality assessment is calculated. In the results level, the results of the criticality assessment are graphically clearly presented and corresponding recommendations for action are given.

The input mask basically consists of a standardized questionnaire. In this questionnaire, the information required for the criticality assessment is entered into the SME. The questionnaire contains two different blocks of questions that aim at different dimensions of the developed criticality assessment method. On the one hand, this involves information on the use of critical metals in the company, i.e. which of the 35 metals to choose from depends on the company (see Figure 9). Since, based on the experience in the 3 pilot SMEs, it can be assumed that this information is not available in many companies, in addition to the direct selection of the metals, the possibility is given to choose between various semi-finished products containing rare metals[5]. The information on the type of metals used is ultimately decisive for the assessment of all criticality aspects in the dimensions "supply risk" (D1), "environmental impact" (D3), and "social impact" (D4). For these dimensions, the risk categories of all criticality indicators and these aspects due to the supply chain focus ("cradle-to-entry gate") are purely dependent on the selected metal or those that are available in the semi-finished metal database (DB 2) were determined.

[5] The database currently contains 42 semi-finished products that are considered essential. Neither can it be guaranteed that the metals it contains are complete in all cases, nor that the list of semi-finished products is to be regarded as exhaustive, but a further step towards a more comprehensive understanding of the complex areas of application of critical metals (“work in progress”).

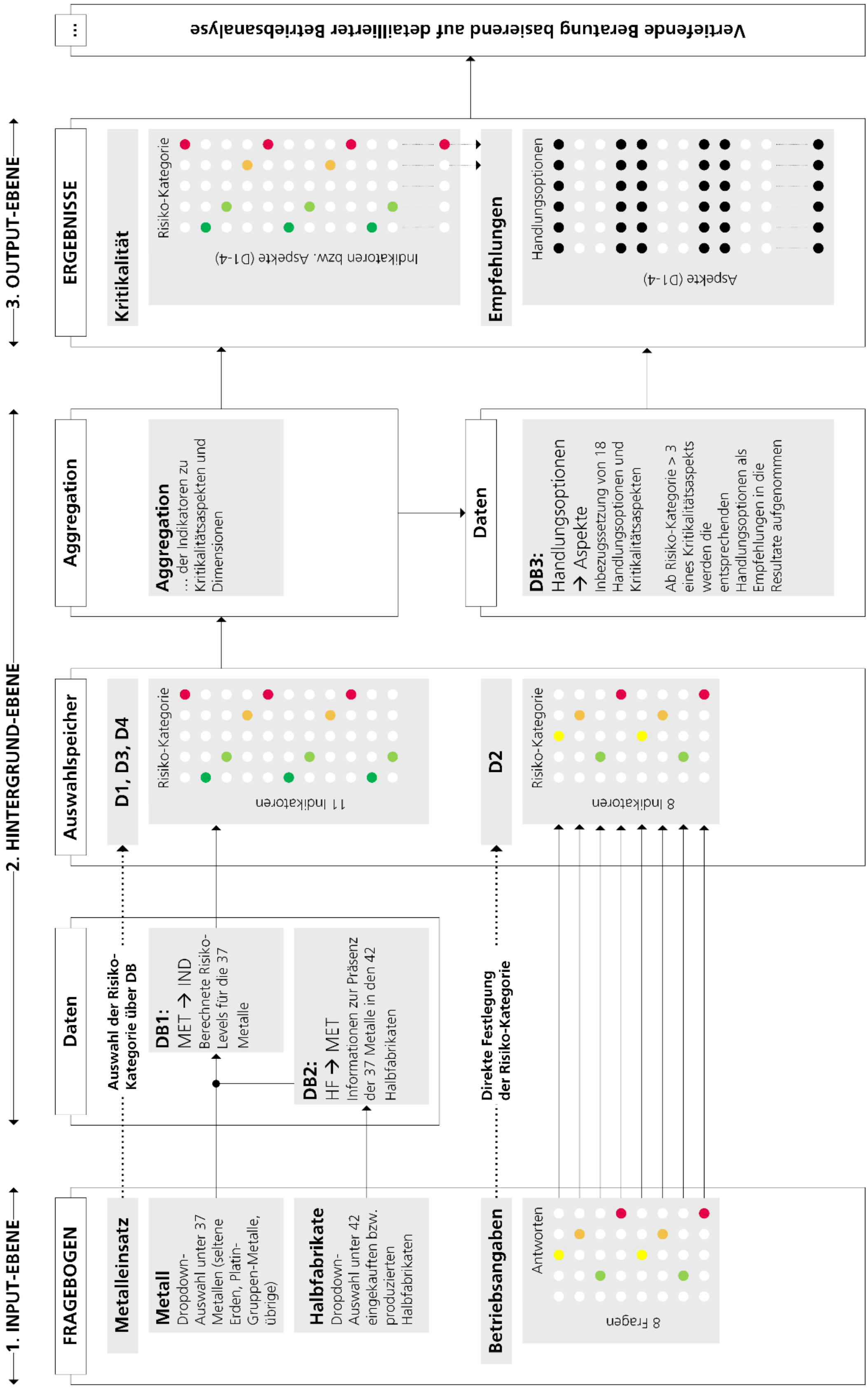

Figure 8: Structure and operating principle of the electronic tool "RESCHECK BASIC" input level.

In the second block of questions, the information is asked on which the assessment of the criticality indicators of dimension 2 “company susceptibility” is based. Each indicator is covered by a question. The answers to these questions are given on a 5-level ordinal scale, which enables a direct assignment of the answer to the 5-level risk category, i.e. the risk category for the corresponding indicator is determined directly by the answer (see Figure 10).

