Analysis of the Economic Benefits of Developing Commercial Deep Sea Mining Operations in Regions where Germany has Exploration Licences of the International Seabed Authority, as well as Compilation and Evaluation of Implementation Options with a Focus on the Performance of a Pilot Mining Test

Study on Behalf of the

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Expert group

Hamburgisches WeltWirtschafts Institut

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1 Background

On 19 November 2015, the Federal Ministry for Economic Affairs and Energy, through its Division IC4, commissioned the Ramboll-IMS and HWWI bidder group to prepare a study on the following subject:

"Analysis of the Economic Benefits of Developing Commercial Deep Sea Mining Operations in Regions where Germany has Exploration Licences of the International Seabed Authority, as well as Compilation and Evaluation of Implementation Options with a Focus on the Performance of a Pilot Mining Test".

The study was prepared by the following companies and individuals:

For the expert group:

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2 Subject matter and aims

The subject matter of the study can be briefly summarised as follows:

- Analysis of the profitability of commercial deep sea mining
- Analysis of the economic benefits for Germany
- Identification of the required investment for a pilot mining test
- Identification of the implementation options of commercial deep sea mining operations in the German licence territories

This study does not assess the environmental compatibility of deep sea mining because its main focus is on economic issues. Within the framework of the pilot mining test, a host of environmental data must be collected as a precondition for a sufficiently detailed environmental compatibility analysis.

Over the past decade, the Federal Republic of Germany supported deep sea mining research and development with around €50m. In this context, exploration licences for polymetallic nodules (manganese nodules) and massive sulphides were also acquired. The German licence territories cover a total area of 85,000 km², distributed to two areas measuring 17,000 km² in the central region and 58,000 km² in the eastern part of the so-called manganese nodule belt (Clarion-Clipperton Zone) as well as an area measuring around 10,000 km² south east of Madagascar with hydrothermal sulphide ores (massive sulphides).

The licence for polymetallic nodules is due to be renewed in the foreseeable future. Other nations are already testing special equipment for mining manganese nodules.

With a view to the special structure of the landscape of German companies involved in deep sea mining, who specialise more in equipment technology and services rather than in concrete mining activities, the overarching aim of the study is to answer the question as to whether and how continued involvement of the German government organisations in deep sea mining makes sense and is justified.

In this context, time is of the essence when it comes to the question as to whether and to what extent Germany will support the performance of a pilot mining test. Compared to other licensees, Germany has made relatively good progress in exploring the deposits of polymetallic nodules. If this leading position is to be maintained in the future, relatively large sums must be invested in the pilot mining test.

Real industrial-scale mining operations could start after the successful completion of the pilot mining tests by applying for a mining licence. The study shows how raw material markets must develop in order to trigger investment in mining operations. Such market developments would be necessary in order to enable Germany to exploit its licenses on a commercial scale.

Section 3 therefore analyses the raw material markets as a first step. Different price scenarios for the raw materials that can be extracted from the polymetallic nodules will be developed and the resultant revenues calculated for the commercial analysis. At the cost end, investment and operating costs will be estimated, paying special attention to identifying Germany's share in the value chain. The outcome will form a comprehensive analysis of the commercial attractiveness of mining operations as a basis for assessing how realistic their implementation will be.

Section 4 addresses the economic effects for Germany, also with a view to the issue of resource security. It also describes the regulatory framework and explores the question as to whether and to what extent production royalties can be generated.

The implementation of the pilot mining test is the next and last step that will complete exploration operations in the German licence territories for polymetallic nodules (Clarion-Clipperton Zone).
Section 5 assesses the necessary financial input and describes options for performing the test.

Deep sea mining must be environmentally compatible in order to be implemented at a political level. That being said, section 5, in particular, shows where further environmental compatibility tests are required as part of a pilot mining test in order to verify the feasibility of deep sea mining under this aspect too.

Section 6 addresses the subject of deep sea mining operations as a whole. It initially describes the way other licensees operate in order to assess how realistic their mining operations are. Strategy options for Germany – especially for the German government – are developed in order to maintain and expand existing deep sea mining opportunities.

In order to harmonise notation with English and US sources, the US notation for decimal numbers (decimal point rather than comma) will be used throughout the entire document.

3 Commercial analysis

This section explores the commercial profitability of polymetallic nodule mining in the German licence territory in the Clarion-Clipperton Zone (note: In the following sections, the term 'manganese nodules' will also be used in addition to the term 'polymetallic nodules'). On the basis of the latest knowledge regarding future revenues and costs, the discounted cash flow (DCF) method will be used for profitability assessments from an investor perspective. In view of the unavoidable uncertainty with regard to the future development of metal prices, different price scenarios are distinguished. One scenario uses prices projected on the basis of an econometric forecasting model: Continuously rising metal prices are expected in this case. The other scenarios use average prices from recent periods of different lengths. It can be seen that the future development of metal prices will have a key role to play when it comes to commercial profitability. In the projection scenario, the project can be rated as clearly profitable. This is, however, not the case when current prices are used. These results are largely independent of the choice of the discounting factor in the cash flow analysis.

3.1 Revenues from deep sea mining

The revenues from deep sea mining are the proceeds that can be generated on the market by selling the metals extracted. To determine the revenues, information is needed regarding possible extraction and smelting volumes as well as expectations regarding future price developments. In light of the fact that, at the time of this study, concrete information regarding raw material reserves is limited to the German manganese nodule licence territory, our profitability analysis in the following will be limited to manganese module mining.

3.1.1 Potential volumes

Deep sea raw material reserves occur in various forms with clear differences in terms of location and appearance as well as metallurgical structures. Table 3-1 shows the four known types of deposits and their key properties. The most interesting types in terms of their raw material content are manganese nodules and hydrothermal sulphide ores (also called massive sulphides). Both types potentially contain considerable amounts of nonferrous metals that can be exploited on an industrial scale. An important difference is their accessibility. On the one hand, manganese nodule deposits occur in significantly deeper water than massive sulphides and this alone already means generally more demanding challenges. On the other hand, the process of mining massive sulphides is by necessity more complex: The metal layers must first be knocked out of the solid rock. In contrast to this, manganese nodules are mostly loosely distributed in the sediment, so that the mining process merely consists of collecting the nodules.

Table 3-1: Types of metal deposits in the deep sea

Type	Description	Volume	Growth	Optimum environment	Raw materials	Major deposits
Hydrothermal sulphide ores (massive sulphides)	Concentrated deposits of sulphidic minerals (>50-60%), resulting from hydrothermal activity on the seabed	Up to several km²; up to several tens of metres thick	Accumulate over hundreds up to tens of thousands of years	Young oceanic crust, such as spreading zones and intraplate volcanoes or island arc regions; hydrothermal sources discharging high-temperature solutions	Pb, Zn, Cu +/- Au, Ag	Red Sea, Manus Basin and mid-oceanic ridges
Polymetallic nodules (manganese nodules)	Concretions of layered iron and manganese oxides with associated valuable metals from the water column or sediment	Nodules: typically 5-10 cm; deposits: up to hundreds of km²; <0.5m thick	Several mm to cm per million years	Deep sea basin, water depth of 4000–6000m, gentle slope with little sedimentation	Mn, Ni, Cu, Co +/- Mo, Zn, Zr, Li, Pt, Ti, Ge, Y, rare earth elements	Clarion-Clipperton Zone, also Peru Basin and central Indian Ocean
Ferro-manganese crusts	Layered manganese and iron oxides with associated valuable metals from the oceanic water column on hard substrate rock of subsea mountains and ridges	Up to several km²; <0.3m thick	1-6mm growth per 1 million years	Vast stock of substrate rock, water depth of 800–2500m	Mn, Co, Ni, Cu, Te, Mo, Zr, Ti, Bi, Ni, Pt, W, rare earth elements	Central equatorial Pacific Ocean, equatorial Pacific Ocean and central Atlantic Ocean
Phosphorites	Sedimentary rock with calcium phosphate of mostly biogenic origin in regions of high bioproductivity	Up to hundreds of km²; typically <0.5m thick	Accumulate over hundreds, thousands or millions of years	Low oxygen, low sedimentation, gentle slope, vicinity of nutrient-rich upward currents	Apatite, a calcium phosphate mineral	Upwelling regions, subsea mountains and island regions

In the area of manganese nodules, the Federal Republic of Germany was granted a licence in 2006 for a territory in the Pacific Ocean measuring 75,000 km² in the Clarion-Clipperton Zone (between Hawaii and Mexico). Table 3-2 is a breakdown of the average metal content of these nodules on the basis of the results from the last exploration trip by Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)
[Federal Institute for Geosciences and Natural Resources] (sample size: 619 nodules). Manganese, the mineral after which the nodules are named, expectedly accounts by far for the largest share. However, substantial quantities of other valuable metals with only limited onshore availability, such as nickel, copper and cobalt, are also found. In general, it can be seen that the composition of the manganese nodules is very heterogeneous. The metals contained would be generally suitable for a wide range of industrial applications (see Annex 2). The total volumes shown in Table 3-2 for the German licence territories were determined by BGR in 2015 on the basis of recent explorations.

It was not until 2014 that Germany was granted a licence territory for massive sulphides. The territory is located at the 'Rodriguez Triple Junction' in the Indian Ocean south-east of Madagascar. An exploration mission by BGR at the end of 2015 led to first findings regarding the metal content of the sulphide deposits in the region. These findings suggest that valuable metals, such as copper, zinc and gold, can be found there. However, more detailed information regarding the concentrations of individual metals is not yet available. As an alternative general orientation guide, Table 3-3 shows estimates of average values of the metal composition of deposits world-wide based on a study by Petersen (2013).

Table 3-2: Raw material potential in the German licence territory in the Clarion-Clipperton Zone

		Total volume in the German licence territory	**Proven onshore reserves**	**Onshore reserves**
	In percent	*BGR*	*USGS*	*USGS*
Metal	[% by weight]	Million tonnes	Million tonnes	Million tonnes
Manganese	31.50	195.365	620	?
Nickel	1.40	8.744	79	130
Copper	1.18	7.318	720	2100
Titanium	0.26	1.588	Ilmenite: 740 Rutile: 54	> 2000
Cobalt	0.18	1.085	7	25
Zinc	0.16	0.962	78	?
Rare earth metals	0.069	0.428	130	?
Vanadium	0.063	0.391	14	41
Molybdenum	0.062	0.385	11	14

Sources: BGR, oral information (2016); USGS (2016); HWWI (2016). Calculation:75,000 km² in der Clarion-Clipperton Zone

Table 3-3: Average metal concentration in massive sulphides occurring world-wide at central oceanic ridges

	Concentration	**Proven onshore reserves**
Element	[% by weight]	Million tonnes
Iron	26.9	85000
Sulphur	34.8	~ 605000
Copper	4.9	720
Zinc	7.7	230
Lead	0.2	87
	[g/t]	
Gold	1.2	0.055
Silver	89	0.530

Sources: Petersen (2013); USGS (2016)

As a precondition for the profitability calculation, it is necessary to determine which of the metals contained in the manganese nodules can be extracted by smelting at a reasonable cost.

Since it is difficult to predict technological developments in this area, this study – in analogy to the analysis of the cost situation – is based on the high-pressure/high-temperature leaching process as the currently most extensively tested method; see also section 3.2.1, pages 19 et seqq.

Although a host of alternative methods have been developed at concept level, any assessment regarding their cost structure would be purely speculative from today's perspective.

This means that extraction of the manganese content is currently not possible on an industrial scale. Copper, cobalt and nickel therefore remain as recoverable metals with recovery rates of far more than 80% possible in each case. In order to determine annual sales volumes on this basis, it is necessary to first determine how many tonnes of each of these metals can be mined each year by mining manganese nodules in the German licence territory. An annual extraction volume of 3 million tonnes[1] of manganese nodules (dry material) is assumed for the purposes of this commercial analysis.

1 This extraction rate leads to an economically reasonable ratio of fixed costs, step fixed costs and quantity-dependent costs as well as investment and operating costs. The quantities of raw materials that can be extracted remain so small that they can be sold without distorting markets. Furthermore, these quantities also represent the technically feasible volume given the present state of the art related to a mining vessel.

Table 3-4: Manganese nodule processing methods and related recovery rates

Metallurgy Method	Level of Readiness	Advantages	Disadvantages	% Recovery (Maximum)			
				Mn	Cu	Co	Ni
Reduction roast/ ammonia leaching[1]	Commercial scale for nickel laterites Pilot scale 100 kg/day for nodules	> Simple organisation > Moderate cost > Mn is recovered in residue /slag and must undergo additional processing	> High energy consumption	N/A	90%	60%	90%
High pressure/high temperature leaching[2] (Using sulphuric acid)	Commercial scale for nickel laterites Lab scale on nodules	> Lower energy consumption > Metals are extracted in concentrate form	> High acid consumption > High capital costs	N/A	95%	85%	95%
Cuprion ammonia leaching[3]	Commercial scale with nickel laterites Pilot scale on nodules	> Low energy consumption	> Mn cannot be recovered	N/A	92%	65%	92%
Smelting/ Sulphuric acid leaching[4]	Pilot scale for nodules	> Mn can be recovered as Fe-Mn or Fe-Si-Mn	> Energy intensive	85%	95%	90%	95%
Reduction hydrochloric acid leaching[5]	Pilot scale on nodules	> Low energy consumption > High metal recovery	> Requires very high concentration of HCL > High operating costs and corrosiveness	98%	98%	98%	98%

Source: Cardno (2016)

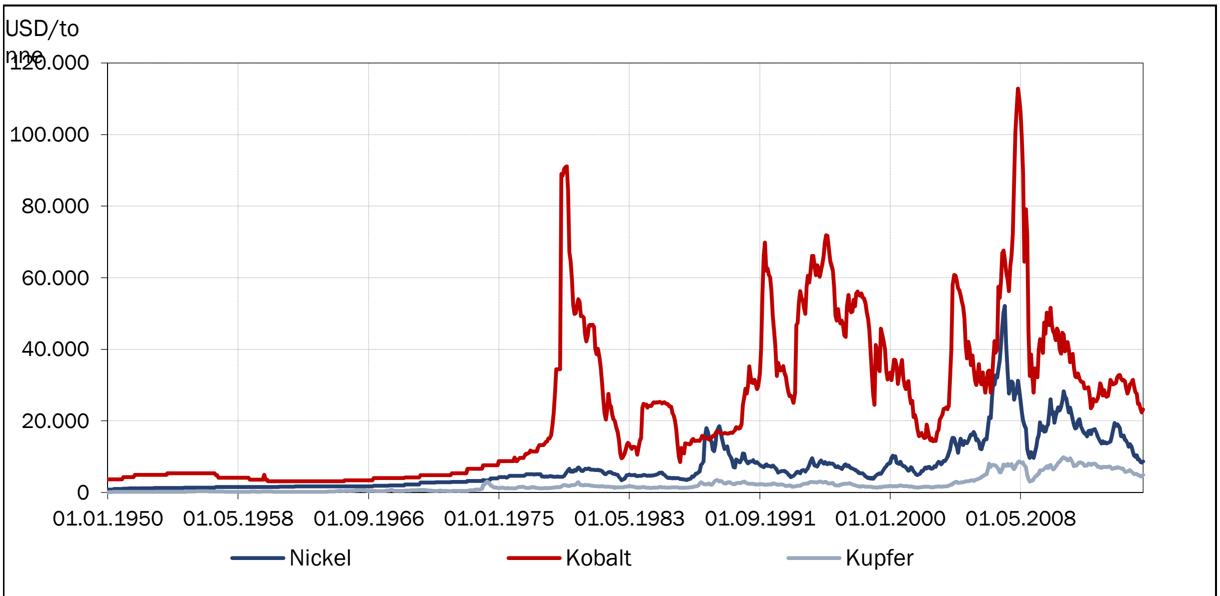
The quantities shown in Table 3-2 for the high-pressure/high-temperature leaching method can serve as a basis for estimating the volumes of the individual metals. If the corresponding recovery rates are applied to these values, annual sales volumes can be broken down as follows:

Table 3-5: Expected annual sales volumes by metals

Metal	**Sales volume (tonnes)**
Cobalt	4,590
Copper	33,345
Manganese	0
Nickel	39,900

3.1.2 Prices

Fig. 3-1 shows the historical price curves of the three metals that can be extracted by high-pressure/high-temperature leaching (HPHTL). Since the mid-1970s, price volatility has increased significantly, especially for cobalt. Temporary peaks sometimes exceed the long-term average several times over. In recent time, strong price peaks were found primarily in the region of 2007/2008. Since 2009, however, the prices of all three metals have been falling almost continuously. In order to enable a sensible continuation of the price time series into the future, the influence factors underlying these trends must first be identified.



Sources: BGR (2013); LME (2016); HWWI (2016).

Fig. 3-1: Historical development of monthly average prices

Metal prices are subject to a host of influence factors. Some of these have a temporary effect, such as speculative bubbles, natural disasters/war and labour disputes in the mining sector. Others, however, are of a more persistent nature and reflect longer-term development trends.

These include, for instance, the economic catch-up process of the newly industrialised countries as well as changes in metal mining and use technologies. An analysis of future price developments must carefully differentiate between these two groups of effects because the time of occurrence and duration of the first group are difficult to forecast due to their chaotic nature. In contrast, certain future development trends can often be predicted for the second group on the basis of historical data.

This makes it possible to estimate a correlation between price and influence factors which permits the use of expected changes in these influence factors in order to forecast future metal prices. However, this also means that the price time series must first be adjusted by the influence of temporary disturbance factors.

Fig. 3-2 identifies the likely special influences in the price curves for the deep sea metals cobalt, copper and nickel. The following profitability calculation is then also based on the corresponding time series.