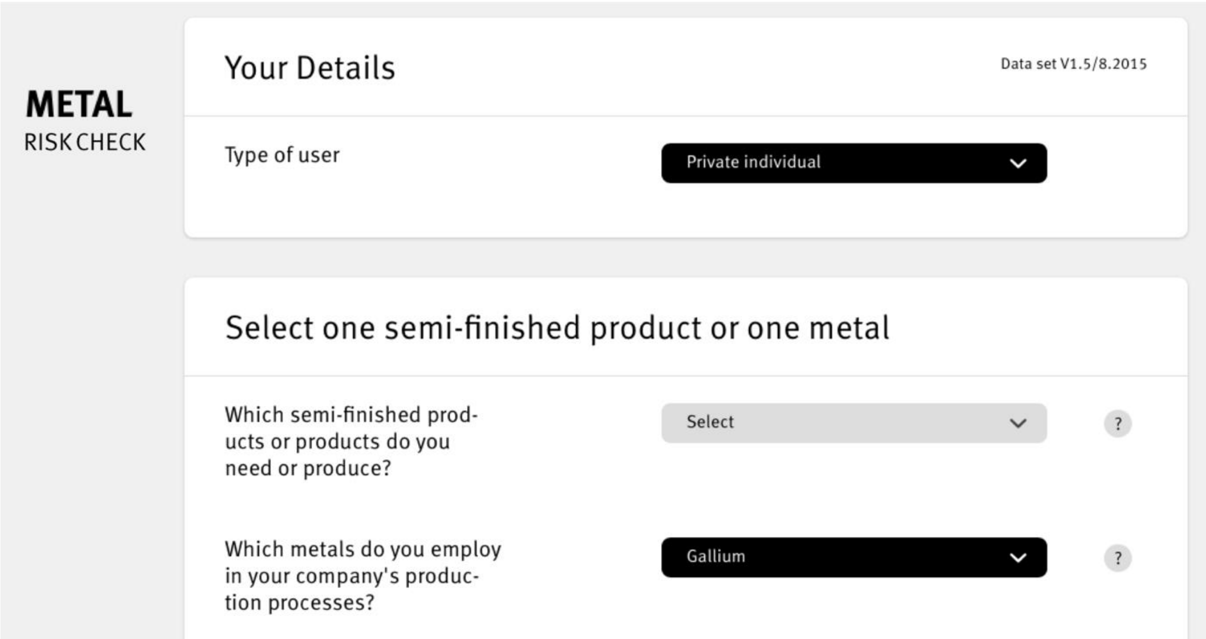

Figure 9: Specification of the critical metal or finished / semi-finished product in the questionnaire

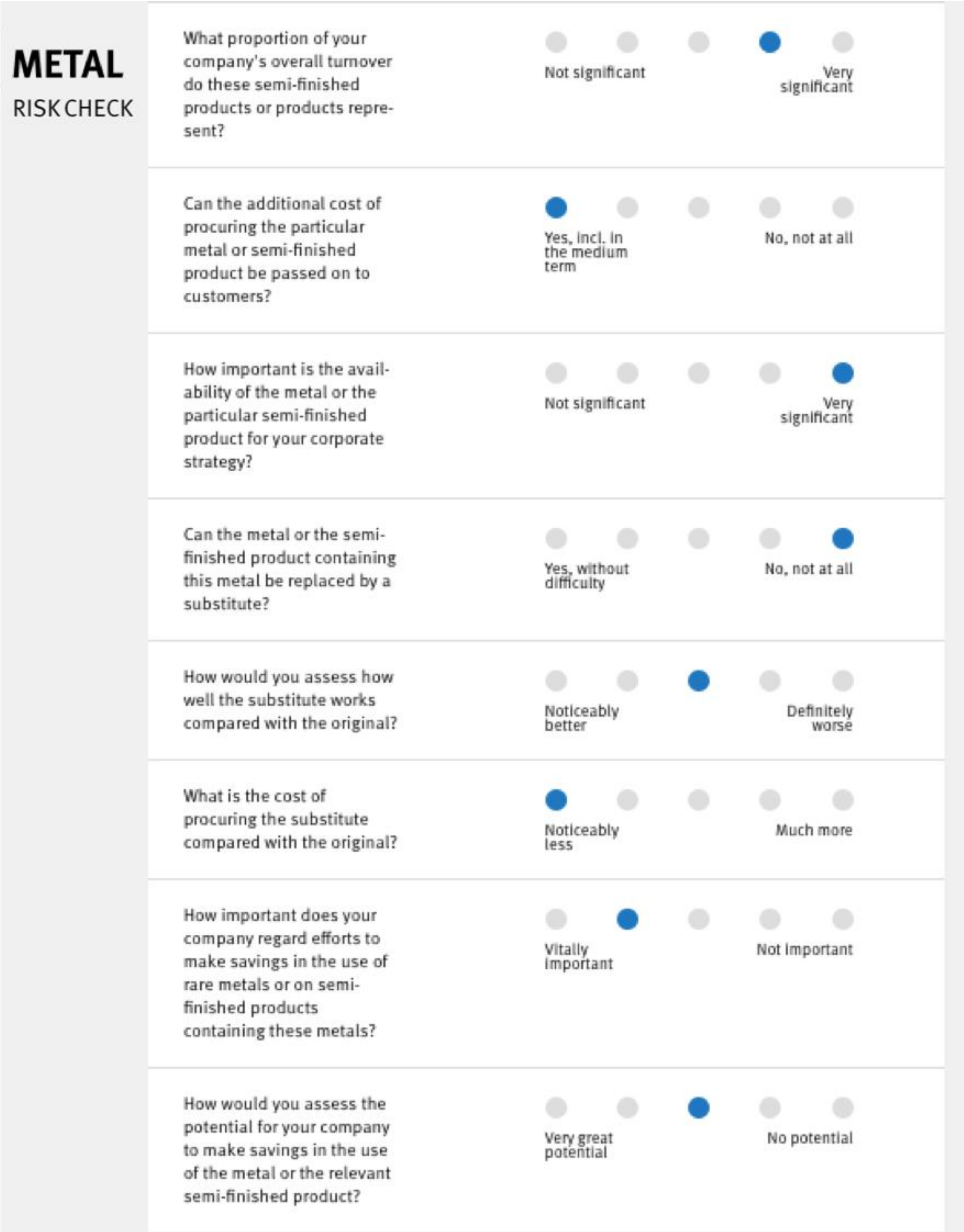

Figure 10: Eight questions to assess the company's vulnerability to supply restrictions.

5.3.1 Backend layer

The backend layer is the area of the web tool that is not visible to the user. On the one hand, all data and information are stored in the backend level, which are necessary for calculating the criticality and for selecting the recommendations for action based on the information from the questionnaire. On the other hand, all criticality data associated with a specific query are stored in a selection memory and aggregated for the output level. The various databases stored in the tool are described below:

Database 1 contains the risk categories for the indicators of all criticality aspects of assessment dimensions 1 (supply risk), 3 (environmental impairment) and 4 (social impact) for all 35 metals considered. Depending on the metal selected in the first question, the corresponding risk categories are selected, aggregated to the different levels of criticality and stored in the selection memory for the subsequent graphic processing.

The information on the metallic composition for the 42 semi-finished or finished products shown is stored in database 2. It enables the connection of the semi-finished or finished products to the rare metals contained therein. When selecting semi-finished products, the metals contained in the corresponding semi-finished product are determined in advance via this database before the corresponding risk categories for these metals are then queried and temporarily stored on the basis of DB1.

Finally, database 3 contains the information basis, which enables the criticality aspects to be linked to these influencing options for action. If risk category 3 is exceeded for one aspect, the recommendations for action associated with this aspect can be selected. Results-dependent strategic recommendations can thus be given to the users, as to which basic approaches to reduce criticality may be further examined.

5.3.2 Output level

The results of the criticality screening and the corresponding recommendations for action are clearly presented and illustrated on the output level. The results are mapped at different hierarchy levels and can be differentiated from the highest level (i.e. dimension) to the level of the indicators. An overview of the different output levels is given below using screens (see Figure 11 to Figure 16).

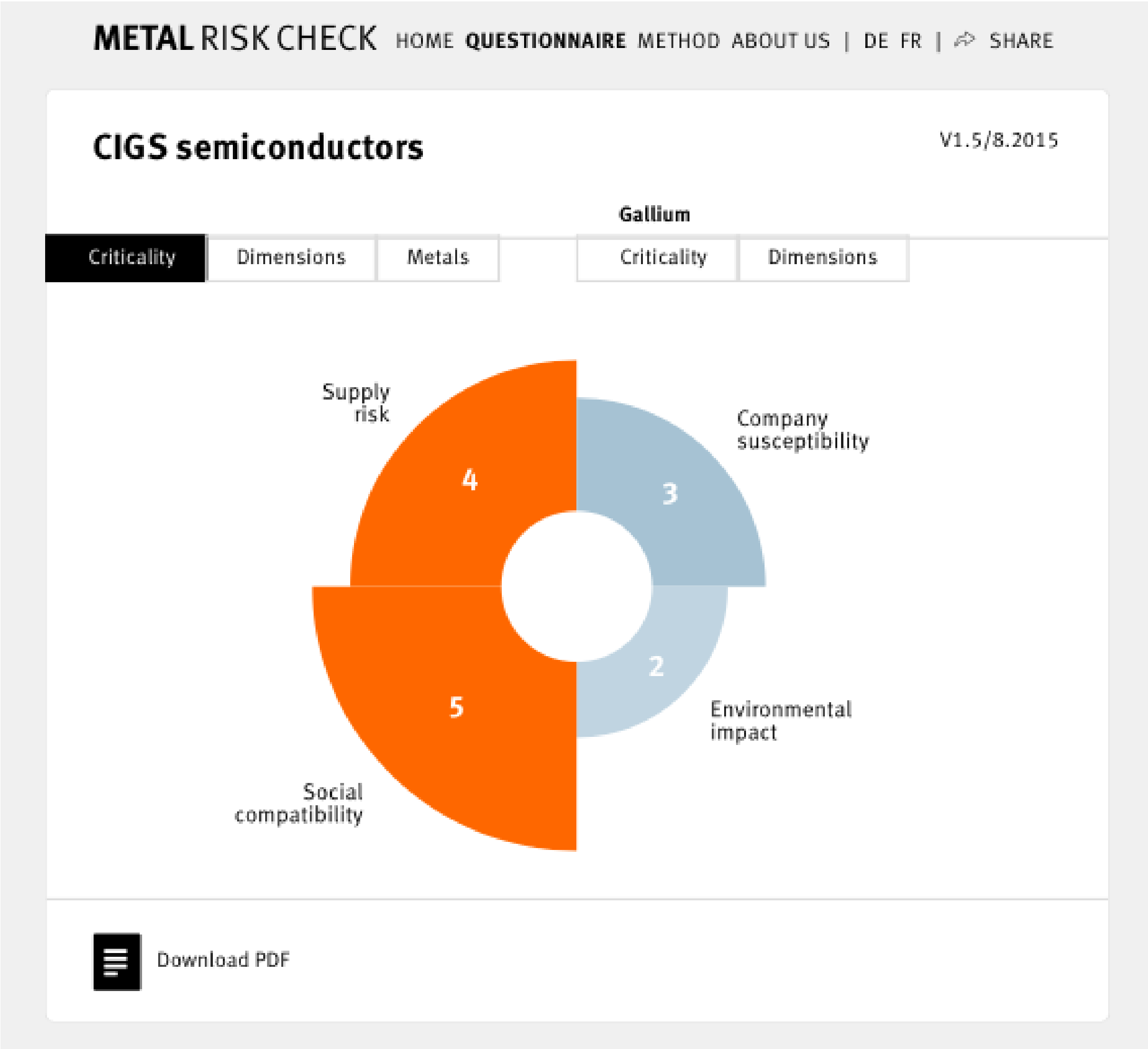

Figure 11: Fully aggregated result of the criticality assessment using the example of the semi-finished product "CIGS semiconductor".

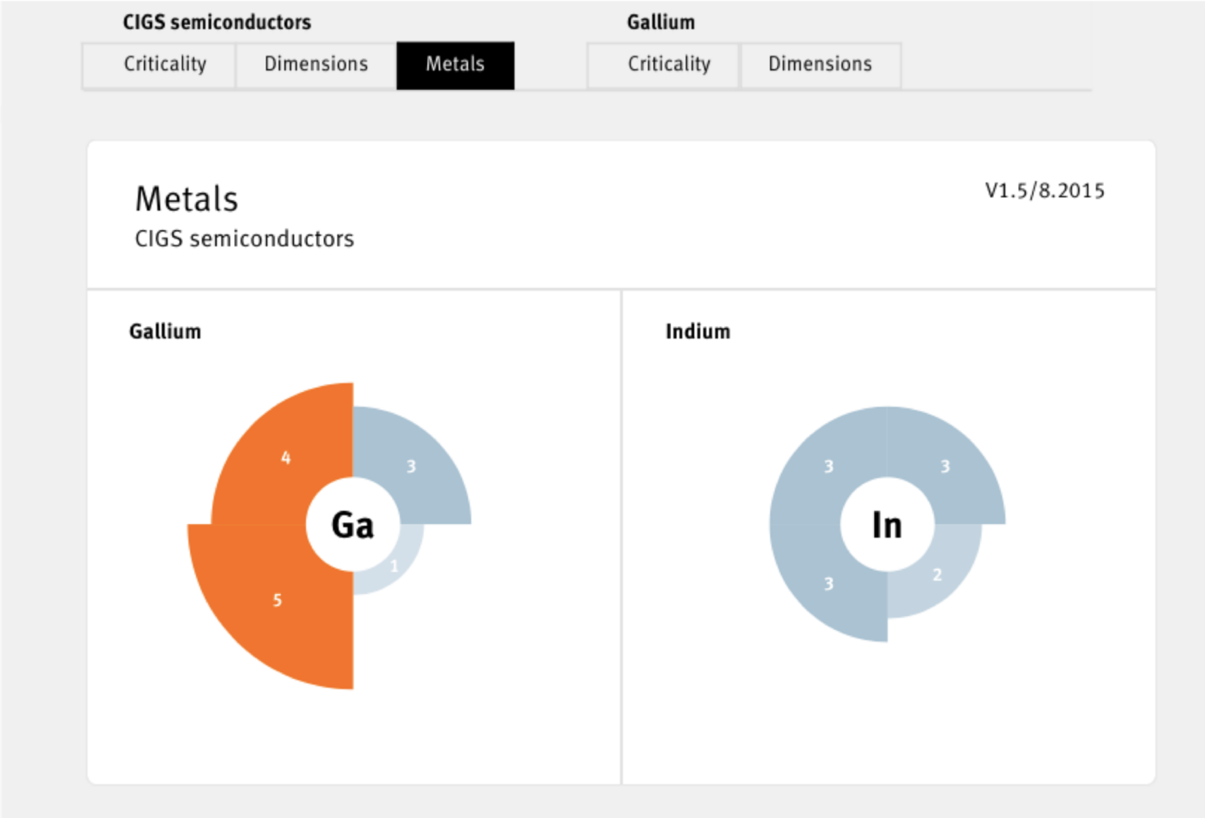

Figure 12: Representation of the critical metals contained in the semi-finished product "CIGS semiconductors"