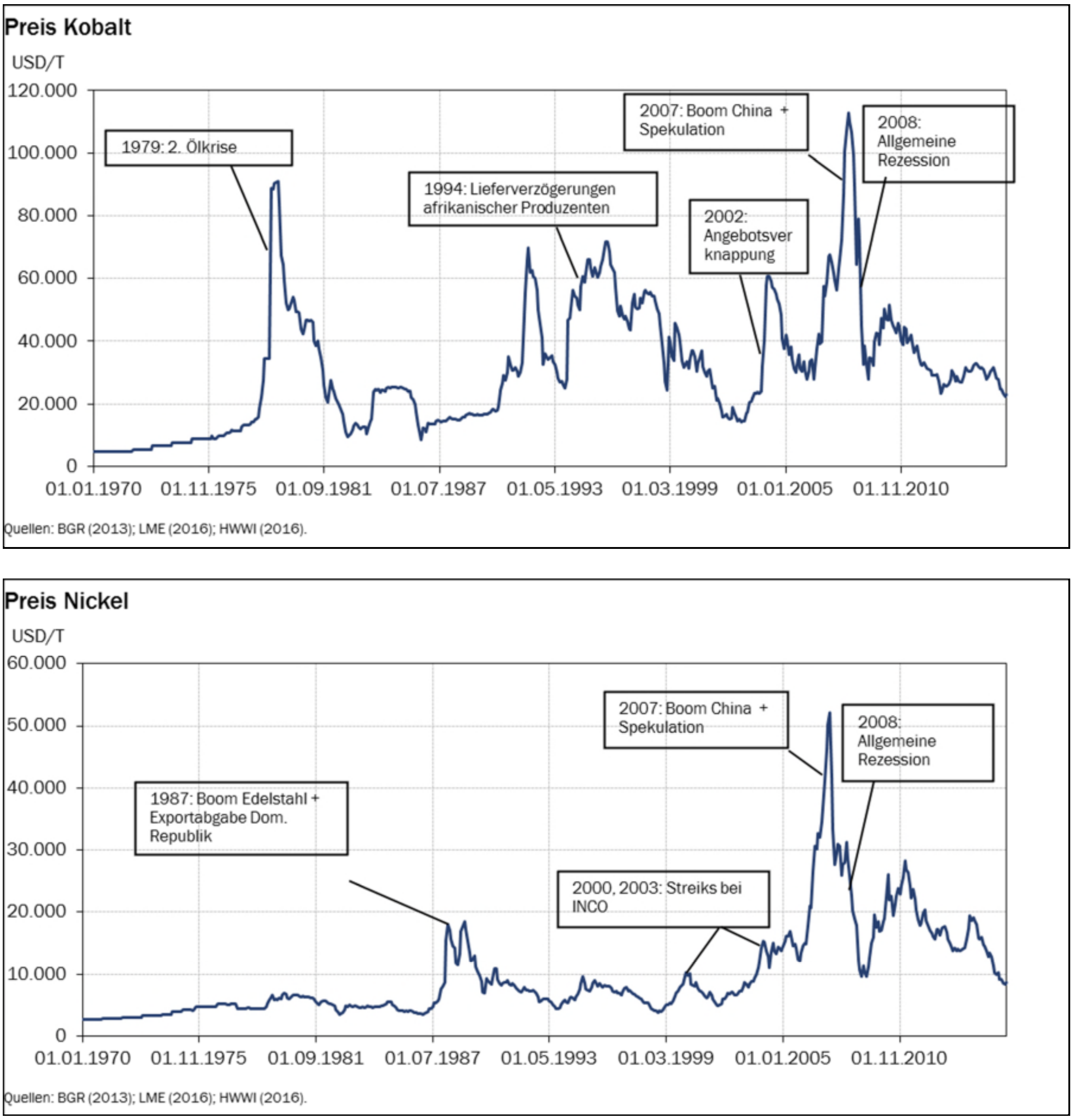


Fig. 3-2: Historical special influences on metal prices (here: cobalt and nickel)

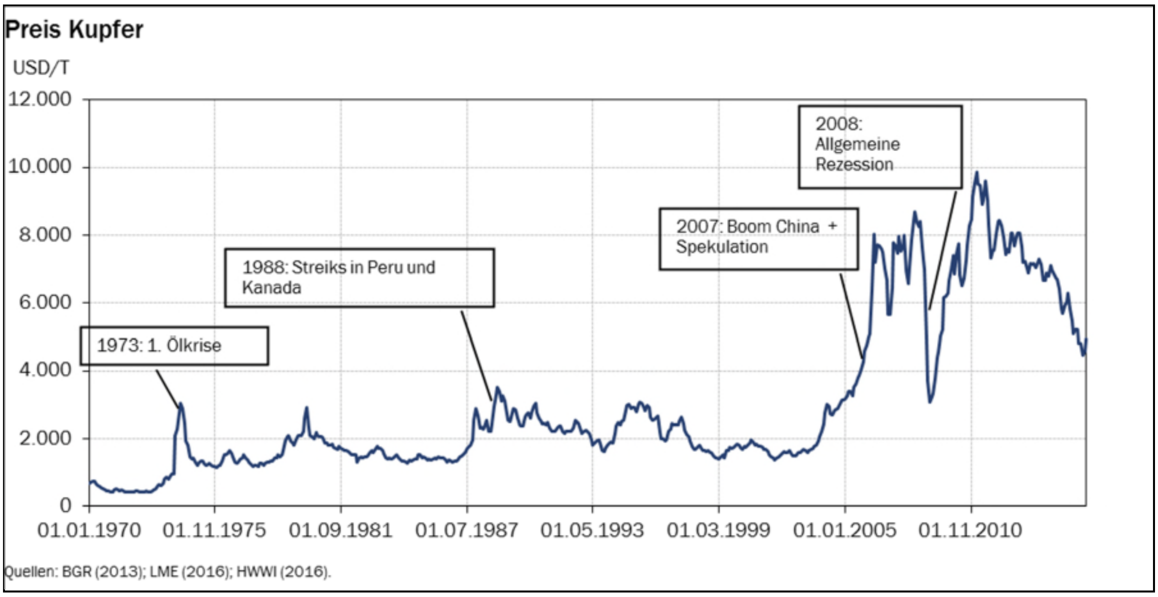


Fig. 3-2: Historical special influences on metal prices (here: copper)

All quantitative price forecasts ultimately represent model-based extrapolations of historical data. The assumptions contained in the model structure have quite a significant impact on the result of the projection. The model structure typically involves a target conflict between level of detail and transparency. It is theoretically possible to design models with any level of complexity in order to map with maximum precision the relationships between metal prices and their influence factors as they exist in reality. However, increasing complexity also always means a loss of transparency because structures and mechanisms of action become increasingly intransparent. Furthermore, an increasing number of variables also means greater data requirements, especially with regard to the updating of influence factors. Against this background, the analysis will be based on a rather simple, but still realistic approach with regard to the interdependencies assumed.

Price projections

Quantitative models for forecasting metal prices can be generally divided into two categories, i.e. univariant time series models and economic fundamental models. Whilst the future projections in models of the first category are based on a purely technical extrapolation of patterns, models of the second category explicitly try to base the projections on observed long-term correlations between prices and other parameters. A fundamental approach is adopted because longer-term price projections are essential for the purposes of this study. This also means that our price projections can be based on transparent assumptions regarding the development of possible influence factors. The projections are therefore scenario-based.

An econometric multi-equation model is used for each of the three metals analysed (cobalt, copper, nickel), with the structure underlying this model being taken from Smithson et. al. (1991). The models for copper and nickel are made up of three equations each. Dependent variables are the (nominal) exchange price, the global production rate and global consumption. Since no longer-term time series are available for cobalt consumption, the model is in this case limited to the explanation of price and production. The explanatory variables considered include the prices of substitute/complementary materials and inventory changes as well as parameters representing the general economic framework, such as global GDP and interest developments. Interaction between the equations is due to the fact that production and consumption are included as variables which have a direct or indirect influence on price development estimates. Interaction between supply and demand on the market is thereby mapped in the model. The observations represent individual years in each case, with simple annual averages used in the case of price variables which are available on a monthly basis.

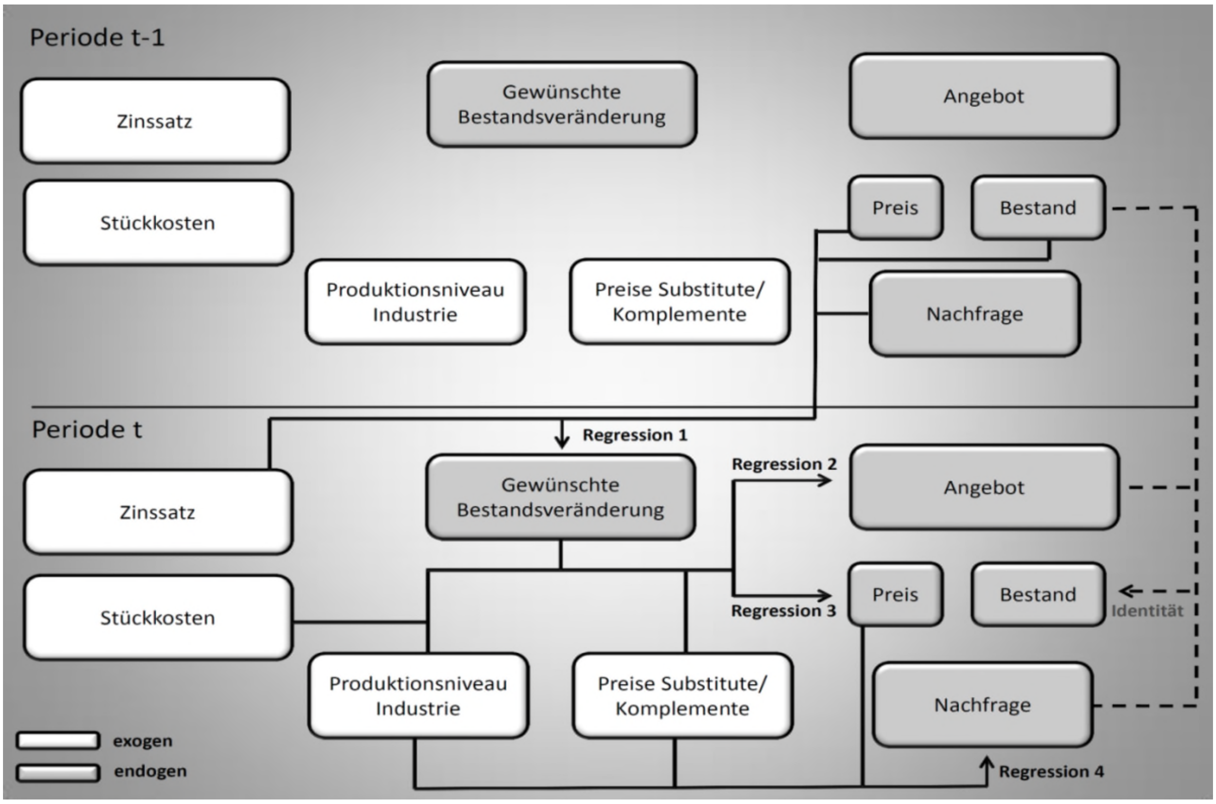


Fig. 3-3: Basic structure of the forecasting model

Fig. 3-3 is a schematic diagram of the basic structure of the model. In the practical estimation, this structure varies slightly between the metals examined, i.e. cobalt, copper and nickel.

As already mentioned, longer time series on global cobalt consumption are not available, so that the model is limited to explaining prices and production volumes in this case. Annexes 1.1 to 1.3 show the variables and model equations used as well as the regression results in detail.

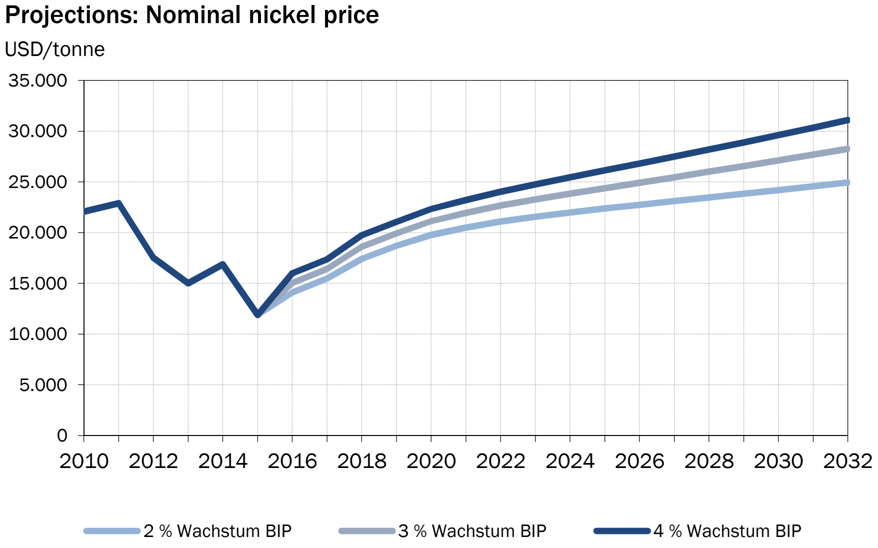
In the case of copper and nickel, the correlations assumed in the model prove to be statistically relevant for the greatest part, and the coefficients of determination are also relatively high. The adjusted models are therefore rated as suitable for our forecasting method. However, this does not apply to cobalt. In the past, the price for cobalt apparently failed to adequately mirror production and consumption trends, probably due to relatively strong supply concentration and related disturbance influences. Projection on this basis is therefore not considered to be suitable for cobalt. Since purely univariant autocorrelation models also fail to show any significant correlations in this case, this metal will be analysed in the following solely on the basis of historical prices.

The ex-post correlations determined by the regression analysis were subsequently extrapolated into the future. Assumptions regarding the development trajectories of the exogenous factors were made for this purpose. Since these development trajectories are of course also subject to forecasting uncertainties, a random approach was chosen in analogy to the cost analysis. This means that percentage changes in the value of the influence factors over the course of time are interpreted as normally distributed random variables. Expectations for these random variables were specified on the basis of historical average values, scatter values were based on assumptions regarding sensible upper and lower limits. As a central prerequisite for the validity of this approach, the correlations found must also be valid for future markets.

Results of the price projections

The results of the price projections resulting from the application of the expectation values and the influence factors considered will be presented in the following. Different annual growth rates are distinguished only in the case of global production (represented by global GDP) as the generally most important influence factor in order to document the sensitivity of the results to the corresponding assumptions.

The price of cobalt is not shown here because, as already mentioned, the model correlation tested is too weak for this metal.



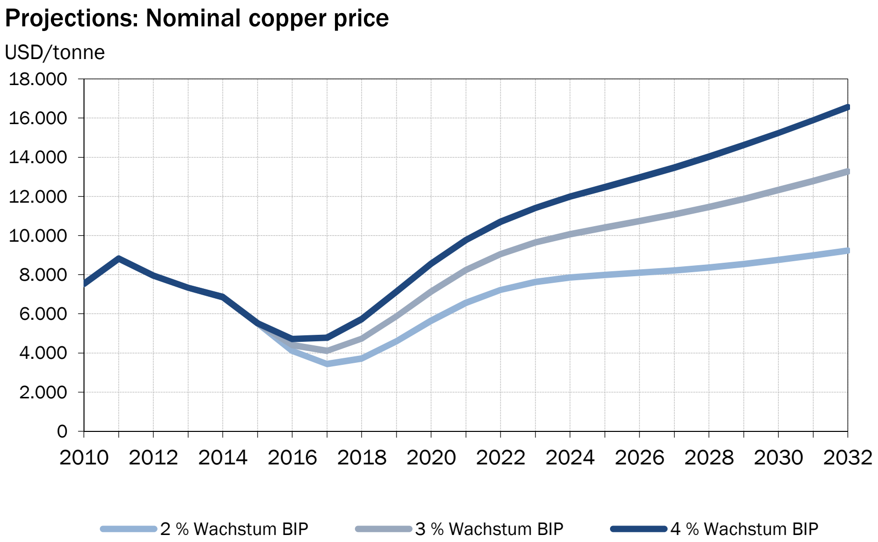


Fig. 3-4: Results of the price projections

Within a corridor of 2% to 4% GDP growth p.a. (a realistic value in historical terms), prices for both metals are forecast to increase in the long term. This ultimately results from the positive correlation between exchange price and the development of the global economy that was observed for both metals in the past. The assumption of stronger GDP growth hence also leads to a projection of a higher price growth rate. In the profitability analysis below, GDP growth – just like the other parameters too – will also be subjected to the above-described Monte Carlo draw where the historical average value of the last 30 years is used as the expected value of distribution, so that the inherent uncertainty of this parameter can be taken into consideration.

3.2 Costs of deep sea mining

3.2.1 Mining and smelting technologies for polymetallic nodules from the deep sea (CCZ)

Since the 1970s, various different concepts have been developed for mining polymetallic nodules and in some cases also been tested in trial facilities or at sea. These concepts are classified as follows; see also ISA, NIOT (2008):

- **Hydraulic mining system**

  The nodules are taken up by a collector that is either dragged over the seabed or actively self-propelled and conveyed through a pipe to the floating base (for instance, a specially equipped mining vessel).

  The vertical transport of the nodules in the conveyor pipe is effected by a system of centrifugal pumps or an airlift system and/or a combined pump/airlift system.

- **Continuous line bucket mining system**

  The nodules are collected on the seabed by a line bucket system, which is operated on one or two vessels, and conveyed to the surface.

- **Modular or shuttle mining system**

  The nodules are collected by an autonomous subsea vehicle with a collector system which is subsequently lifted to the surface activating a buoyancy reserve. The vehicle then docks on to the base vessel where it is emptied before it descends to the seabed for the next cycle.

In terms of large-scale industrial use, hydraulic mining is the system almost exclusively used today.

The continuous line bucket mining system and the modular or shuttle mining system are subject to certain inherent technical problems which, in addition to a number of fundamental issues in terms of reliable operation, are primarily related to issues of intervention in the marine environment (line bucket system) and costs (modular system). The line bucket system has been obsolete for many years, while the modular system is now limited to a very few cases.

A concept based on hydraulic mining with the following components – see Fig. Fig. 3-5 – is therefore chosen as the reference for this study.

1. **Mining vessel**
   - Propulsion with dynamic positioning features, for instance, in the form of azimuth thrusters
   - A moonpool that is connected via the conveying line.
   - A system for compensating for the vessel's pitching movements at the head of the conveying line
   - A rack for the pipe (riser) sections of the conveying line
   - Crane and other handling systems for assembling, lowering and raising the conveying line
   - Garage and handling systems for lowering and raising the collectors
   - Equipment for separating the nodule material from the two-phase or three-phase transport mixture
   - Equipment for separating the remaining solids/sediments from the transport water
   - Equipment for dewatering and, when necessary, further treatment of the nodule material
   - Hold for intermediate storage of the nodule material
   - Hawsers, winches, pulleys, catapults and further equipment for the temporary connection of the bulk carrier to the mining vessel
   - Pipelines, floating hose system, coupling devices and pumps for transferring (transshipment) of the nodule material to the bulk carrier

2. **Conveying line**
   - Riser sections with flexible or rigid couplings, with/without uplift elements
   - Pump systems (centrifugal pumps for the two-phase mixture of sea water and nodule material) integrated into several stations in the conveying line,
     or
     airlift system with injection of air into the riser at two or three subsea levels of the conveying line (three-phase mixture of sea water, nodule material and air)

- Buffer (intermediate storage) arranged at the lower end of the riser in order to compensate for swell during the extraction of the nodules by the collectors and therefore to generate a largely continuous feed-in rate into the riser
- Flexible hose system between the buffer and the collectors in order to largely de-couple the movements and current positions of the conveying line and of the collectors
- Power and data cables integrated into the riser sections and the flexible hose system
- Sensors, control and instrumentation systems

3. Collector

- Crawler chassis with drive and collector housing; suitable dimensions of crawlers and arrangement of the wheels in order to ensure a low penetration depth into the sediment
- Nodule collection system, crusher, pumps, sediment separator
- Sensors and navigation, control and instrumentation systems

4. Process water separation system

- Connection to the conveying line
- Riser sections with flexible or rigid couplings
- Pump systems to return the cleaned process water to a subsea level that corresponds to mining level
- Power and data cables integrated into the riser sections
- Sensors, control and instrumentation systems

5. Bulk carrier to transport the nodules from the mining area to the base harbour

- Number of carriers used, cargo capacity and speed (eco) in line with the logistics concept
- Equipment for docking on to the mining vessel and offshore loading (transshipment)

This concept for mining polymetallic nodules reflects the state of the art, including the latest results of the EU's ongoing 'Blue Mining' and 'Blue Nodules' research projects.

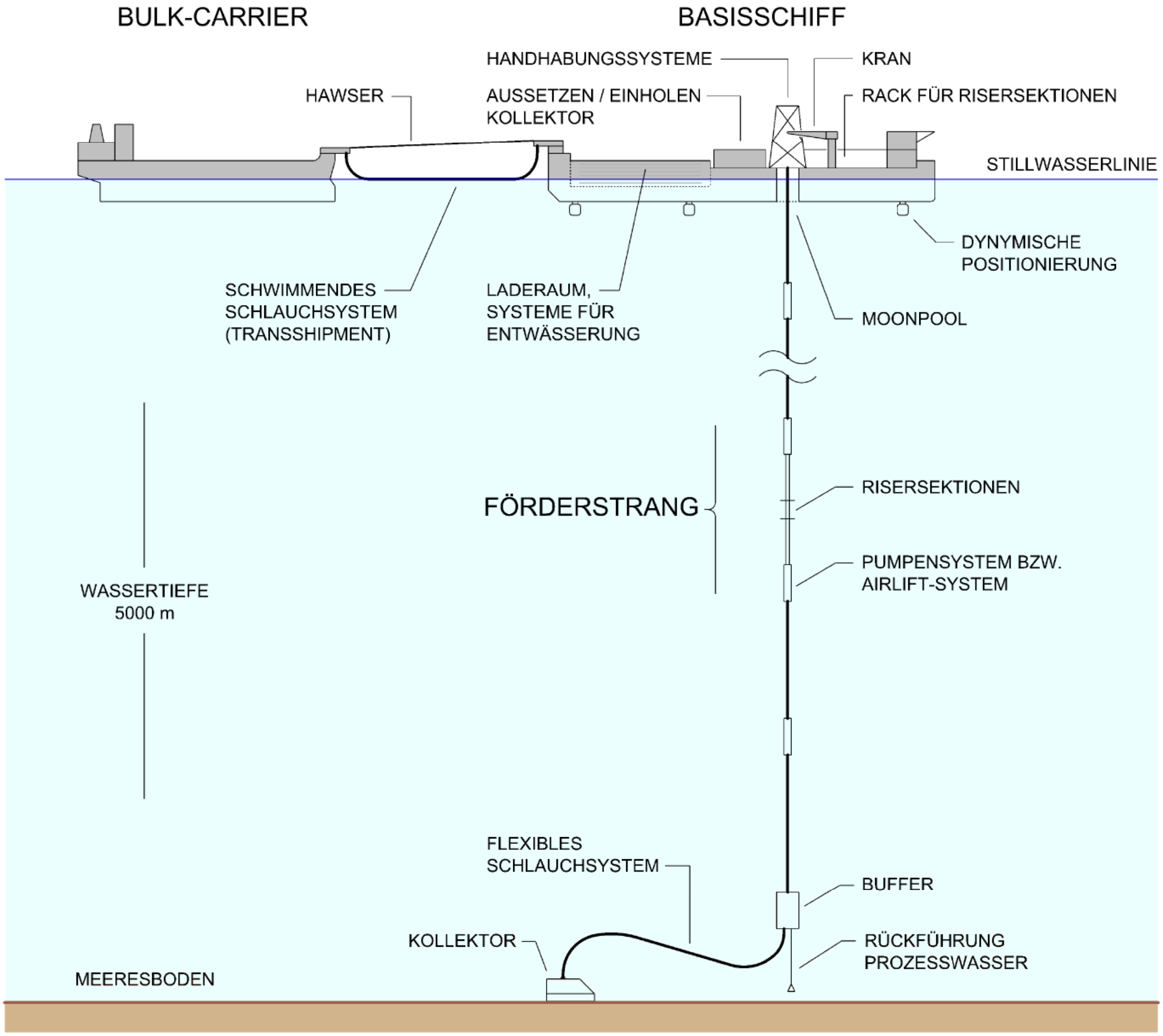


Fig. 3-5: Reference system for mining polymetallic nodule, consisting of mining vessel, conveying line, collectors, process water discharge system, bulk carrier and loading system (transshipment).

The other elements of the overall system, including smelting/metallurgical operations, are:

6. **Harbour facilities (base harbour)**
   - Transshipment and warehouse systems
   - Buildings, open spaces and infrastructure
7. **Processing and smelting plants**
   - Nodule material processing plants
   - Plants for the metallurgical extraction of the metals
   - Disposal of residual material
   - Buildings
   - Transshipment systems
   - Open spaces and infrastructure

Research and development primarily focus on the following processes for the metallurgical extraction of metals from the material of polymetallic nodules:

I. Reduction roast/ammonia leaching

II. High-pressure/high-temperature leaching
using sulphuric acid

III. Pressure leaching with ammonium carbonate solution
(Cuprion process)
Cuprion ammonia leaching

IV. Smelting followed by sulphuric acid leaching

V. Selective reduction followed by leaching with hydrochloric acid
Reduction and hydrochloric acid leaching

VI. INCO process

See Cardno (2016); Randhawa, Hait (2016);
Friedmann, Pophanken, Friedrich (2015);
Friedrich, Friedmann (2015); ISA (2013);
Pophanken, Friedmann, Friedrich (2013);
Friedrich, Pophanken (2013); United Nations (1986).

The processes mentioned under I to V are shown and evaluated in Table 3-4; see page 8.

The processes I to III and VI include the extraction of copper, cobalt and nickel, whilst the processes IV and V additionally extract manganese. In the case of the processes I and VI, it is also possible to extract manganese from the slags in another process step.

Further differences between the processes lie in the extraction rates possible today for the different metals, energy demand, the concentration of the acids and lyes used (corrosion) as well as in investment and operating costs.

The INCO route is very similar to the metallurgical primary route of nickel production. The process steps of the INCO process are therefore largely known in other metallurgical industries.

Advantages compared to other processes include lower acid and water consumption, less waste water, less leaching residues and precipitates as well as easier production of valuable metals.

Furthermore, the INCO process also includes points where technology metals can be concentrated and thereby channelled out as (intermediate) products from the process. Furthermore, molybdenum and vanadium can be extracted from the slag; see Pophanken, Friedmann, Friedrich (2013).

The INCO process also permits the extraction of manganese or ferromanganese from the slag, however, at an additional cost.

Although the need to dry the polymetallic nodules requires higher energy input for the pyrometallurgical INCO process compared to purely hydrometallurgical processes, significantly larger volumes of lye must be heated in the latter case.

All pyrometallurgical and hydrometallurgical processes are currently at laboratory and/or pilot scale for the melting of polymetallic nodules.

3.2.2 Investment and operating costs for polymetallic nodules

The determination of investment and operating costs is based on the overall system described above and the following operating conditions:

- Mining of polymetallic nodules in BGR's licence territory in the Clarion-Clipperton Zone
- Average water depth: 5000m
- Average population density
  Wet weight (lower limit): 16.5 kg/sqm
- Extraction rate: 3.0 million tonnes p.a. (dry material)
- Mining operation hours: 7,200 hours = 300 days p.a.
  corresponding to an availability rate of: 82%
- Location of base harbour: Lazaro Cardenas, Mexico
- Average distance between
  mining area and base harbour: 1000 nautical miles
- Location of processing and smelting plants: Mexico

The following main parameters are derived from these requirements:

- **Mining vessel:**
  - Overall length 270.0 m
  - Width: 40.0 m
  - Moulded depth: 19.5 m
  - Draught (during mining): 12.5 m
  - Displacement: 125,000 t
  - Nodule material carrying capacity: 55,000 t
  - Power: 15,000 kW
  - Total crew: 59 max.
- **Bulk carriers:**
  - Quantity 2 -
  - Class: Supramax
  - Overall length 190.0 m
  - Width: 32.0 m
  - Draught (during mining): 12.5 m
  - Speed from logistics: 12.0 knots
  - Nodule material carrying capacity: 50,000 t
  - Number of trips p.a.: 2 x 34 trips p.a.
- **Conveying line:**

- Average density of the two-phase mixture of sea water and nodule material: 1,150 – 1,300 kg/m³

Pump system operation:

– Average pumping rate of the two-phase mixture:	4.0 – 4.5	m/sec
– Number of pump stations:	4 – 8	-
– Nominal width of riser sections, including liner:	13 - 15	inches

Airlift system operation:

– Number of feed-in points:	2 – 4	-
– Nominal width of riser section:	13 - 28	inches

- **Collectors:**

– Quantity	2	-
– Width of node collection system	10	m
– Average speed of the collector:	0.5	m/sec
– Collection efficiency:	0.8	-

- **Discharge system for process water, with pump system:**
  - Connection to the conveying line

– Average pumping rate of the cleaned process water:	1.7 – 2.1	m/sec
– Number of pump stations:	2 - 3	-
– Nominal width of riser section:	18 - 20	inches

- **Harbour facilities (base harbour):**
  - Acquisition of suitable property with pier (water access)
  - Space requirement of approx. 30,000 m^2
  - Pier length of approx. 300m
  - Groundworks and technical equipment
  - Building (office and social rooms)
  - Facilities for unloading the bulk carriers
  - Conveyor belts, earthmovers and further transshipment and warehousing equipment

- **Processing and smelting plants:**

  A decision for a particular process is not possible given the present state of research and development in the field of metallurgy.

  The investment and operating costs assumed for the metallurgical plant correspond to processes which have already reached market maturity in other areas where, for instance, high-pressure/high-temperature acid leaching using sulphuric acid (HP-HT-AL) was adopted; see section 3.1.1, page 7.

- **Research vessel for environmental monitoring**

  Monitoring of the marine environment as well as the observation, measurement and evaluation of the effects of the different processes are key elements of industrial deep sea mining. This is why the acquisition of a suitable research vessel, including complete equipment for environmental monitoring, is considered as part of the assessment of investment costs.

Based on the information available to the expert group, investment and operating costs are estimated as follows:

- State of the cost level as per 2016
- All prices are quoted in US dollars (USD) as the lead currency for both international commodity industries as well as offshore systems.
- The cost estimates include additional uncertainties because many details were still unclear at the time the study was written. This is why bands with upper and lower limits are specified for the costs (upper and lower approach) to be considered in the commercial analysis.
- Investment costs in each case also include the costs for engineering services, system integration, commissioning and testing.
- The cost estimate further considers the results of the following projects which were or still are being carried out with major involvement on the part of Ramboll IMS and MH Wirth:
  - BLUE MINING – Breakthrough Solutions for the Sustainable Deep Sea Mining Value Chain
    Funding organisation: European Commission, EU 7th Framework Programme for Research (RP7)
    Period: 2014 – 2017
  - Polymetallic Nodule Mining – Economical Study
    Commissioned by: DeepGreen Resources Inc. Vancouver
    Period: 2014 – 2015

– Wirtschaftlichkeitsuntersuchungen eines Konzepts für den Abbau von polymetallischen Knollen aus der Tiefsee [Analysis of the economic efficiency of a concept for mining polymetallic nodules from the deep sea]
  Commissioned by: Federal Ministry for Economic Affairs and Energy (BMWi)
  Period: 2011 – 2012
– Technische Entwicklung und Wirtschaftlichkeitsuntersuchungen eines Konzepts für den Abbau von polymetallischen Knollen aus der Tiefsee [Technical development and analysis of the economic efficiency of a concept for mining polymetallic nodules from the deep sea]
  Commissioned by: Federal Institute for Geosciences and Natural Resources
  Period: 2009 – 2010

The results of the investment cost estimates are compiled in Table 3-6 to Table 3-12 and Fig. 3-6 to Fig. 3-11.

Table 3-13 shows the individual items of the list of investment costs vs. the relevant economic activities.

Table 3-14 to Table 3-17 and Fig. 3-12 to Fig. 3-15 additionally show the operating cost estimates.

Table 3-6 is a detailed list of total investment costs for the following items:

1. Mining vessel
2. Conveying line
3. Collector
4. Process water separation system
5. Bulk carriers
6. Harbour facilities
7. Processing and smelting plants
8. Research vessel for environmental monitoring
9. Disciplines on behalf of owner

Investment costs with the upper and lower limits were determined for the following scenarios:

- Primary German supply
- Primary European supply
- International supply

Two possible supply options were considered for the bulk carriers as follows: new build or second market (second-hand market) and retrofit as required. Acquisition of second-hand vessels could save costs of 24 to 26 million USD, i.e. 1.5 to 2.1% of total investment costs, depending on the underlying scenario. Unless stated otherwise, the investment costs represent the costs of newly built bulk carriers.

Total investment costs amount to
(newly built bulk carriers):

- Primary German supply: 1392 to 1693 million USD
- Primary European supply: 1377 to 1683 million USD
- Primary international supply 1245 to 1644 million USD

Compared to German supply, cost savings are relatively low for the 'European' and 'international' options:

- Primary European supply: 0.59 to 1.08 %
- Primary international supply 2.89 to 10.56 %

The main reason being that investment focuses on top-notch, often innovative technologies where sourcing on international markets does not generate significant cost savings compared to German or European sources.

Table 3-7 summarises the investment costs for the various items in order to provide a better overview.

Fig. 3-6 shows the distribution of the investment costs for the mining system to its individual components, i.e.:

- Mining vessel
- Conveying line
- Collector
- Process water separation system

The above-mentioned option of *primary Germany supply* is chosen in the following example. In this case, investment costs for the mining system total 626 million USD, with the conveying line accounting for 39.1%, the mining vessel 33.2%, the collector 14.1% and the separation system 13.6%.

Table 3-6-1: Investment cost estimate
Detailed breakdown

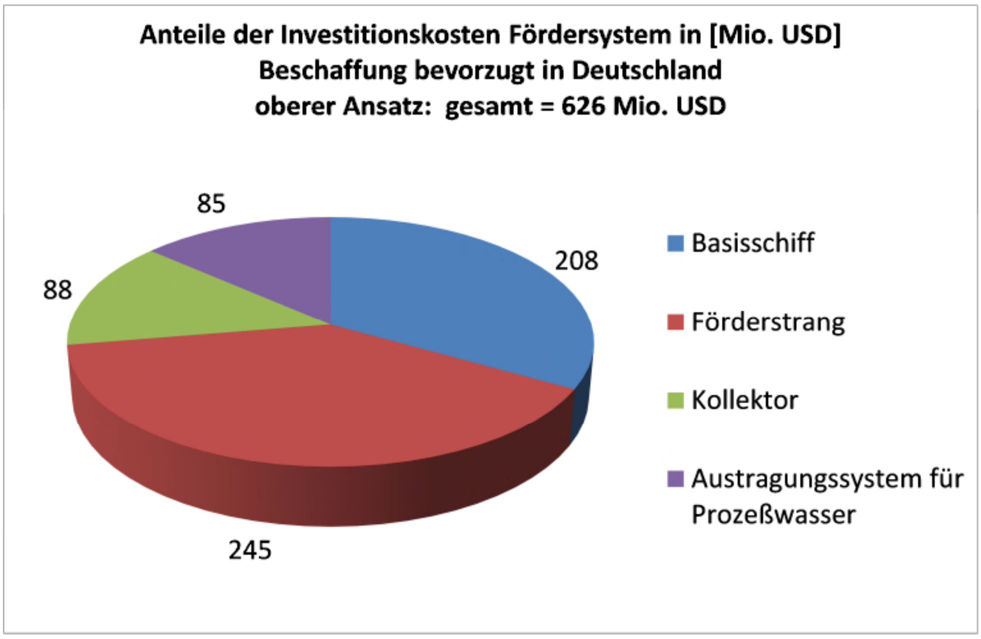
				Schätzung der Investitionskosten [Mio. USD]					
Pos.	**Beschreibung**	**Anzahl**		**Beschaffung bevorzugt in Deutschland**		**Beschaffung bevorzugt in Europa**		**Beschaffung international**	
		Einsatz	**Reserve**	**unterer Ansatz**	**oberer Ansatz**	**unterer Ansatz**	**oberer Ansatz**	**unterer Ansatz**	**oberer Ansatz**
1	**Basisschiff (Förderplattform)**	**1.0**	**0.0**	**172.0**	**208.0**	**162.0**	**198.0**	**137.0**	**173.0**
1.1	Schiffskörper	1.0	0.0	58.0	65.0	48.0	55.0	30.0	36.0
1.2	Schiffsspezifische Ausrüstung	1.0	0.0	55.0	72.0	55.0	72.0	50.0	68.0
1.3	Abbauspezifische Ausrüstung	1.0	0.0	45.0	55.0	45.0	55.0	45.0	55.0
1.4	Werftkosten	1.0	0.0	14.0	16.0	14.0	16.0	12.0	14.0
2	**Förderstrang**	**1.0**	**1.0**	**208.0**	**245.0**	**208.0**	**245.0**	**189.0**	**245.0**
2.1	Risersektionen mit flexiblen oder starren Kopplungen, mit/ohne Auftriebselemente, bei Airlift-System zusätzlich Leitungen zur Luftversorgung	1.0	1.0	115.0	125.0	115.0	125.0	105.0	125.0
2.2	Pumpensystem bzw. Airlift-System	1.0	1.0	50.0	60.0	50.0	60.0	45.0	60.0
2.3	Buffer (Zwischenspeicher)	1.0	1.0	15.0	18.0	15.0	18.0	14.0	18.0
2.4	Flexibles Schlauchsystem zwischen Buffer und Kollektoren	2.0	2.0	20.0	28.0	20.0	28.0	18.0	28.0
2.5	Kabel zur Energie- und Datenübertragung, integriert in Risersektionen und flexiblem Schlauchsystem, Sensorik, Mess- und Kontroll-Systeme	1.0	1.0	8.0	14.0	8.0	14.0	7.0	14.0
3	**Kollektor**	**2.0**	**2.0**	**72.0**	**88.0**	**72.0**	**88.0**	**64.0**	**84.0**
3.1	Fahrwerk mit Antrieb und Einhausung des Kollektors	2.0	2.0	16.0	20.0	16.0	20.0	14.0	20.0
3.2	Knollenaufnahmesystem, Brechwerk und Pumpen	2.0	2.0	34.0	42.0	34.0	42.0	30.0	38.0
3.3	Sensorik und Navigation, Meß- und Kontroll-Systeme	2.0	2.0	22.0	26.0	22.0	26.0	20.0	26.0
4	**Austragungssystem für Prozeßwasser**	**1.0**	**1.0**	**69.0**	**85.0**	**69.0**	**85.0**	**60.0**	**85.0**
4.1	Risersektionen mit flexiblen/starren Kopplungen	1.0	1.0	42.0	50.0	42.0	50.0	35.0	50.0
4.2	Pumpen-System	1.0	1.0	24.0	30.0	24.0	30.0	22.0	30.0
4.3	Sensorik, Mess- und Kontroll-Systeme	1.0	1.0	3.0	5.0	3.0	5.0	3.0	5.0