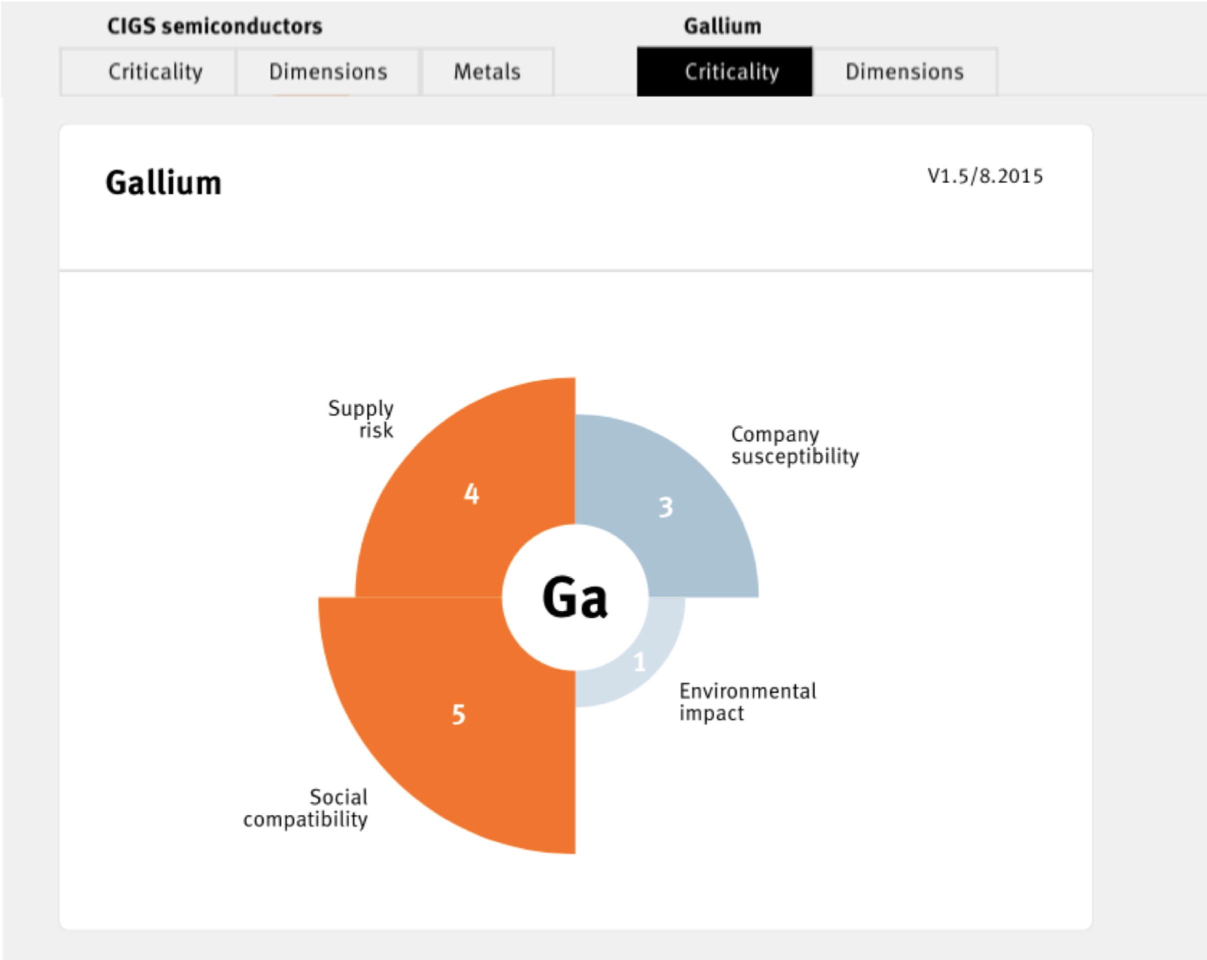

Figure 13: Fully aggregated result of the criticality assessment at dimension level of the metal "Gallium" contained in the semi-finished product "CIGS-Semiconductor".