Table 3-6-2: Investment cost estimate
Detailed breakdown

				Schätzung der Investitionskosten [Mio. USD]					
Pos.	Beschreibung	Anzahl		Beschaffung bevorzugt in Deutschland		Beschaffung bevorzugt in Europa		Beschaffung international	
		Einsatz	Reserve	unterer Ansatz	oberer Ansatz	unterer Ansatz	oberer Ansatz	unterer Ansatz	oberer Ansatz
5-A	**Bulk-Carrier (Neubau)**	**2.0**	**0.0**	**103.0**	**127.0**	**103.0**	**127.0**	**101.0**	**127.0**
5.1-A	Neubau Supramax Bulkcarrier	2.0	0.0	85.0	95.0	85.0	95.0	85.0	95.0
5.2-A	Ausrüstung für die Offshore-Beladung des Bulk-Carriers (Transshipment)	2.0	0.0	18.0	32.0	18.0	32.0	16.0	32.0
5-B	**Bulk-Carrier (Secondhand)**	**2.0**	**0.0**	**79.0**	**101.0**	**79.0**	**101.0**	**75.0**	**101.0**
5.1-B	Beschaffung Secondhand Supramax Bulkcarrier	2.0	0.0	55.0	65.0	55.0	65.0	55.0	65.0
5.2-B	Umrüstung für die Offshore-Beladung des Bulk-Carriers (Transshipment)	2.0	0.0	24.0	36.0	24.0	36.0	20.0	36.0
6	**Hafenanlagen**	**1.0**	**0.0**	**45.0**	**60.0**	**45.0**	**60.0**	**40.0**	**60.0**
6.1	Umschlag- und Lagertechnik, Gebäude	1.0	0.0	35.0	45.0	35.0	45.0	30.0	45.0
6.2	Flächen und Infrastruktur	1.0	0.0	10.0	15.0	10.0	15.0	10.0	15.0
7	**Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)**	**1.0**	**0.0**	**610.0**	**730.0**	**610.0**	**730.0**	**560.0**	**730.0**
7.1	Anlagentechnik und Gebäude	1.0	0.0	550.0	650.0	550.0	650.0	500.0	650.0
7.2	Flächen und Infrastruktur	1.0	0.0	60.0	80.0	60.0	80.0	60.0	80.0
8	**Forschungsschiff zur Umweltüberwachung**	**1.0**	**0.0**	**70.0**	**80.0**	**65.0**	**80.0**	**55.0**	**70.0**
8.1	Neubau eines speziell für das Umweltmonitoring beim Tiefseebergbau ausgelegten Forschungsschiffes	1.0	0.0	45.0	50.0	40.0	50.0	35.0	40.0
8.2	Ausrüstung für das Umweltmonitoring	1.0	0.0	25.0	30.0	25.0	30.0	20.0	30.0
9	**Leistungen des Bauherrn**	**1.0**	**0.0**	**43.0**	**70.0**	**43.0**	**70.0**	**39.0**	**70.0**
9.1	Ingenieurleistungen, Überwachung	1.0	0.0	20.0	30.0	20.0	30.0	16.0	30.0
9.2	Zertifizierungen / Klasse	1.0	0.0	8.0	15.0	8.0	15.0	8.0	15.0
9.3	Management	1.0	0.0	15.0	25.0	15.0	25.0	15.0	25.0

Table 3-7: Investment cost estimate
Summary

				Schätzung der Investitionskosten [Mio. USD]					
Pos.	Beschreibung	Anzahl		Beschaffung bevorzugt in Deutschland		Beschaffung bevorzugt in Europa		Beschaffung international	
		Einsatz	Reserve	unterer Ansatz	oberer Ansatz	unterer Ansatz	oberer Ansatz	unterer Ansatz	oberer Ansatz
1	Basisschiff (Förderplattform)	1.0	0.0	172.0	208.0	162.0	198.0	137.0	173.0
2	Förderstrang	1.0	1.0	208.0	245.0	208.0	245.0	189.0	245.0
3	Kollektor	2.0	2.0	72.0	88.0	72.0	88.0	64.0	84.0
4	Austragungssystem für Prozeßwasser	1.0	1.0	69.0	85.0	69.0	85.0	60.0	85.0
5-A	Bulk-Carrier (Neubau)	2.0	0.0	103.0	127.0	103.0	127.0	101.0	127.0
5-B	Bulk-Carrier (Secondhand)	2.0	0.0	79.0	101.0	79.0	101.0	75.0	101.0
6	Hafenanlagen	1.0	0.0	45.0	60.0	45.0	60.0	40.0	60.0
7	Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	1.0	0.0	610.0	730.0	610.0	730.0	560.0	730.0
8	Forschungsschiff zur Umweltüberwachung	1.0	0.0	70.0	80.0	65.0	80.0	55.0	70.0
9	Leistungen des Bauherrn	1.0	0.0	43.0	70.0	43.0	70.0	39.0	70.0
	Gesamtinvestitionskosten mit Neubau der Bulk-Carrier			1392.0	1693.0	1377.0	1683.0	1245.0	1644.0
	Gesamtinvestitionskosten mit Beschaffung der Bulk-Carrier auf dem Zweiten Markt			1368.0	1667.0	1353.0	1657.0	1219.0	1618.0



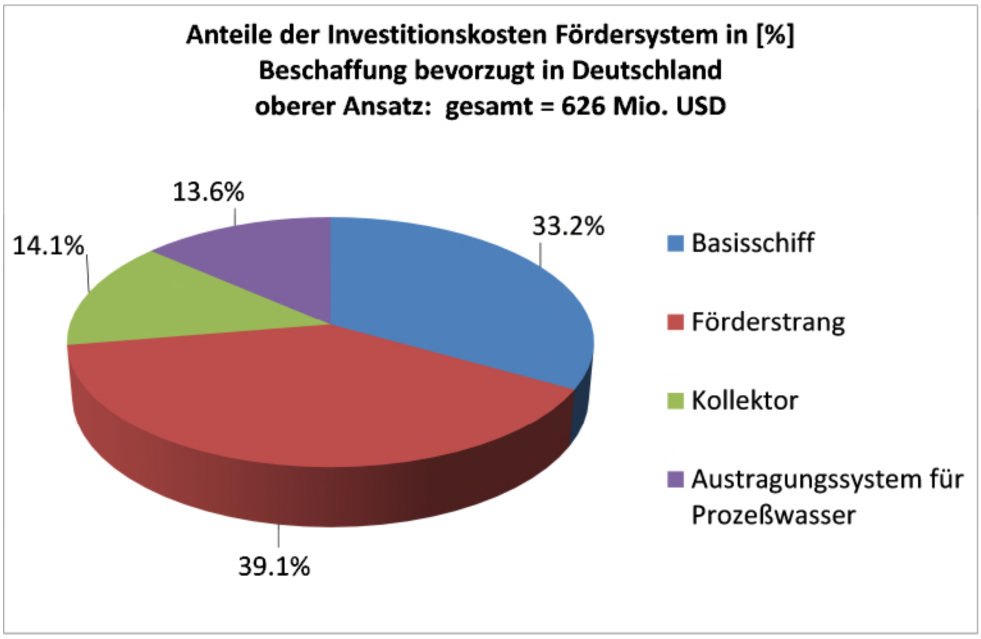


Fig. 3-6: Investment cost estimate for the mining system consisting of mining vessel, conveying line, collector and process water separation system

Primary German supply
Upper approach

Table 3-8 to Table 3-10 and Fig. 3-7 to Fig. 3-9 summarise the investment costs in the following groups and show the respective shares for the *upper approach*:

- Mining system (items 1 to 4)
- Bulk carriers (second hand) and harbour facilities (items 5B and 6)
- Processing and smelting plants (item 7)
- Research vessel for environmental monitoring (item 8)
- Disciplines on behalf of owner (item 9)

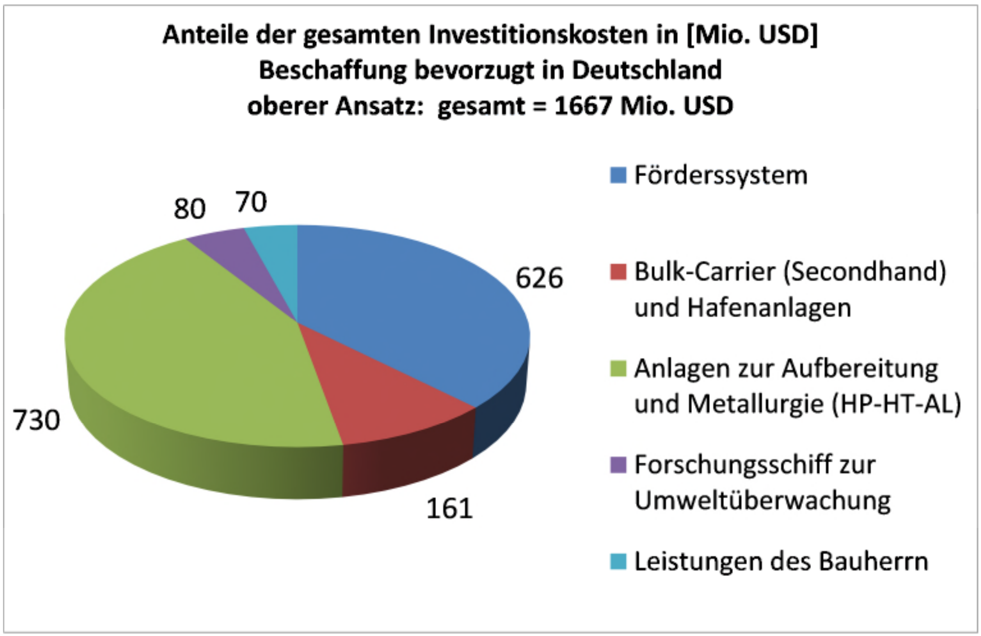
in each case for supply:

- primarily German
- primarily European
- international

The processing and smelting plants (43.8 to 45.1%) and the mining system (36.3 to 37.6%) together account for around 80% of total investment costs of 1,618 to 1,667 million USD. The bulk carriers and the harbour facilities account for 9.7 to 10%, the research vessel for 4.3 to 4.8% and disciplines on behalf of the owner for 4.2 to 4.3%.

Table 3-8: Estimates of investment costs and their respective shares in total investment costs
Primary German supply

				Schätzung der Investitionskosten			
Pos.	Beschreibung	Anzahl		Beschaffung bevorzugt in Deutschland			
				[Mio. USD]		Anteil an Gesamtinvestitionskosten	
		Einsatz	Reserve	unterer Ansatz	oberer Ansatz	unterer Ansatz	oberer Ansatz
1 - 4	Förderssystem	1.0	0.0	521.0	626.0	38.1%	37.6%
5B + 6	Bulk-Carrier (Secondhand) und Hafenanlagen	1.0	1.0	124.0	161.0	9.1%	9.7%
7	Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	2.0	2.0	610.0	730.0	44.6%	43.8%
8	Forschungsschiff zur Umweltüberwachung	1.0	1.0	70.0	80.0	5.1%	4.8%
9	Leistungen des Bauherrn	2.0	0.0	43.0	70.0	3.1%	4.2%
	Gesamtinvestitionskosten mit Beschaffung der Bulk-Carrier auf dem Zweiten Markt			1368.0	1667.0	100.0%	100.0%



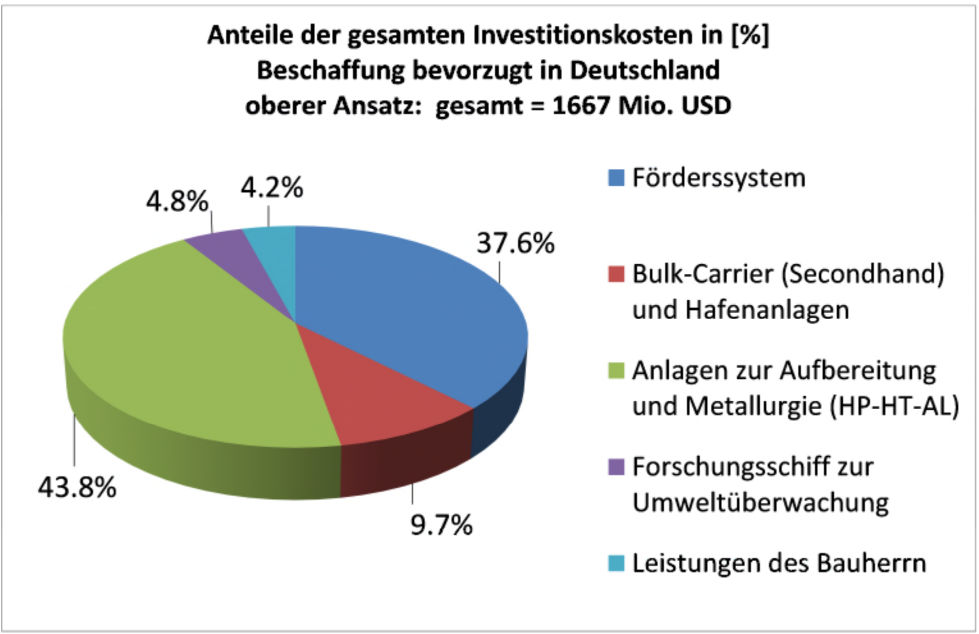
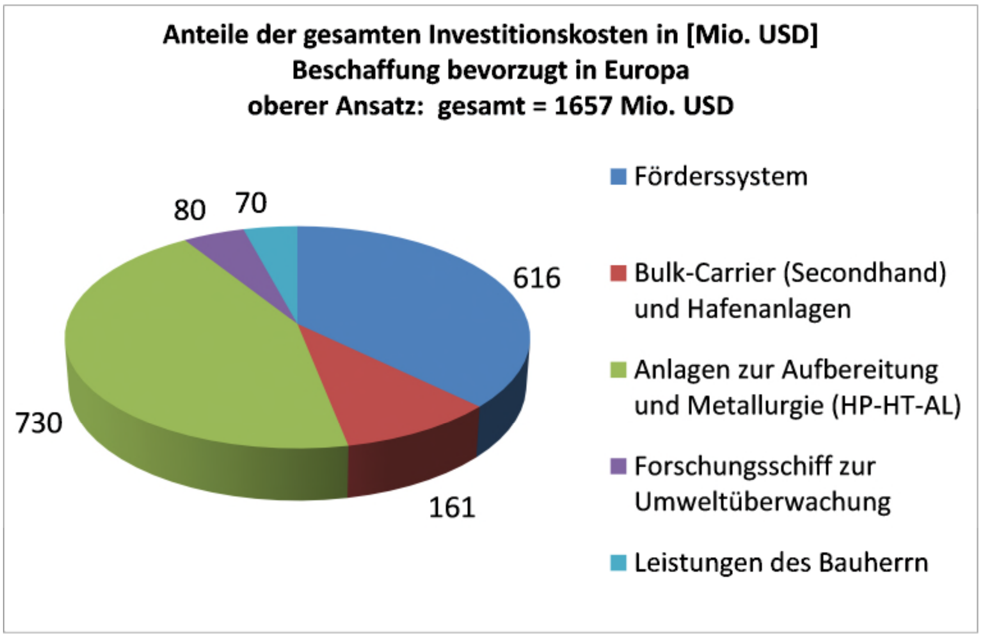


Fig. 3-7: Estimates of investment costs and their respective shares in total investment costs

Primary German supply
Upper approach

Table 3-9: Estimates of investment costs and their respective shares in total investment costs
Primary European supply

Pos.	Beschreibung	Anzahl		Schätzung der Investitionskosten – Beschaffung bevorzugt in Europa			
				[Mio. USD]		Anteil an Gesamtinvestitionskosten	
		Einsatz	Reserve	unterer Ansatz	oberer Ansatz	unterer Ansatz	oberer Ansatz
1 - 4	Förderssystem	1.0	0.0	511.0	616.0	37.8%	37.2%
5B + 6	Bulk-Carrier (Secondhand) und Hafenanlagen	1.0	1.0	124.0	161.0	9.2%	9.7%
7	Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	2.0	2.0	610.0	730.0	45.1%	44.1%
8	Forschungsschiff zur Umweltüberwachung	1.0	1.0	65.0	80.0	4.8%	4.8%
9	Leistungen des Bauherrn	2.0	0.0	43.0	70.0	3.2%	4.2%
	Gesamtinvestitionskosten mit Beschaffung der Bulk-Carrier auf dem Zweiten Markt			1353.0	1657.0	100.0%	100.0%