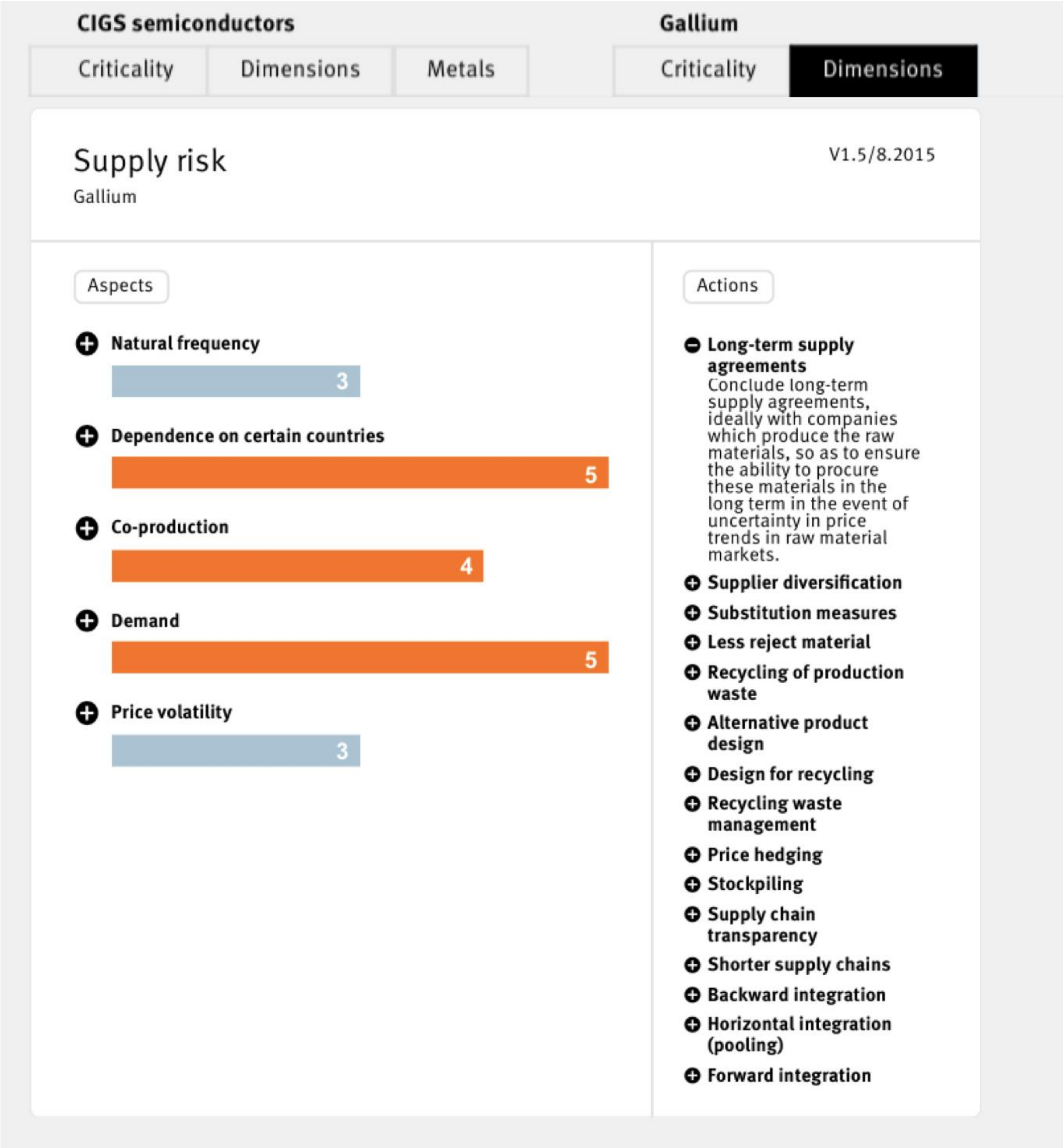

Figure 14: Assessment of the individual criticality aspects of the dimension supply risk for the metal "Gallium" contained in the semi-finished product "CIGS semiconductor".

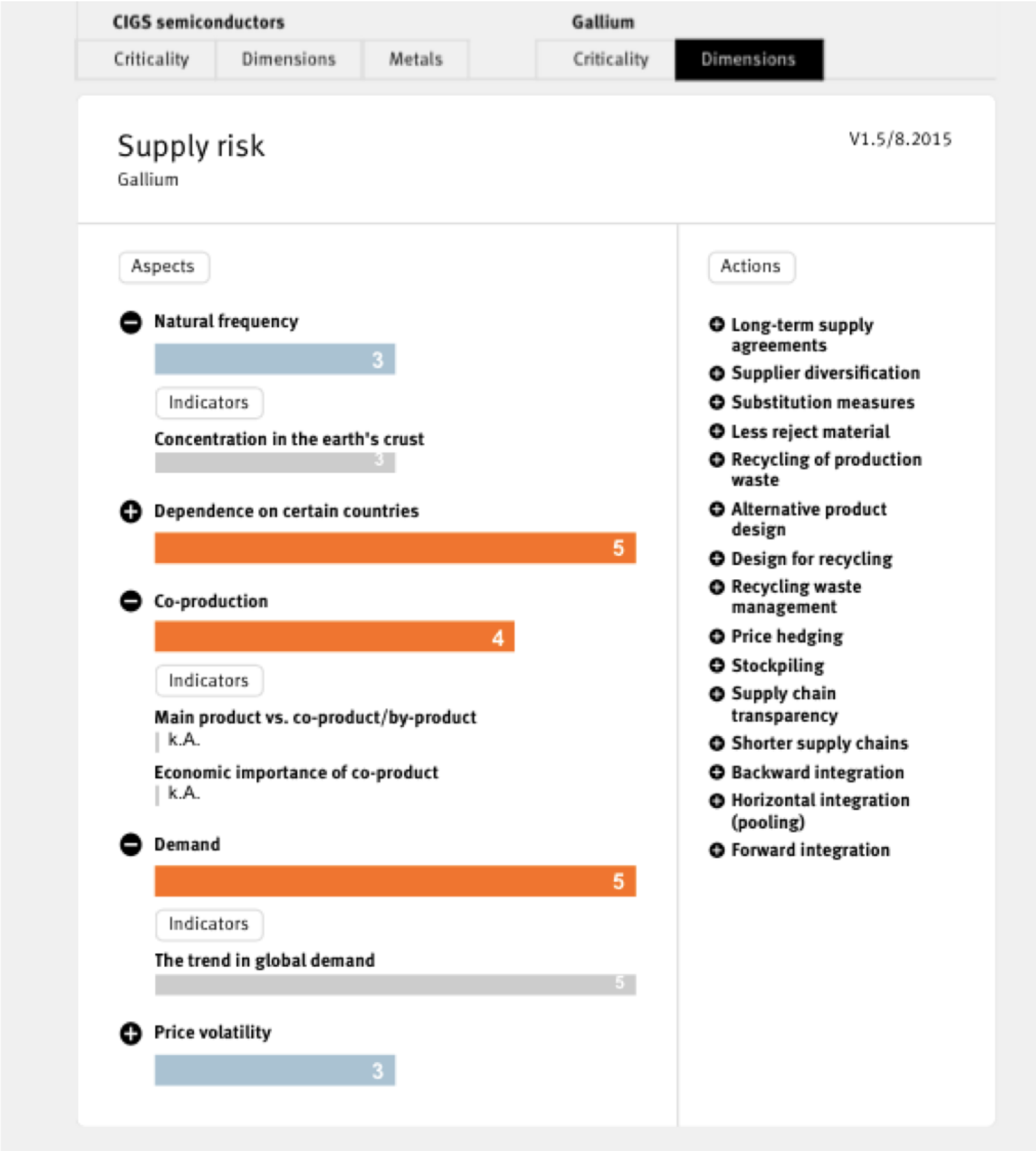

Figure 15: Criticality assessment of the most detailed level (indicators of the aspects) using the example of the supply risk dimension for gallium.

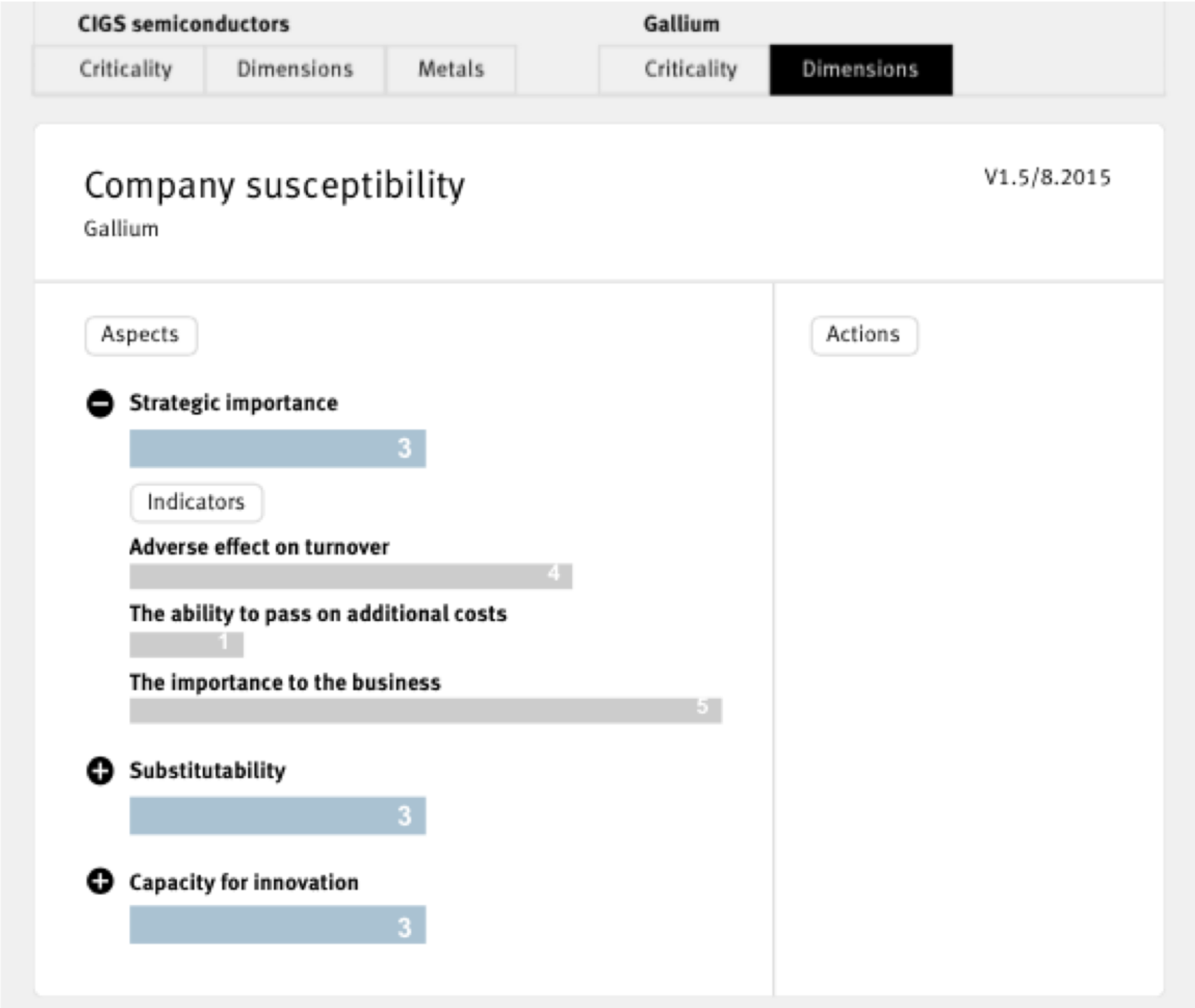

Figure 16: Fully differentiated result (level indicators) of the criticality assessment using the example of gallium.

6 Conclusion and further investigation

6.1 Summary & discussion

The RESCHECK project was intended to develop new foundations and findings on the dependencies of SMEs on rare metals, i.e. on the risks and the ecological and social effects of the use of rare metals, and on recommendations for action to reduce critical dependencies. Finally, the knowledge gathered was synthesized in a practical tool in such a way that SMEs are able to determine the location of these dependencies on critical metals pragmatically and well managed and to make appropriate recommendations for action.

For this purpose, a situation survey was carried out in a first module on small case studies in three selected pilot SMEs, whose activities and products depend on a secure supply of critical metals. This survey was carried out using a questionnaire and data entry forms and was guided by the vulnerability concept, which combines all two perspectives of supply risks and operational vulnerability to a restricted supply situation and also takes adaptability into account. Based on the knowledge gained in the pilot SMEs and known methodological approaches in science, a multi-criteria method for criticality assessment around the use of metals in SMEs was developed in the second module and applied to the pilot SMEs. The method is based on the four dimensions of supply risk, susceptibility of the company to supply restrictions, environmental damage and social impact. These dimensions were made measurable over a total of ten aspects or over 19 indicators and transferred to a five-stage criticality scale. The third module focused on the development of building blocks for a resource strategy. On the basis of the situation survey in the pilot SMEs and our own research, a total of 18 different recommendations for action, which address different criticality dimensions or aspects, were compiled and briefly described. In the final fourth module, the results were then translated into the actual product - the electronic tool. Based on the requirements for monitoring the use of the tool, this was implemented in the form of a “Metal Risk Check” web tool. By choosing one of the 35 critical metals or one of the 42 semi-finished products and answering eight questions, a company receives an appealing overview of the criticality hotspots, which can be analyzed in depth over various levels of detail, and an overview and description of the possible starting points for reducing criticality. A user registration gives you the opportunity to save several criticality assessments carried out at different times and to be able to track the development of the criticality profiles.

The developed methodology for criticality assessment and the corresponding implementation in the web tool Metal Risk Check can be classified as the first basic version. The use of the method or the web tool allows - in the sense of a criticality screening - an initial rough, pragmatic and easily communicable assessment of different criticality aspects around the metals used in a company and provides an overview of suitable options for reducing criticality. The criticality hotspots and options for action identified using the “Metal Risk Check” are to be regarded as a set of rules that need to be analyzed more closely in the course of in-depth follow-up.

It has also been shown that it is very difficult to map the supply chains of the critical metals obtained from a company because the companies often only have information about the first supplier level and further information about the supply chains is hardly or only very costly to access. Accordingly, the developed valuation method and the web tool Metal Risk Check on the supply side only take into account the value creation stage of raw material extraction or resource extraction. Other characteristics of the supply chains relevant to the assessment of criticality, which refer to other stages of the value chain, could not be included in the method or in the Metal Risk Check. Examples of this are the diversity of suppliers, the number of companies that produce a certain semi-finished product, or the regional location of processing stages.

Another problem is the limited number of 42 semi-finished products that were implemented in the development of the “Metal Risk Check” web tool. The work has shown that companies that do not purchase the metals in elementary form, but rather as a component in semi-finished and finished products, cannot provide any or only very little information about the types and quantities of the critical metals contained therein. Accordingly, the companies rely on the fact that tools for evaluating criticality must be set up in such a way that a statement based on information on the semi-finished products used is possible. This means that the tool must contain information on the metallic composition of semi-finished products so that it can be used for the broad corporate landscape. With the refurbishment of 42 semi-finished products, an essential first step in this direction was taken as part of the RESCHECK project. However, this would have to be expanded to make the tool more widely applicable in the corporate landscape. At the same time, the variety of applications of the metals under consideration is huge and also increasing (e.g. in electronic devices or technologies for the use of renewable energies) and information on the metallic composition of semi-finished products is only available in a limited and highly fragmented manner.

6.2 Need for further investigation

In order to further deepen the topic of criticality assessment or to enable more comprehensive statements to be made for a wide variety of companies, the authors see a need for further clarifications.

Comprehensive operationalization of the assessment dimensions: For the two dimensions of supply risk and social risk, there is potential to extend the assessment framework to other aspects in order to be able to assess these two dimensions more holistically. The supply risk is about analyzing and, if necessary, supplementing further characteristics that influence the supply risk in the stages following extraction (e.g. manufacture of semi-finished products). The social impact dimension has so far been operationalized via one aspect i.e. two different indicators (corruption, conflict metal) that focus strongly on the social level. The perspective of the employees (e.g. working hours, child labor, fair wages) and of local communities (e.g. rights of indigenous people, displacement) is not included in the method and accordingly in the web tool. The idea is to add aspects and indicators to the method and the tool so that the statements on social effects and risks become more holistic and therefore more meaningful.