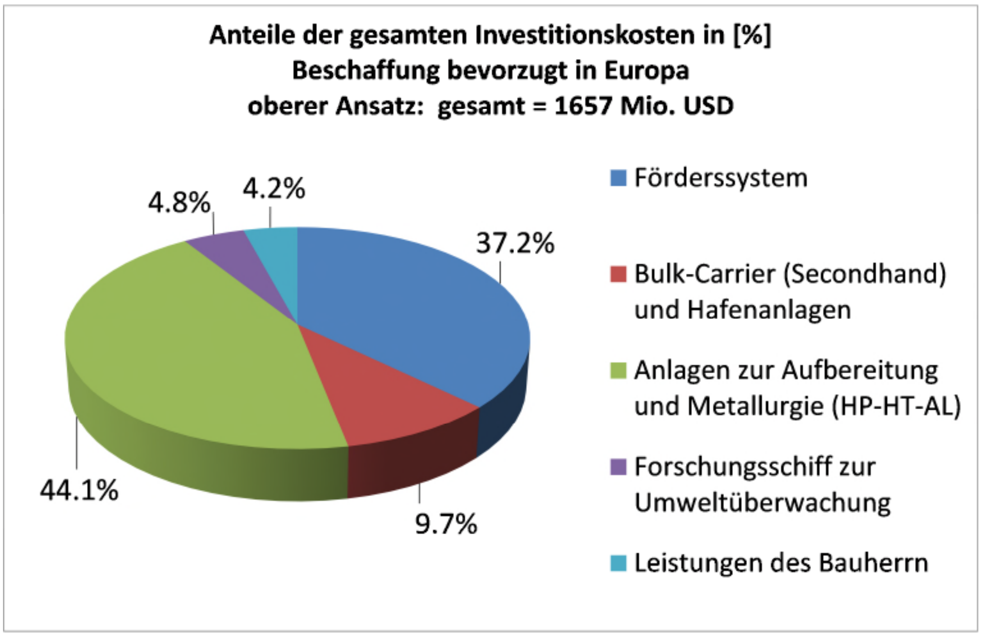
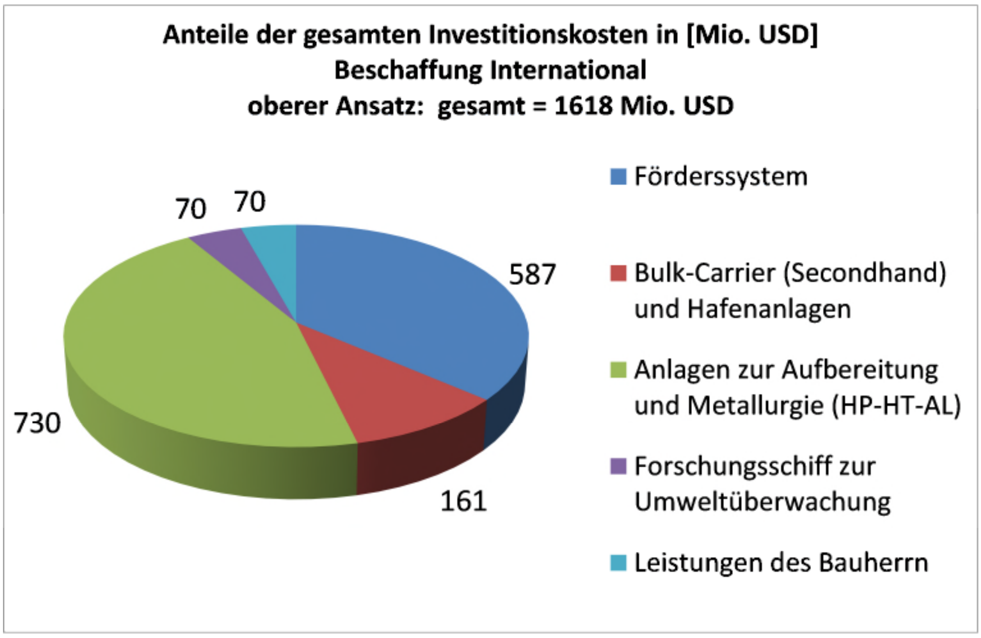


Fig. 3-8: Estimates of investment costs and their respective shares in total investment costs

Primary European supply
Upper approach

Table 3-10: Estimates of investment costs and their respective shares in total investment costs International supply

Pos.	Beschreibung	Anzahl		Schätzung der Investitionskosten Beschaffung international			
				[Mio. USD]		Anteil an Gesamtinvestitionskosten	
		Einsatz	Reserve	unterer Ansatz	oberer Ansatz	unterer Ansatz	oberer Ansatz
1 - 4	Förderssystem	1.0	0.0	450.0	587.0	36.9%	36.3%
5B + 6	Bulk-Carrier (Secondhand) und Hafenanlagen	1.0	1.0	115.0	161.0	9.4%	10.0%
7	Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	2.0	2.0	560.0	730.0	45.9%	45.1%
8	Forschungsschiff zur Umweltüberwachung	1.0	1.0	55.0	70.0	4.5%	4.3%
9	Leistungen des Bauherrn	2.0	0.0	39.0	70.0	3.2%	4.3%
	Gesamtinvestitionskosten mit Beschaffung der Bulk-Carrier auf dem Zweiten Markt			1219.0	1618.0	100.0%	100.0%



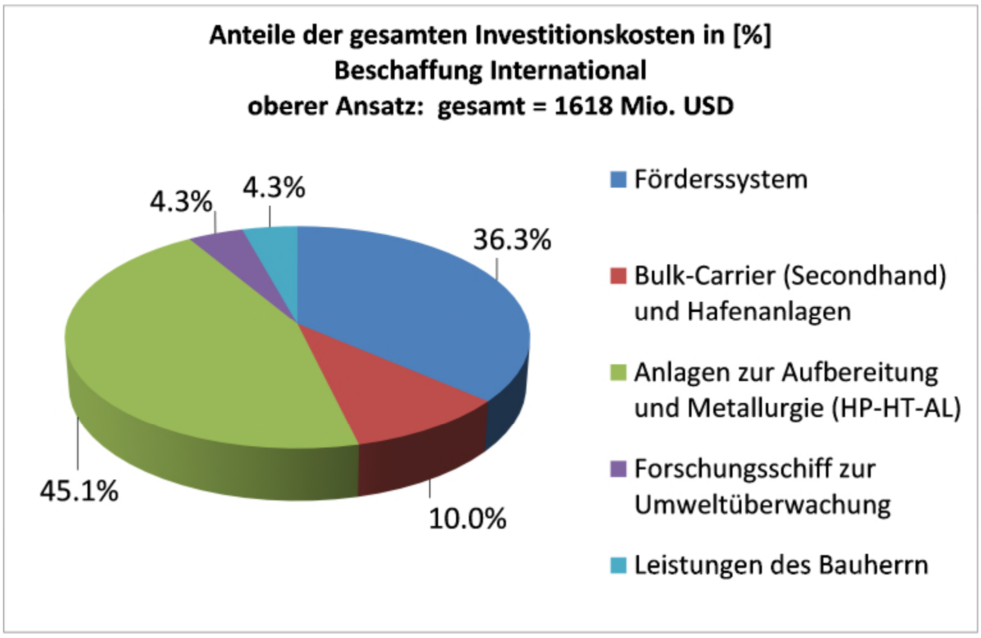


Fig. 3-9: Estimates of investment costs and their respective shares in total investment costs

International supply
Upper approach

In order to set up a detailed list of investment costs, the achievable delivery share of German suppliers is estimated for the individual items. The *International supply* scenario was used as basis for this. In this case too, the results are shown as a band with an upper and a lower limit (upper and lower approach).

TableTable 3-11 and Table 3-12 show the achievable delivery shares in detailed form and as a summary.

German suppliers can achieve the following shares in total investment costs:

- Total investment costs: 1245 to 1644 million USD
- Achievable German delivery share: 325 to 959 million USD
  corresponding to: 26.1 to 58.4 %

The clear difference between the upper and lower limit shows that the success of German suppliers on the technology market for deep sea mining applications will depend on several factors:

- Quality
- Price
- Reference system
- Access to international consortiums
- Possible market access restrictions

Fig. 3-10 and Fig. 3-11 show the achievable delivery share of German suppliers for the following groups, in each case for the lower and upper approach:

- Mining system (items 1 to 4)
- Bulk carriers (second hand) and harbour facilities (items 5B and 6)
- Processing and smelting plants (item 7)
- Research vessel for environmental monitoring (item 8)
- Disciplines on behalf of owner (item 9)

Although the processing and smelting equipment (150 to 455 million USD) and the mining system (129 to 393 million USD) account for a large volume, the research vessel also offers good prospects for a high delivery share.

The percentages shown in the diagrams describe the respective shares in the total volume (in million USD) of the mining system and the other four groups considered. The percentages therefore do not add up to 100%. In the ideal case of a 100% delivery share in all five groups, the total would hence amount to 500%.

Table 3-11-1: Estimate of investment costs and of the achievable German delivery share International supply

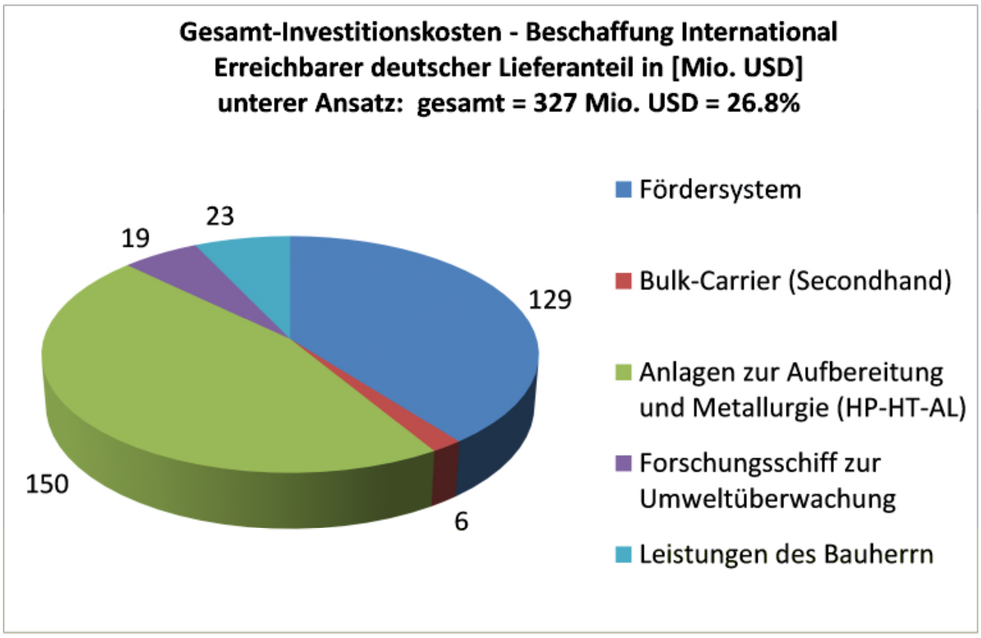
				Beschaffung international			
Pos.	**Beschreibung**	**Anzahl**		**Schätzung der Investitionskosten [Mio. USD]**		**erreichbarer deutscher Lieferanteil**	
		Einsatz	**Reserve**	**unterer Ansatz**	**oberer Ansatz**	**unterer Ansatz**	**oberer Ansatz**
1	**Basisschiff (Förderplattform)**	**1.0**	**0.0**	**137.0**	**173.0**		
1.1	Schiffskörper	1.0	0.0	30.0	36.0	0%	20%
1.2	Schiffsspezifische Ausrüstung	1.0	0.0	50.0	68.0	30%	75%
1.3	Abbauspezifische Ausrüstung	1.0	0.0	45.0	55.0	50%	75%
1.4	Werftkosten	1.0	0.0	12.0	14.0	0%	50%
2	**Förderstrang**	**1.0**	**1.0**	**189.0**	**245.0**		
2.1	Risersektionen mit flexiblen oder starren Kopplungen, mit/ohne Auftriebselemente, bei Airlift-System zusätzlich Leitungen zur Luftversorgung	1.0	1.0	105.0	125.0	25%	60%
2.2	Pumpensystem bzw. Airlift-System	1.0	1.0	45.0	60.0	50%	80%
2.3	Buffer (Zwischenspeicher)	1.0	1.0	14.0	18.0	30%	90%
2.4	Flexibles Schlauchsystem zwischen Buffer und Kollektoren	2.0	2.0	18.0	28.0	0%	60%
2.5	Kabel zur Energie- und Datenübertragung, integriert in Risersektionen und flexiblem Schlauchsystem, Sensorik, Mess- und Kontroll-Systeme	1.0	1.0	7.0	14.0	40%	65%
3	**Kollektor**	**2.0**	**2.0**	**64.0**	**84.0**		
3.1	Fahrwerk mit Antrieb und Einhausung des Kollektors	2.0	2.0	14.0	20.0	20%	90%
3.2	Knollenaufnahmesystem, Brechwerk und Pumpen	2.0	2.0	30.0	38.0	20%	90%
3.3	Sensorik und Navigation, Meß- und Kontroll-Systeme	2.0	2.0	20.0	26.0	40%	65%
4	**Austragungssystem für Prozeßwasser**	**1.0**	**1.0**	**60.0**	**85.0**		
4.1	Risersektionen mit flexiblen/starren Kopplungen	1.0	1.0	35.0	50.0	20%	50%
4.2	Pumpen-System	1.0	1.0	22.0	30.0	50%	80%
4.3	Sensorik, Mess- und Kontroll-Systeme	1.0	1.0	3.0	5.0	40%	65%

Table 3-11-2: Estimate of investment costs and of the achievable German delivery share International supply

				Beschaffung international			
Pos.	Beschreibung	Anzahl		Schätzung der Investitionskosten [Mio. USD]		erreichbarer deutscher Lieferanteil	
		Einsatz	Reserve	unterer Ansatz	oberer Ansatz	unterer Ansatz	oberer Ansatz
5-A	**Bulk-Carrier (Neubau)**	**2.0**	**0.0**	**101.0**	**127.0**		
5.1-A	Neubau Supramax Bulkcarrier	2.0	0.0	85.0	95.0	0%	0%
5.2-A	Ausrüstung für die Offshore-Beladung Basisschiff/Bulk-Carrier	2.0	0.0	16.0	32.0	25%	40%
5-B	**Bulk-Carrier (Secondhand)**	**2.0**	**0.0**	**75.0**	**101.0**		
5.1-B	Beschaffung Secondhand Supramax Bulkcarrier	2.0	0.0	55.0	65.0	-	-
5.2-B	Umrüstung für die Offshore-Beladung Basisschiff/Bulk-Carrier	2.0	0.0	20.0	36.0	30%	60%
6	**Hafenanlagen**	**1.0**	**0.0**	**40.0**	**60.0**		
6.1	Umschlag- und Lagertechnik, Gebäude	1.0	0.0	30.0	45.0	25%	60%
6.2	Fläche und Infrastruktur	1.0	0.0	10.0	15.0	-	-
7	**Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)**	**1.0**	**0.0**	**560.0**	**730.0**		
7.1	Anlagentechnik und Gebäude	1.0	0.0	500.0	650.0	30%	70%
7.2	Flächen und Infrastruktur	1.0	0.0	60.0	80.0	-	-
8	**Forschungsschiff zur Umweltüberwachung**	**1.0**	**0.0**	**55.0**	**70.0**		
8.1	Neubau eines speziell für das Umweltmonitoring beim Tiefseebergbau ausgelegten Forschungsschiffes	1.0	0.0	35.0	40.0	25%	50%
8.2	Ausrüstung für das Umweltmonitoring	1.0	0.0	20.0	30.0	50%	75%
9	**Leistungen des Bauherrn**	**1.0**	**0.0**	**39.0**	**70.0**		
9.1	Ingenieurleistungen, Überwachung	1.0	0.0	16.0	30.0	50%	75%
9.2	Zertifizierungen / Klasse	1.0	0.0	8.0	15.0	50%	75%
9.3	Management	1.0	0.0	15.0	25.0	75%	90%

Table 3-12: Estimate of investment costs and
of the achievable German delivery share
International supply
Summary

		Beschaffung international					
Pos.	Beschreibung	Schätzung der Investitionskosten		Erreichbarer deutscher Lieferanteil			
		[Mio. USD]		[Mio. USD]		[%]	
		unterer Ansatz	oberer Ansatz	unterer Ansatz	oberer Ansatz	unterer Ansatz	oberer Ansatz
1	Basisschiff (Förderplattform)	137.0	173.0	37.5	106.5	27.4%	61.5%
2	Förderstrang	189.0	245.0	55.8	165.1	29.5%	67.4%
3	Kollektor	64.0	84.0	16.8	69.1	26.3%	82.3%
4	Austragungssystem für Prozeßwasser	60.0	85.0	19.2	52.3	32.0%	61.5%
5-A	Bulk-Carrier (Neubau)	101.0	127.0	4.0	12.8	4.0%	10.1%
5-B	Bulk-Carrier (Secondhand)	75.0	101.0	6.0	21.6	8.0%	21.4%
6	Hafenanlagen	40.0	60.0	0.0	0.0	0.0%	0.0%
7	Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	560.0	730.0	150.0	455.0	26.8%	62.3%
8	Forschungsschiff zur Umweltüberwachung	55.0	70.0	18.8	42.5	34.1%	60.7%
9	Leistungen des Bauherrn	39.0	70.0	23.3	56.3	59.6%	80.4%
	Gesamt (Bulk-Carrier Neubau):	1245.0	1644.0	325.3	959.5	26.1%	58.4%
	Gesamt (Bulk-Carrier Secondhand):	1219.0	1618.0	327.3	968.3	26.8%	59.8%