Operationalization of selected criticality aspects: Selected criticality aspects in the developed evaluation method are to be critically examined from the point of view of the current discussions or could be operationalized even more meaningfully. This concerns for example the aspect of “natural frequency” in the dimension of supply risk. In the present project, the aspect of geological availability via geological frequency, i.e. operationalized via the average mass fraction of the metal in the earth's crust (ppm). It would have to be checked whether the "natural frequency" could e.g. be replaced by the “extractable global resources” indicator, which quantifies the potentially degradable geological storage without taking economic aspects into account (cf. Graedel & Reck, 2015; Henckens et al., 2016).

Understanding the supply chains: Improving the understanding of the supply chains of critical metals in companies is considered central to refine the criticality assessment and to analyze and potentially integrate previously not considered, but criticality-determining characteristics in the supply chains. In cooperation with suitable industrial partners, the stages of the supply chain after resource extraction are to be examined in more depth in order to be able to derive the essential "criticality characteristics" in the supply chains and, based on this, to improve the method and the tool with regard to their informative value.

Knowledge base for semi-finished products: To make the criticality assessment or the web tool “Metal Risk Check” accessible and better usable for a broader scope of the corporate landscape, but also to be able to better assess certain aspects, such as the development of demand, the expansion of the knowledge base on the use of critical metals in various semi-finished products and in products or technologies would be essential. The work has shown that companies that procure the metals as part of semi-finished products know only to a limited extent which critical metals their production activities actually depend on. The idea is to expand the developed knowledge base on semi-finished products and their metallic components into a comprehensive database in order to ensure the applicability of the developed criticality assessment to a broader section of the corporate landscape.

Metal Risk Check v.2: Version 2.0 of the Metal Risk Check is implemented based on the findings from the other clarifications outlined above. This would ensure a broader applicability by the companies and contain the relevant, previously not considered criticality aspects of the supply chains.

7 References

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A Interview Guide

Guide-based interview on resource check for rare / critical metals

Goals of the interview

1. Collection of data for the assessment of the procurement risk (supply risk) of rare / critical metals
2. Collection of data for the assessment of the company's vulnerability
3. Collection of experience and corresponding strategic approaches and measures to improve the supply situation

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Part A: General companies

4. How is your company structured (ownership structure, locations, divisions, ...)?
5. How many employees do you employ?
6. What fraction of the total costs (e.g. in percent) roughly make up your material costs and production costs?

Part B: Risk of procurement of rare / critical metals

B1: Products and elements / critical metals

7. What are your manufactured products?
8. What rare / critical metals are used in your products? (see Appendix I)
9. In which products or product components are the rare / critical metals used (e.g. magnetic bars)?
10. Do you use rare / critical metals indirectly, e.g. in aids or tools (abrasives, drills, etc.)?
11. What are the most important rare / critical metals in purchasing (direct purchasing or as part of a product component).
12. Is there a recycling system for your products? If so, who carries out the recycling?
13. Which time period is relevant for you to assess the criticality of the metals? 1-5 years or 5-10 years?
14. If the criticality were assessed for a particular year, what would it be? 2012?

B2: Importance of the affected products

15. How important are these products for your company? (on a scale from 0 to 100) or

16. What is the annual requirement (mass) of the rare / critical metals in the respective products?
17. What is the percentage of the affected products in turnover? ("How big would the loss be (in percent) if the product (s) could no longer be manufactured")
18. How important is the affected product for the corporate strategy? (on a scale from 0 to 100).
19. How good are the options for passing a price increase on to the customer? (on a scale from 0 to 100).

B3: market

20. Which market(s) do you access? CH / international?
21. Which customer segments do you supply?
22. What is the competitive situation (who are the main competitors and what are the current market shares)?

B4: Value chain

23. At what stage in the value chain of the end product is your production? (see Appendix II)
24. In which countries are the respective suppliers located?
25. Are there other suppliers and how competitive are they in terms of price and delivery times?
26. How good is the opportunity to switch to other providers?

Part C: Vulnerability to Rare / Critical Metals

C1 Importance of the affected products for the company

-> see B2

C2 substitutability

27. How well can the element or product component be substituted (on a scale from 0 to 100)? or
28. How can the element or the product component be substituted? Do substitutes exist that are immediately available?
29. How suitable are these substitutes (on a scale from 0 to 100)?
30. How good are the company's opportunities to develop your own substitute (perceived level of difficulty and the time required for development) (on a scale from 0 to 100)?
    1. C3: Capacity for innovation
31. How high do you estimate the innovative capacity of your company? (on a scale from 0 to 100) or

32. What proportion of your turnover do you use for research and development?
33. How many patents have you created in recent years?
34. Do you work with a university (for research and development)?

Part D: Measures to secure raw materials

D1: Shortage of raw materials / company strategy

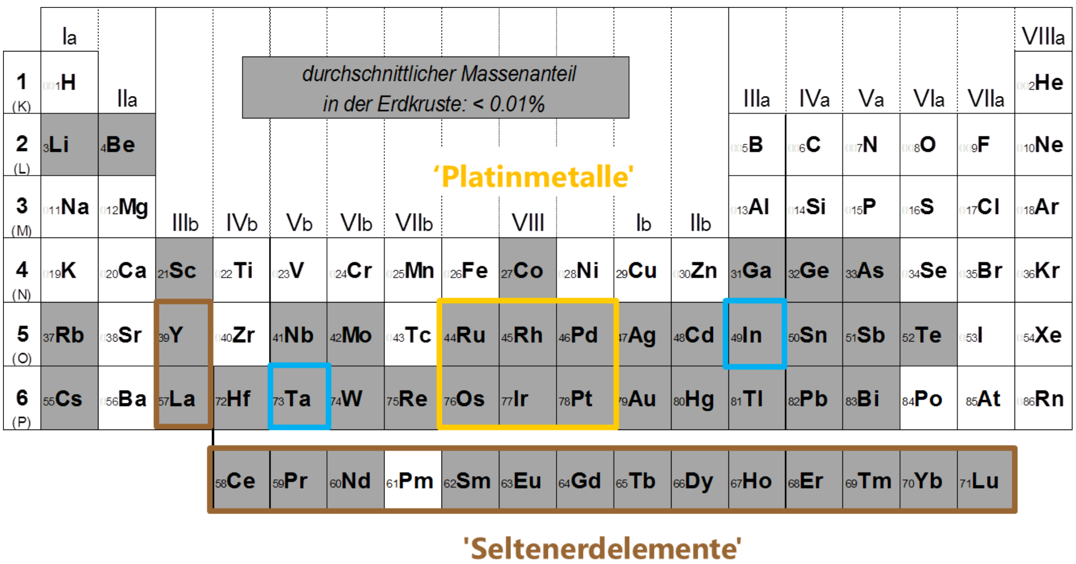
35. Have you ever been hit by a shortage of a metal?
36. Are you pursuing specific strategies for securing raw materials?
37. Is your production affected by certain laws / strategies for handling raw materials regarding Swiss politics?