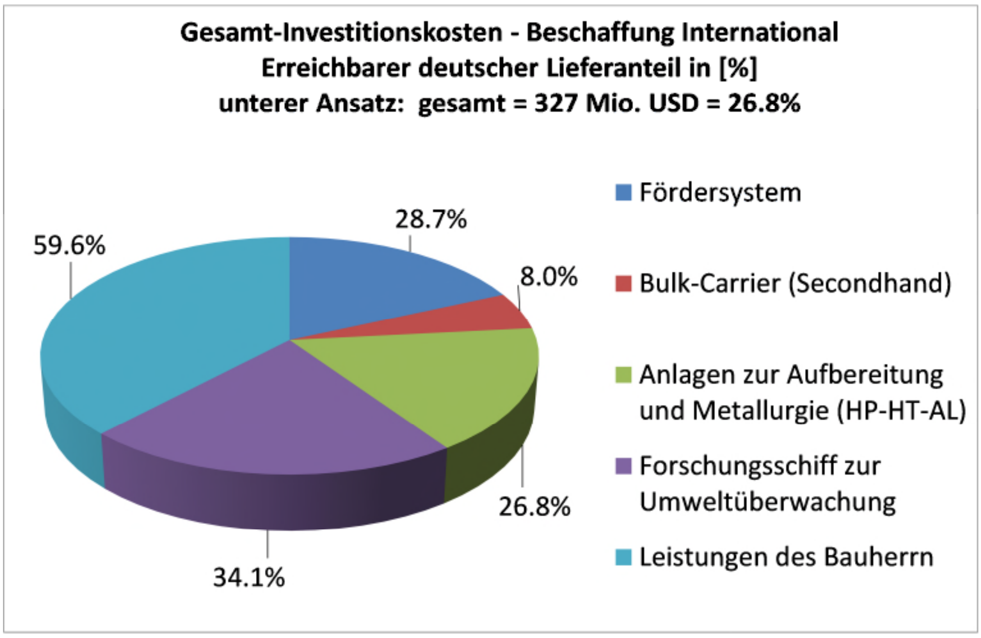
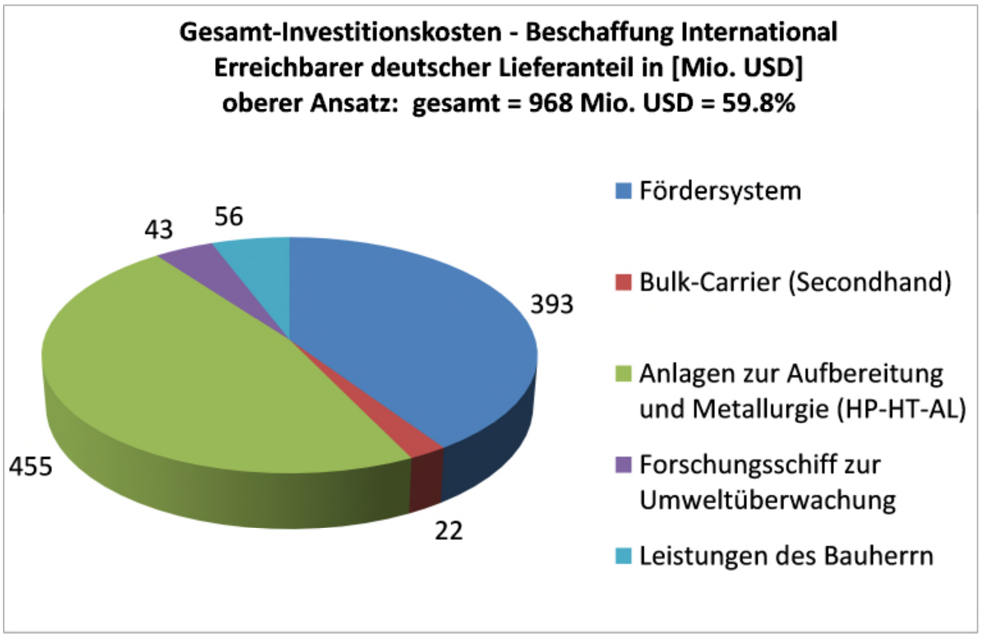


Fig. 3-10: Total investment costs for
- Mining system
- Bulk carriers
- Processing and smelting plants
- Research vessel for environmental monitoring
- Disciplines on behalf of owner

International supply
Lower approach

Achievable German delivery share

Note: *The percentages shown in the diagrams describe the respective shares in the total volume (in million USD) of the mining system and the other four groups considered. The percentages therefore do not add up to 100%.*



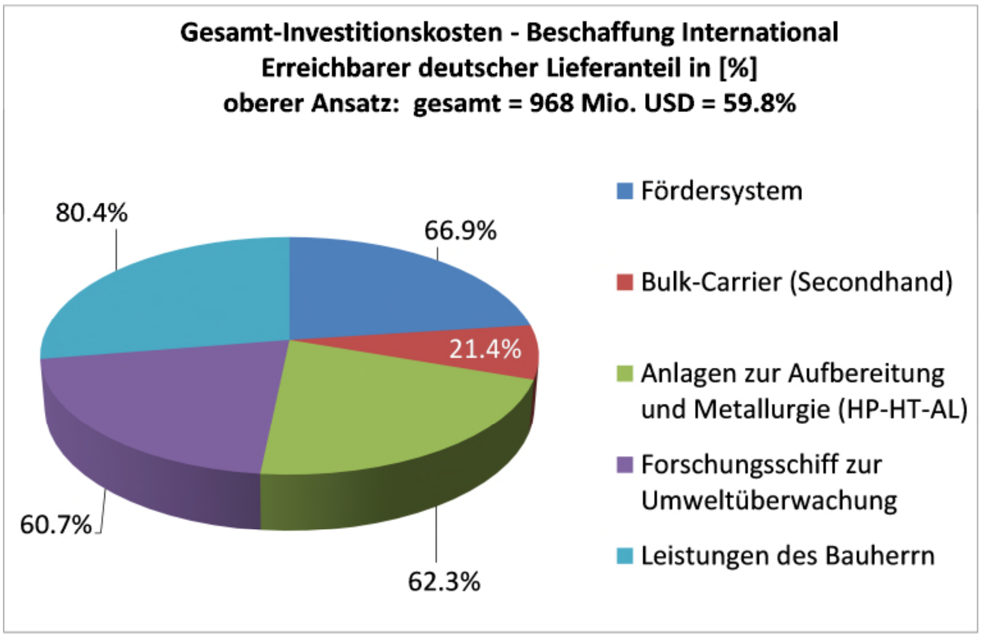


Fig. 3-11: Total investment costs for
- Mining system
- Bulk carriers
- Processing and smelting plants
- Research vessel for environmental monitoring
- Disciplines on behalf of owner

International supply
Upper approach

Achievable German delivery share

Note: *The percentages shown in the diagrams describe the respective shares in the total volume (in million USD) of the mining system and the other four groups considered. The percentages therefore do not add up to 100%.*

Table 3-13 shows the individual items of the list of investment costs vs. the relevant economic activities.

The assignment is based on the

Classification of economic activities
with explanations)
2008
Published by: Federal Statistical Office.

Several economic activities can usually be assigned to the individual items of the list of investment costs.

Besides the identification of the economic activity and the code according to the German Classification of Economic Activities (WZ 2008 Kode), the individual economic activities are therefore additionally weighted in the context of further relevant economic activities.

Table 3-13-1: Investment costs
Assignment of economic activities

Pos.	Beschreibung	WZ 2008 Kode	Wirtschaftszweig
1	**Basisschiff (Förderplattform)**		
1.1	Schiffskörper	30.11	Schiffbau (100%)
1.2	Schiffsspezifische Ausrüstung	28 27 33.2	Maschinenbau (50%) Herstellung von elektrischen Ausrüstungen (35%) Installation von Maschinen und Ausrüstungen a. n. g. (15%)
1.3	Abbauspezifische Ausrüstung	28.22 28.29 27 26.51 33.2 71.12.2	Herstellung von Hebezeugen und Fördermitteln (30%) Herstellung von sonstigen nicht wirtschaftszweigspezifischen Maschinen a. n. g. (25%) Herstellung von elektrischen Ausrüstungen (20%) Herstellung von Mess-, Kontroll-, Navigations-, u. ä. Instrumenten und Vorrichtungen (10%) Installation von Maschinen und Ausrüstungen a. n. g. (10%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
1.4	Werftkosten	30.11	Schiffbau (100%)
2	**Förderstrang**		
2.1	Risersektionen mit flexiblen oder starren Kopplungen, mit/ohne Auftriebselemente, bei Airlift-System zusätzlich Leitungen zur Luftversorgung	24.20 25.50 22.19 71.12.2	Herstellung von Stahlrohren, Rohrform-, Rohrverschluss- und sonsigen Rohrverbindungsstücken aus Stahl (70%) Herstellung von Schmiede-, Press-, Zieh- und Stanzteilen, gewalzten Ringen und pulvermetallurischen Erzeugnissen (15%) Herstellung von sonstigen Gummiwaren (10%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
2.2	Pumpensystem bzw. Airlift-System	28.13 27 33.2 71.12.2	Herstellung von Pumpen und Kompressoren a. n. g. (75%) Herstellung von elektrischen Ausrüstungen (15%) Installation von Maschinen und Ausrüstungen a. n. g. (5%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
2.3	Buffer (Zwischenspeicher)	28 27 33.2 71.12.2	Maschinenbau (60%) Herstellung von elektrischen Ausrüstungen (20%) Installation von Maschinen und Ausrüstungen a. n. g. (10%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (10%)
2.4	Flexibles Schlauchsystem zwischen Buffer und Kollektoren	22.19 24.20 71.12.2	Herstellung von sonstigen Gummiware (80%) Herstellung von Stahlrohren, Rohrform-, Rohrverschluss- und sonsigen Rohrverbindungsstücken aus Stahl (10%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (10%)
2.5	Kabel zur Energie- und Datenübertragung, integriert in Risersektionen und flexiblem Schlauchsystem, Sensorik, Mess- und Kontroll-Systeme	27.3 27.9 26.51 26.20 33.2 71.12.2	Herstellung von Kabeln und elektrischem Installationsmaterial (60%) Herstellung von sonstigen elektrischen Ausrüstungen und Geräten a. n. g. (10%) Herstellung von Mess-, Kontroll-, Navigations-, u. ä. Instrumenten und Vorrichtungen (10%) Herstellung von Datenverarbeitungsgeräten und peripheren Geräten (10%) Installation von Maschinen und Ausrüstungen a. n. g. (5%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)

Table 3-13-2: Investment costs
Assignment of economic activities

Pos.	Beschreibung	WZ 2008 Kode	Wirtschaftszweig
3	**Kollektor**		
3.1	Fahrwerk mit Antrieb und Einhausung des Kollektors	28.15 25.11 27 33.2 71.12.2	Herstellung von Lagern, Getrieben, Zahnrädern und Antriebselementen (40%) Herstellung von Metallkonstruktionen (25%) Herstellung von elektrischen Ausrüstungen (20%) Installation von Maschinen und Ausrüstungen a. n. g. (10%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
3.2	Knollenaufnahmesystem, Brechwerk und Pumpen	25.11 28.13 28.29 27 33.2 71.12.2	Herstellung von Metallkonstruktionen (30%) Herstellung von Pumpen und Kompressoren a. n. g. (30%) Herstellung von sonstigen nicht wirtschaftszweigspezifischen Maschinen a. n. g. (10%) Herstellung von elektrischen Ausrüstungen (15%) Installation von Maschinen und Ausrüstungen a. n. g. (10%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
3.3	Sensorik und Navigation, Meß- und Kontroll-Systeme	26.51 26.20 27 33.2 71.12.2	Herstellung von Mess-, Kontroll-, Navigations-, u. ä. Instrumenten und Vorrichtungen (40%) Herstellung von Datenverarbeitungsgeräten und peripheren Geräten (30%) Herstellung von elektrischen Ausrüstungen (10%) Installation von Maschinen und Ausrüstungen a. n. g. (10%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (10%)
4	**Austragungssystem für Prozeßwasser**		
4.1	Risersektionen mit flexiblen/starren Kopplungen	24.20 25.50 22.19 71.12.2	Herstellung von Stahlrohren, Rohrform-, Rohrverschluss- und sonsigen Rohrverbindungsstücken aus Stahl (70%) Herstellung von Schmiede-, Press-, Zieh- und Stanzteilen, gewalzten Ringen und pulvermetallurischen Erzeugnissen (15%) Herstellung von sonstigen Gummiware (10%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
4.2	Pumpen-System	28.13 27 33.2 71.12.2	Herstellung von Pumpen und Kompressoren a. n. g. (75%) Herstellung von elektrischen Ausrüstungen (15%) Installation von Maschinen und Ausrüstungen a. n. g. (5%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
4.3	Sensorik, Mess- und Kontroll-Systeme	27.3 26.51 26.20 27.9 33.2 71.12.2	Herstellung von Kabeln und elektrischem Installationsmaterial (25%) Herstellung von Mess-, Kontroll-, Navigations-, u. ä. Instrumenten und Vorrichtungen (30%) Herstellung von Datenverarbeitungsgeräten und peripheren Geräten (25%) Herstellung von sonstigen elektrischen Ausrüstungen und Geräten a. n. g. (10%) Installation von Maschinen und Ausrüstungen a. n. g. (5%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)

Table 3-13-3: Investment costs
Assignment of economic activities

Pos.	Beschreibung	WZ 2008 Kode	Wirtschaftszweig
5-A	**Bulk-Carrier (Neubau)**		
5.1-A	Neubau Supramax Bulkcarrier	30.11	Schiffbau (100%)
5.2-A	Ausrüstung für die Offshore-Beladung des Bulk-Carriers (Transshipment)	28.22 22.1 27 26.51 33.2 71.12.2	Herstellung von Hebezeugen und Fördermitteln (30%) Gummi- und Kunststoffwaren (30%) Herstellung von elektrischen Ausrüstungen (15%) Herstellung von Mess-, Kontroll-, Navigations-, u. ä. Instrumenten und Vorrichtungen (10%) Installation von Maschinen und Ausrüstungen a. n. g. (10%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
5-B	**Bulk-Carrier (Secondhand)**		
5.1-B	Beschaffung Secondhand Supramax Bulkcarrier	46.14.2	Handelsvermittlung von Wasser- und Luftfahrzeugen (100%)
5.2-B	Umrüstung für die Offshore-Beladung des Bulk-Carriers (Transshipment)	30.11 28.22 22.1 27 26.51 33.2 71.12.2	Schiffbau (12.5%) Herstellung von Hebezeugen und Fördermitteln (27.5%) Gummi- und Kunststoffwaren (27.5%) Herstellung von elektrischen Ausrüstungen (12.5%) Herstellung von Mess-, Kontroll-, Navigations-, u. ä. Instrumenten und Vorrichtungen (7.5%) Installation von Maschinen und Ausrüstungen a. n. g. (7.5%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
6	**Hafenanlagen**		
6.1	Umschlag- und Lagertechnik, Gebäude	28.22 25.11 27 F 33.2 71.12.2	Herstellung von Hebezeugen und Fördermitteln (55%) Herstellung von Metallkonstruktionen (15%) Herstellung von elektrischen Ausrüstungen (10%) Baugewerbe (10%) Installation von Maschinen und Ausrüstungen a. n. g. (5%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
6.2	Flächen und Infrastruktur	F 71.12.2	Baugewerbe (95%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
7	**Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)**		
7.1	Anlagentechnik und Gebäude	28.91 27 F 33.2 71.12.2	Herstellung von Maschinen für die Metallerzeugung, von Walzwerkseinrichtungen und Gießmaschinen (70%) Herstellung von elektrischen Ausrüstungen (10%) Baugewerbe (10%) Installation von Maschinen und Ausrüstungen a. n. g. (5%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
7.2	Flächen und Infrastruktur	F 71.12.2	Baugewerbe (95%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)

Table 3-13-4: Investment costs
Assignment of economic activities

Pos.	Beschreibung	WZ 2008 Kode	Wirtschaftszweig
8	**Forschungsschiff zur Umweltüberwachung**		
8.1	Neubau eines speziell für das Umweltmonitoring beim Tiefseebergbau ausgelegten Forschungsschiffes	30.11	Schiffbau (100%)
8.2	Ausrüstung für das Umweltmonitoring	26.51 26.20 27 33.2 71.12.2	Herstellung von Mess-, Kontroll-, Navigations-, u. ä. Instrumenten und Vorrichtungen (40%) Herstellung von Datenverarbeitungsgeräten und peripheren Geräten (25%) Herstellung von elektrischen Ausrüstungen (15%) Maschinen (10%) Installation v. Maschinen u. Ausrüstungen (5%) Ingenieurbüros für technische Fachplanung und Ingenieurdesign (5%)
9	**Leistungen des Bauherrn**		
9.1	Ingenieurleistungen, Überwachung	71.12.2 71.12.9	Ingenieurbüros für technische Fachplanung und Ingenieurdesign (75%) Sonstige Ingenieurbüros (25%)
9.2	Zertifizierungen / Klasse	71.12.9	Sonstige Ingenieurbüros (100%)
9.3	Management	70.10	Verwaltung und Führung von Unternehmen und Betrieben (100%)

Table 3-14 is a detailed list of the estimated annual operating costs for the following items:

1. Energy consumption for mining the nodules
2. Maintenance of mining vessel and mining system
3. Ship management, mining vessel
4. Mining vessel crew
5. Bulk carriers, 2 units to transport the nodules from the location (CCZ) to the Lazaro Cardenas (Mexico) base harbour
6. Lazaro Cardenas base harbour
7. Energy consumption for smelting the nodule material (processing and smelting HP-HT-AL)
8. Other operating costs of the smelting process

The operating cost estimates are also subject to an upper and lower limit in order to address any uncertainty that currently exists.

Total annual operating costs amount to

389 million USD (lower approach) to 435 million USD (upper approach)

and hence between

26 and 32% of total investment costs.

This shows that the level of operating costs will be the crucial factor at the cost end of the economic efficiency analysis for a deep sea mining project aimed to extract polymetallic nodules with a time horizon of 15 to 30 years.

Table 3-15 summarises the annual operating costs considering the following additional groups:

- Mining of the polymetallic nodules (items 1 to 4)
- Sea transport and base harbour (items 5 and 6)
- Smelting (items 7 and 8)

This list as well as Fig. 3-12 and Fig. 3-13 show that smelting accounts for 77% and hence the dominant share of total operating costs:

- Mining of polymetallic nodules: 16.9 to 17.1%
- Sea transport and base harbour: 5.7%
- Smelting: 77.2 to 77.4%

Table 3-14-1: Annual operating costs
Detailed breakdown

				Schätzung der jährlichen Betriebsskosten [Mio. USD/a]	
Pos.	**Beschreibung**			**unterer Ansatz**	**oberer Ansatz**
1	**Energieverbrauch beim Abbau der Knollen**	**Energie-bedarf [kW]**	**Betriebs-stunden [h/a]**	**30.440**	**33.484**
	Basisschiff: 1.01 bis 1.09				
1.01	Propulsion und Positionierung	2000	7200	3.182	3.501
1.02	Aktive Kompensation der Tauchbewegungen	250	7200	0.398	0.438
1.03	Kransysteme	2000	8640	3.819	4.201
1.04	Handhabungssysteme	900	7200	1.432	1.575
1.06	Separatoren und Kreiselpumpen	500	7200	0.796	0.875
1.07	Schiffseitige Transport- und Fördersysteme	100	7200	0.159	0.175
1.08	Umschlagsystem (Transshipment)	120	2400	0.064	0.070
1.09	Hotel-Last (58 Personen)	1200	8640	2.291	2.520
1.10	Förderstrang: Pumpen bzw. Airlift System	7400	7200	11.775	12.952
1.11	Buffer	50	7200	0.080	0.088
1.12	2 Kollektoren	2400	7200	3.819	4.201
1.05	Austragungssytem für Prozeßwasser	650	7200	1.034	1.138
1.13	Remotely Operated Vehicles (ROV), Seafloor Working Units (SWU)	1000	7200	1.591	1.750
2	**Instandhaltung Basisschiff und Fördersystem**	**-**	**-**	**9.500**	**11.400**
2.01	Basisschiff			3.000	3.600
2.02	Fördersystem: - Förderstrang - Kollektoren - Austragungssystem für Prozesswasser			6.500	7.800

Table 3-14-2: Annual operating costs
Detailed breakdown

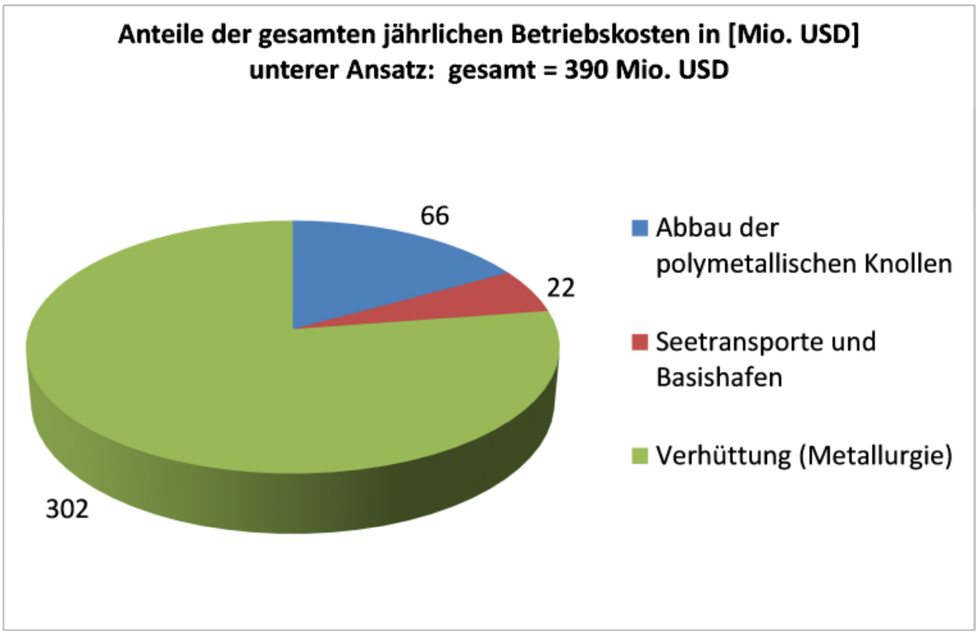
				Schätzung der jährlichen Betriebsskosten [Mio. USD/a]	
Pos.	**Beschreibung**			**unterer Ansatz**	**oberer Ansatz**
3	**Schiffsmanagement Basisschiff**	**-**	**-**	**1.425**	**2.025**
3.01	Kommerzielles und technisches Management			0.700	1.000
3.02	Klasse einschl. Dockung			0.400	0.600
3.03	Versicherung (Haftpflicht + Hull & Machinery)			0.325	0.425
4	**Besatzung Basisschiff**	**-**	**Stärke der Besatzung (2 Crews)**	**24.500**	**27.400**
4.01	Schiffsbesatzung		2 x 16	2.100	2.200
4.02	Besatzung für Betrieb Fördersystem		2 x 40	7.800	8.200
4.03	Unterbringung und Verpflegung		56	5.240	5.760
4.04	Besatzungs-Wechsel		56	9.360	11.240
5	**Bulk-Carrier Supramax - 2 Einheiten (Transport nach Mexiko, Lazaro Cardenas)**	**-**	**-**	**20.100**	**22.800**
5.01	Treibstoff, 2 x 34 Fahrten 2 x 1000 nm plus Transshipment und Entladung			15.900	17.500
5.02	Besatzung			2.200	2.600
5.03	Kommerzielles und technisches Management			0.800	1.100
5.04	Klasse einschl. Dockung			0.500	0.700
5.05	Versicherung (Haftpflicht + Hull & Machinery)			0.300	0.400
5.06	Schmieröle und Unterhaltung			0.400	0.500
6	**Basishafen (Mexiko, Lazaro Cardenas)**	**-**	**-**	**1.970**	**2.190**
6.01	Energiekosten (Treibstoffe und elektrische Energie)			0.400	0.440
6.02	Lohnkosten (12 Mitarbeiter)			0.720	0.750
6.03	Feste Kosten (Verwaltung, Instandhaltung, Versicherung etc.)			0.850	1.000

Table 3-14-3: Annual operating costs
Detailed breakdown

				Schätzung der jährlichen Betriebsskosten [Mio. USD/a]	
Pos.	**Beschreibung**			**unterer Ansatz**	**oberer Ansatz**
7	**Energieverbrauch bei der Verhüttung (Metallurgie HP-HT-AL)**	**-**	**-**	**217.700**	**231.600**
7.01	Brennstoffe			68.700	75.600
7.02	Elektrische Energie			149.000	156.000
8	**Weitere Betriebskosten Verhüttung (Metallurgie HP-HT-AL)**	**-**	**-**	**84.000**	**104.200**
8.01	Hilfsstoffe für den metallurgischen Prozeß			23.600	31.900
8.02	Lohnkosten			18.200	19.100
8.03	Entsorgung Reststoffe			10.700	13.800
8.04	Feste Kosten (Verwaltung, Instandhaltung, Versicherung etc.)			31.500	39.400

Table 3-15: Annual operating costs
Summary (1)

		Schätzung der jährlichen Betriebsskosten [Mio. USD/a]			
Pos.	Beschreibung	unterer Ansatz		oberer Ansatz	
		[Mio. USD/a]	Anteil an Gesamtkosten	[Mio. USD/a]	Anteil an Gesamtkosten
1	Energieverbrauch beim Abbau der Knollen	30.440		33.484	
2	Instandhaltung Basisschiff und Fördersystem	9.500		11.400	
3	Schiffsmanagement Basisschiff	1.425		2.025	
4	Besatzung Basisschiff	24.500		27.400	
1 - 4	Abbau der polymetallischen Knollen	65.865	16.9%	74.309	17.1%
5	Bulk-Carrier Supramax - 2 Einheiten (Transport nach Mexiko, Lazaro Cardenas)	20.100		22.800	
6	Basishafen (Mexiko, Lazaro Cardenas)	1.970		2.190	
5 + 6	Seetransporte und Basishafen	22.070	5.7%	24.990	5.7%
7	Energieverbrauch bei der Verhüttung (Metallurgie)	217.700		231.600	
8	Weitere Betriebskosten Verhüttung (Metallurgie)	84.000		104.200	
7 + 8	Verhüttung (Metallurgie HP-HT-AL)	301.700	77.4%	335.800	77.2%
	Jährliche Gesamtkosten Betrieb	389.635	100.0%	435.099	100.0%



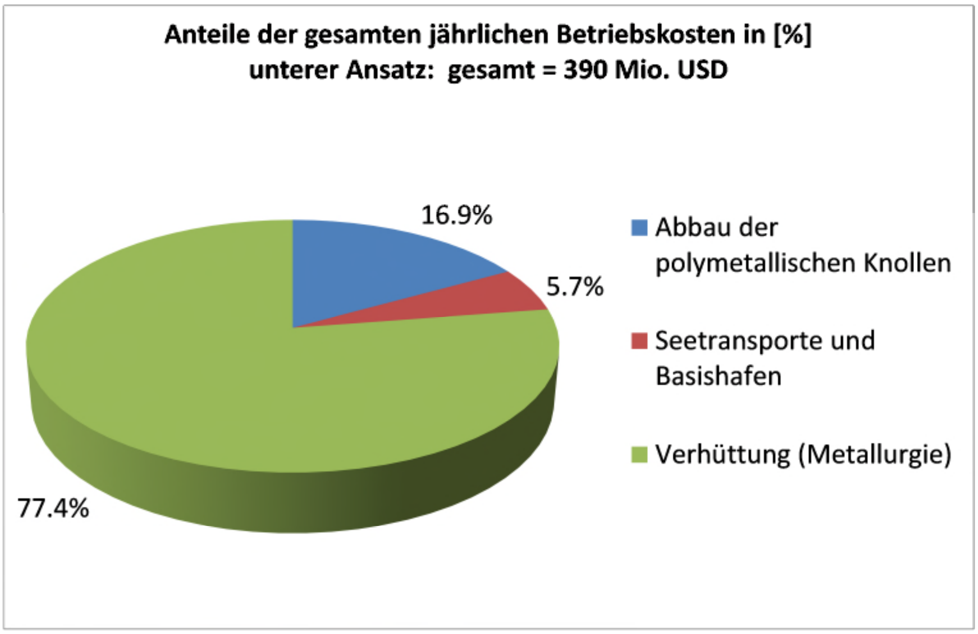
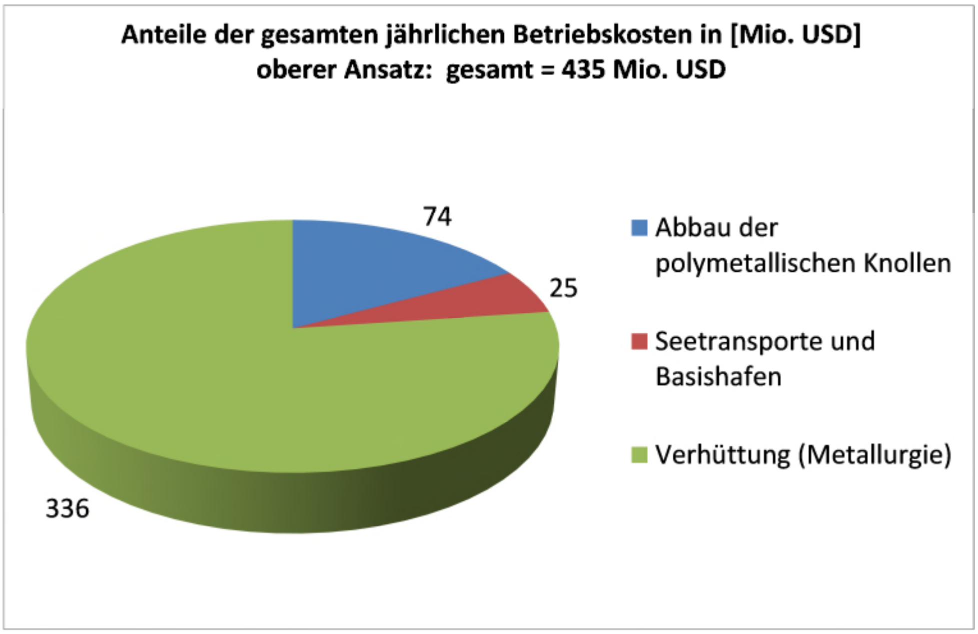


Fig. 3-12: Annual operating costs (summary 1)

- Mining of the polymetallic nodules
- Sea transport and base harbour
- Smelting

Lower approach



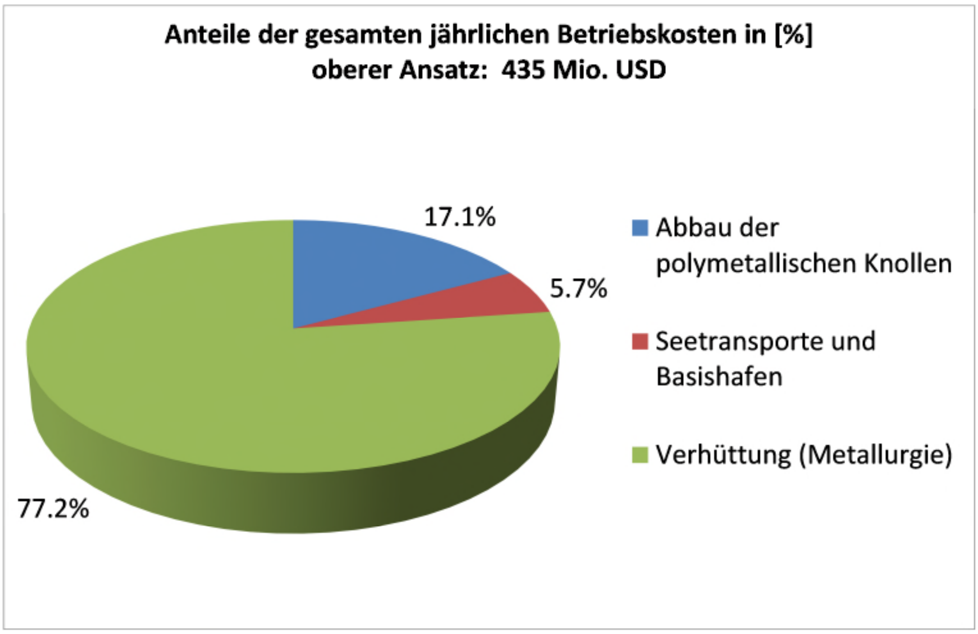


Fig. 3-13: Annual operating costs (summary 1)

- Mining of the polymetallic nodules
- Sea transport and base harbour
- Smelting

Upper approach

Operating costs were broken down and classified further not with a view to the successive steps of the overall project, but on the basis of the following categories:

1. Total energy costs
   - Fuel
   - Electrical energy

2. Auxiliary materials
   - Auxiliary materials for the metallurgical process
   - Lubricants
   - Other auxiliary materials

3. Total administration, maintenance, insurance costs:
   - Commercial and technical management
   - Maintenance of mining vessel and mining system
   - Maintenance of bulk carriers
   - Class
   - Base harbour maintenance
   - Smelting equipment maintenance
   - Insurance

4. Total wage and other personnel costs:
   - Ship crews
   - Crews for operation of the mining system
   - Accommodation and catering
   - Mining vessel crew changes
   - Base harbour staff
   - Smelting operation staff

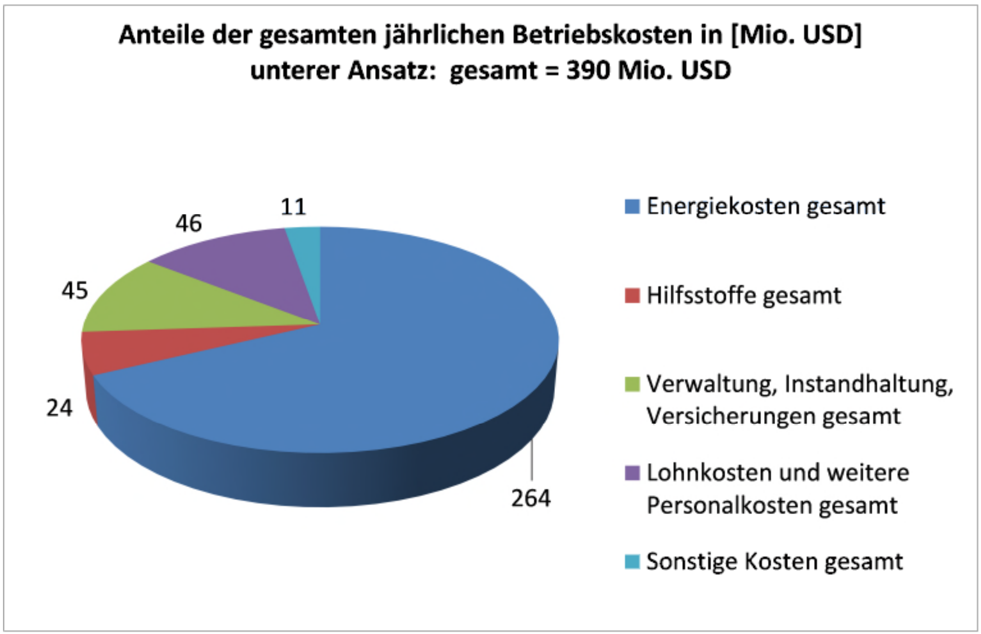
5. Total other costs
   - Disposal of residual materials from smelting operations

The results show that energy costs totalling 264 to 283 million USD account for around 65% of total annual operating costs; see Table 3-16 as well as Fig. 3-14 and Fig. 3-15:

1. Energy costs:	65.0	to	67.9	%
2. Auxiliary materials:	6.1	to	7.3	%
3. Administration, maintenance, insurance:	11.6	to	13.0	%
4. Wages and other personnel costs:	11.5	to	11.7	%
5. Other costs	2.7	to	3.2	%

Table 3-16: Operating costs
Summary (2)

		Schätzung der jährlichen Betriebsskosten [Mio. USD/a]			
Pos.	Beschreibung	unterer Ansatz		oberer Ansatz	
		[Mio. USD/a]	Anteil an Gesamtkosten	[Mio. USD/a]	Anteil an Gesamtkosten
1 - 8	Jährliche Gesamtkosten Betrieb	389.635	100.0%	435.099	100.0%
davon	Energiekosten gesamt	264.440	67.9%	283.024	65.0%
	Hilfsstoffe gesamt	23.600	6.1%	31.900	7.3%
	Verwaltung, Instandhaltung, Versicherungen gesamt	45.275	11.6%	56.525	13.0%
	Lohnkosten und weitere Personalkosten gesamt	45.620	11.7%	49.850	11.5%
	Sonstige Kosten gesamt	10.700	2.7%	13.800	3.2%



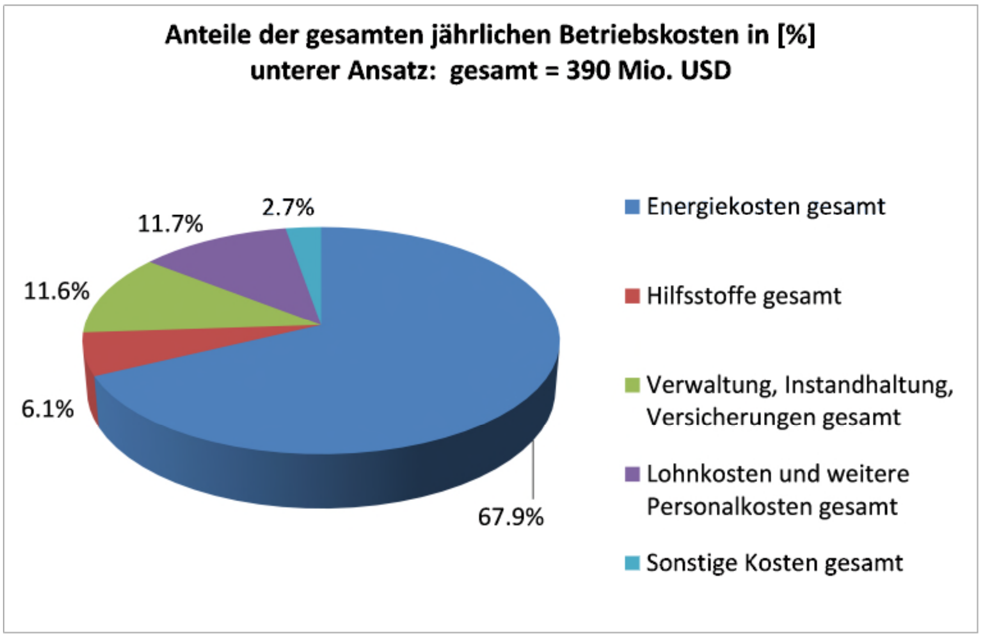
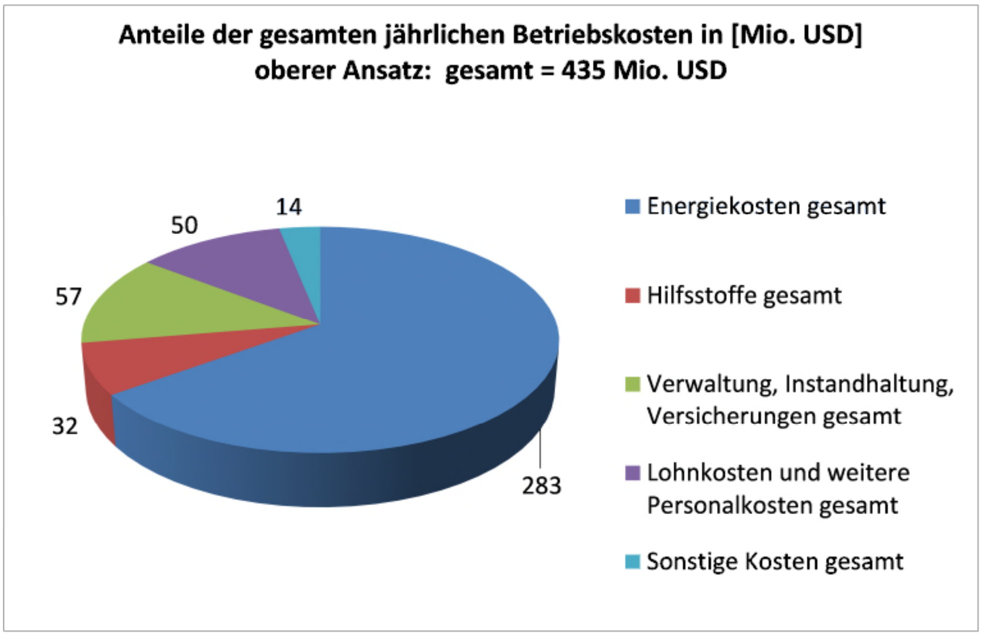