D2: Measures

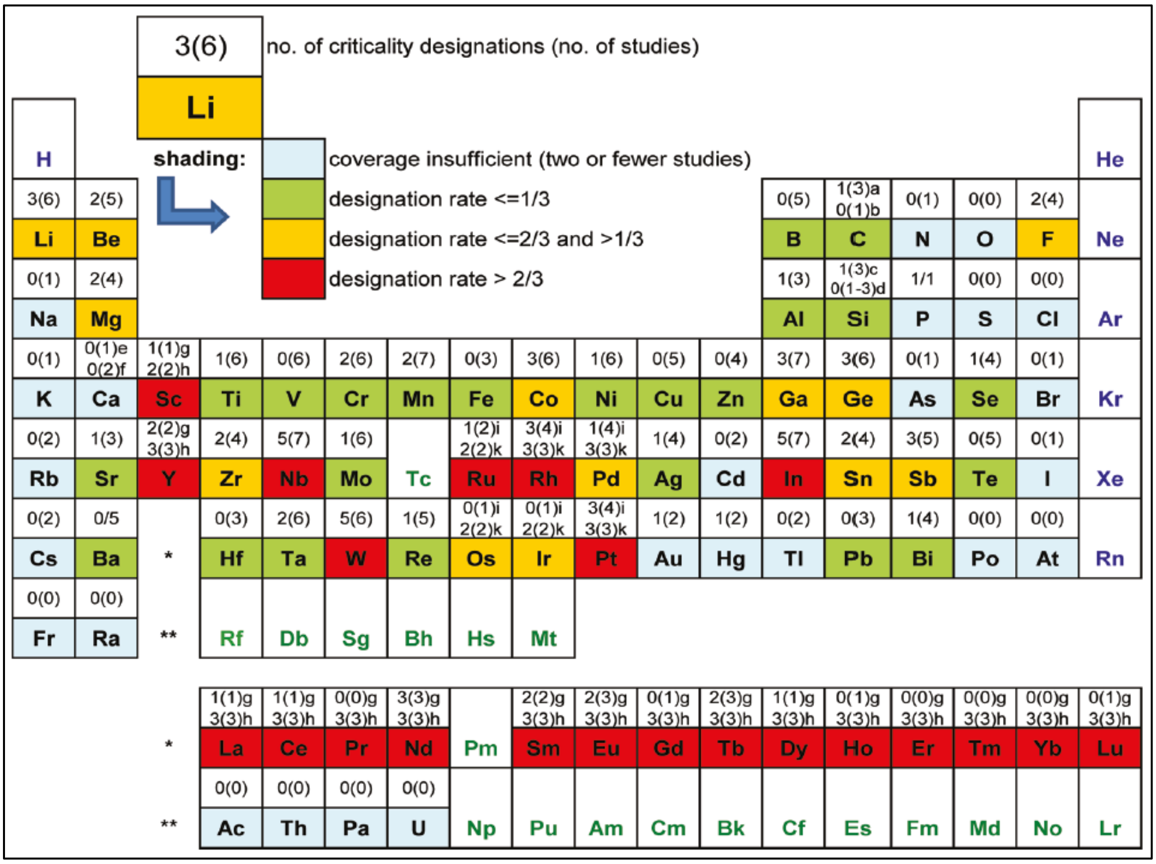
38. What measures to secure raw materials have you already taken?
39. Do you run a warehouse with the raw materials / intermediate products? If so, how long will the reserves last in the event of a total loss of delivery?
40. Have you implemented specific measures in the past 3 years to save material in production? If yes, which?
41. Are there other possible product improvements that lead to less material usage?

Appendix to the questionnaire:

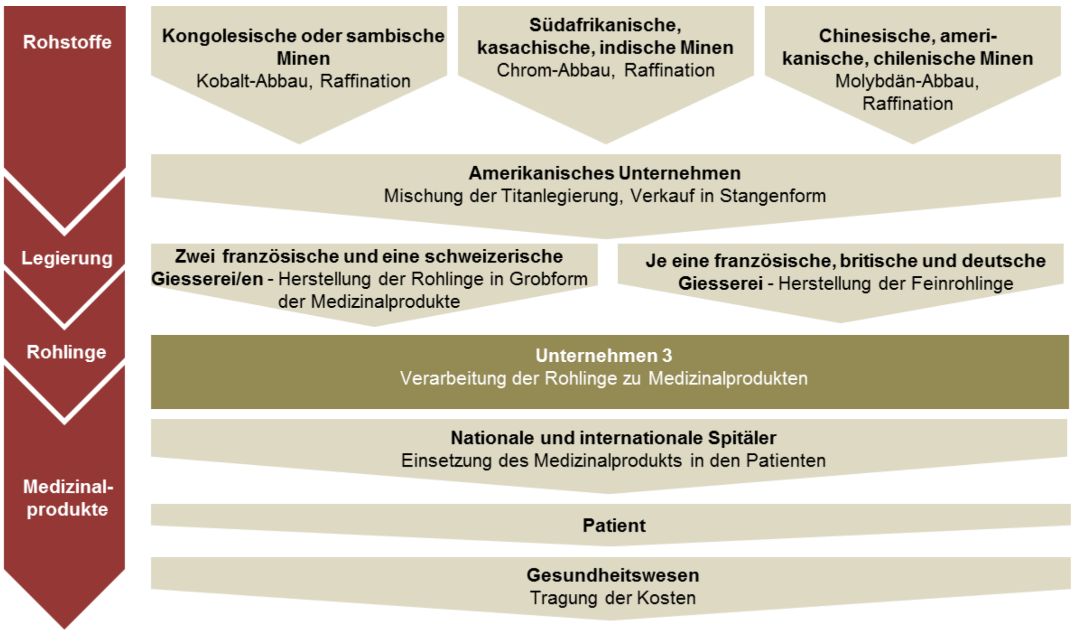
Critical and rare metals



Binder (1999); Skinner (1979); Wäger et al., 2010



Example of a value chain for the manufacture of a medical product



Data entry form

NAME COMPANY

Metal use in SME	**Metals**	**Amount** (kg/a)
	Antimony	
	Beryllium	
	Cerium	
	Chrome	
	Cobalt	
	Dysprosium	
	Erbium	
	Europium	
	Gadolinium	
	Gallium	
	Germanium	
	Holmium	
	Indium	
	Iridium	
	Lanthanum	
	Lithium	
	Lutetium	
	Magnesium	
	Molybdenum	
	Neodymium	
	Niobium	
	Osmium	
	Palladium	
	Platinum	
	Praseodymium	
	Rhodium	
	Ruthenium	
	Samarium	
	Scandium	
	Tantalum	
	Terbium	
	Thulium	

		Tungsten	
		Ytterbium	
		Yttrium	
Susceptibility SME		**Scale 0-100**	
Importance for SME	Adverse effect on turnover		
	Transfer of additional costs to customers		
	Strategic importance for companies		
Substitutability	Availability substitutes		
	Functionality substitute		
	Procurement costs substitutes		
Capacity for innovation	Measures to save material		
	Potential material savings		