Fig. 3-14: Annual operating costs (summary 2)

- Total energy costs
- Total auxiliary material costs
- Total administration, maintenance, insurance costs
- Total wage and other personnel costs
- Total other costs

Lower approach



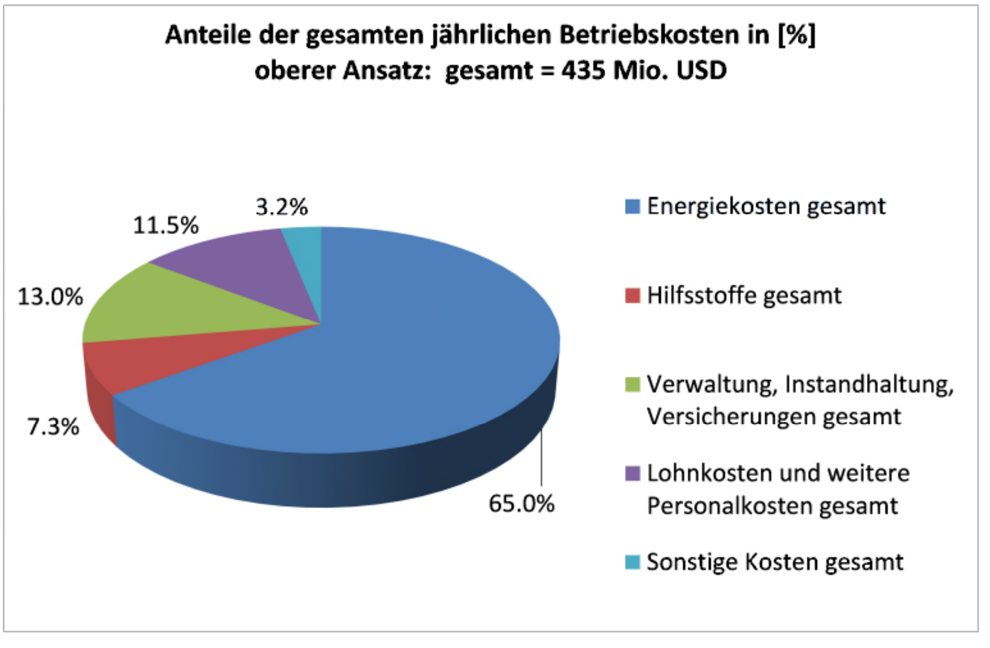


Fig. 3-15: Annual operating costs (summary 2)

- Total energy costs
- Total auxiliary material costs
- Total administration, maintenance, insurance costs
- Total wage and other personnel costs
- Total other costs

Upper approach

Total operating costs per tonne of dry material of polymetallic nodules are an important commercial parameter.

An assumed nominal annual production of 3.0 million tonnes of dry material translates into the costs summarised in Table 3-17.

Total operating costs per tonne of dry material:

- Lower approach: 129.9 USD per tonne
- Upper approach: 145.0 USD per tonne

Table 3-17: Operating costs per tonne of dry material Summary

Pos.	Beschreibung	Schätzung der Betriebsskosten pro Tonne Trockenmaterial			
		unterer Ansatz		oberer Ansatz	
		[USD/t]	Anteil an Gesamtkosten	[USD/t]	Anteil an Gesamtkosten
1	Energieverbrauch beim Abbau der Knollen	10.1		11.2	
2	Instandhaltung Basisschiff und Fördersystem	3.2		3.8	
3	Schiffsmanagement Basisschiff	0.5		0.7	
4	Besatzung Basisschiff	8.2		9.1	
1 - 4	Abbau der polymetallischen Knollen	22.0	16.9%	24.8	17.1%
5	Bulk-Carrier Supramax - 2 Einheiten (Transport nach Mexiko, Lazaro Cardenas)	6.7		7.6	
6	Basishafen (Mexiko, Lazaro Cardenas)	0.7		0.7	
5 + 6	Seetransporte und Basishafen	7.4	5.7%	8.3	5.7%
7	Energieverbrauch bei der Verhüttung (Metallurgie)	72.6		77.2	
8	Weitere Betriebskosten Verhüttung (Metallurgie)	28.0		34.7	
7 + 8	Verhüttung (Metallurgie HP-HT-AL)	100.6	77.4%	111.9	77.2%
	Gesamte Betriebskosten pro Tonne Trockenmaterial	129.9	100.0%	145.0	100.0%

3.3 Methodology of the commercial analysis

From a commercial perspective, future subsea mining operations are first of all a long-term investment project. Therefore, when assessing the purely economic profitability of this project, methods should be adopted that are widely used for investment analysis purposes. Besides fundamental approaches, such as the net present value method, complex calculation methods, such as option pricing, as well as scenario analyses have become increasingly common over the course of time especially in order to enable more precise mapping of the specific risk structure of complex projects. However, for the purposes of this study, we will focus on the classical discounted cash flow method that enables a transparent project assessment on the basis of a comparison of project-related payments and disbursements during a given period. Future cash flows are discounted in order to enable a comparison based on their net present value. The time of observation is the situation at the time the project starts, i.e. the time of first investments (rather than the commencement of mining operations) from a financial perspective.

The key characteristic of the investment project in question is delayed generation of revenue. The initial years will be characterised solely by technical preparations for mining and the establishment of the value chain (mining, transport, smelting of the nodules). The only cash flows are therefore disbursements in conjunction with the investments to be made. This will be followed by the mining phase which will also include a certain lead time during which full utilisation of capacities will not yet be possible. During the mining phase, payments will occur as proceeds from the sale of the metals mined as well as disbursements in the form of operating costs (material, personnel, energy, equipment) along the value chain.
Fig. 3-16 is a schematic rendering of the payment structure over time and the related demand for information.

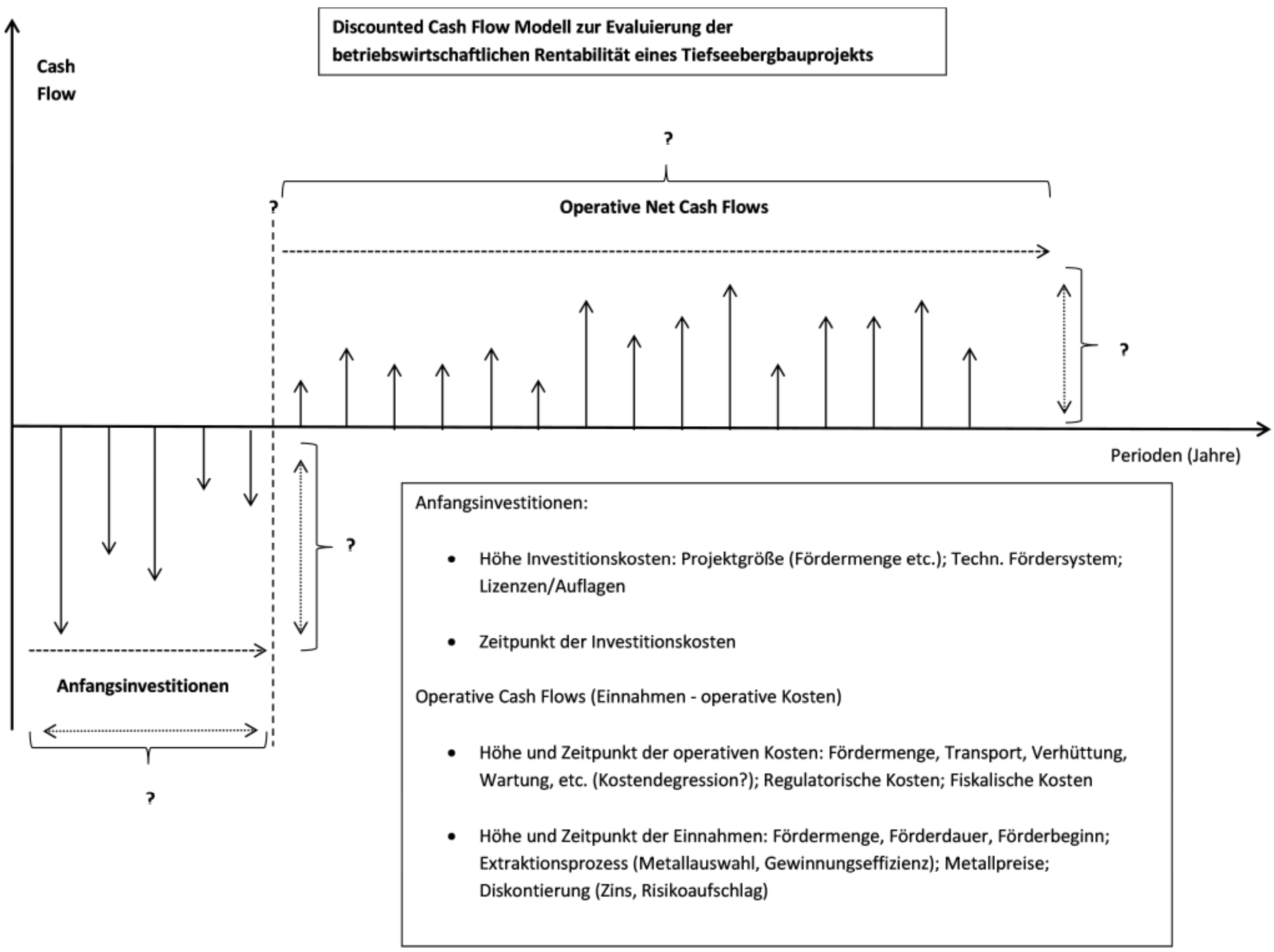


Fig. 3-16: System of the discounted cash flow method

The discounted cash flow (DCF) method ultimately supplies a capital value which represents the total net value of payments made during the course of the project translated into the value at the time the project began. A positive capital value means that the project can be considered to be financially profitable, whilst a negative value indicates the opposite.

The general problem is that future payments and disbursements are always subject to uncertainty. This applies, in particular, to payments which are influenced not only by the future mining potential but also and to a significant extent by price trends on commodity markets. This uncertainty is typically addressed in the DCF method by using a higher discount rate for future payments. The underlying logic being that in the interest of comparability the rate of return to be used in the discounting step should be based on investments on the market that feature a comparable risk structure. Greater uncertainty is usually compensated for on the market by an expected higher rate of return. The chosen discount rate is therefore very important for our analysis.

Choice of discount rate

The discount rate is the annual discount factor by which the weight of future payments and disbursements is reduced in relation to present cash flows. The discount rate has two functions in assessments of real investment projects: On the one hand, it enables comparisons of projects with cash flow profiles spanning different periods by expressing payments effected at different points in time in terms of their present value. The basis for this is the alternative rate of interest on the capital market: The present value corresponds to the amount that would have to be invested at the present time in order for redemption and interest to add up to the corresponding payment at the future point in time.

The core issue is the definition of alternative investment. This is where the second function of the discount rate comes into play: In a volatile environment, it must also reflect uncertainty regarding the actual occurrence of the planned cash flow. Assuming that investors, just like the average population, have a certain degree of aversion to risks, this takes the form of a penalty factor: The higher the estimated realisation risk, the higher the value chosen for the discount rate. This then also determines the criterion for suitable alternative investment: Its risk structure should be as similar as possible to that of the project to be assessed. Since the capital market usually rewards greater risks with a higher expected rate of return, this corresponds to the logic of a higher alternative rate of interest.

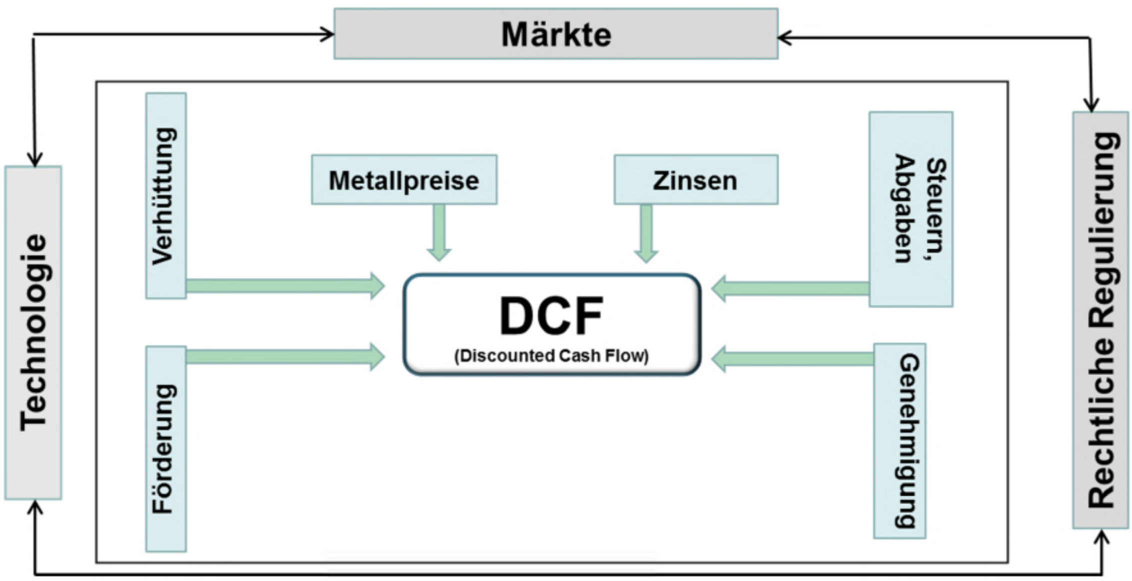


Fig. 3-17: Risk types in deep sea mining

In structural terms, the discount rate hence consists of a risk-free component, that reflects the present value of the money, and a risk premium. This premium ideally reflects the extent of all risks (including their possible correlation). This first requires the types of risks in a given project to be identified. Fig. 3-17 summarises the risk components of deep sea mining in as far as they are relevant from an investor's perspective. They can be roughly divided into technological, political/legal and market-related risks. Although a specific risk premium would have to be determined separately for each of these components and added to the discount rate, the bandwidths proposed in literature are enormous. Baurens (2010), for instance, proposes a bandwidth of 3 to 16% for project-specific risks and 0 to 14% for political country risks. Park and Matun-hire (2011) propose a bandwidth of 6 to 20% for the risk premium for mining projects.

Furthermore, the aforementioned authors refer to onshore mining projects, so that the specific technical and legal uncertainties of deep sea mining are completely disregarded. Another fundamental problem in this context is also the question regarding the correlation between the risk classes: Changes on commodity markets can influence the technological development and vice versa. Identifying a specific discount rate is hence hardly possible on this basis, so that customary practice alone can serve as guidance.

Runge (1998) identifies a real discount factor of 15% as a conventional guideline in the mining industry. Surface Mining (1990) suggests a factor of at least 20% for projects involving entirely new operations. Summers (1987) reports a 15% median for the nominal discount rate from a survey of large enterprises. In the following, this value will be adopted as a parameter for our baseline scenario. In view of the fact that the literature referred to in this study has not yet considered the special risks of deep sea mining, this choice can be considered to be somewhat optimistic. A subsequent sensitivity analysis will make the sensitivity of the profitability assessment to the discount rate transparent.

Time structure of payments

Another important assumption concerns the time structure of the project. We assume a twelve-year observation period for the entire project. This time window is long enough for a surplus to be generated, but not too long for funds to be tied up in a commercially sensible manner. The total period is divided into two phases. The investment phase covers the first four years during which the capacities along the value chain will be created without any commercial nodule mining activities. The investment costs are hence allocated to this phase. The costs are allocated to the individual years according to the following key: 15%/30%/30%/25%. After a start-up phase in the first year, most of the investments will therefore take place during years 2 to 4 which we consider to be a realistic assumption.

The investment phase will then be followed by the mining phase during which commercial mining operations will be carried out and the metals produced by the subsequent smelting processes sold on the market. Besides revenues at the income end, operating costs are incurred at the expenses end. In this case too, we assume a start-up phase, with limited capacity during the first years of mining activity, which will correspond to 50% (1st year) and 75% (2nd year) of full capacity with regard to mining volumes.

Monte Carlo simulation

Furthermore, one can also ask whether a mere score result really provides sufficient information for a sensible profitability analysis in this uncertain environment because such a score does not reflect the downside risk, i.e. the risk of falling significantly short of the expected capital value in the event of unfavourable development of boundary conditions (falling metal prices, etc.). In this way, it is, in particular, not possible to assess the probability of occurrence of a negative capital value.

In order to express the corresponding uncertainty in the model, several methods to consider stochastic influences in DCF approaches have been developed over the course of time in financial literature. Among these methods, the Monte Carlo simulation is particularly popular because it is relatively easy to apply. It treats external influences (metal prices, cost developments, etc.) as random variables which feature a certain distribution, with normal distribution being assumed unless better distribution information is available. The parameters of these distributions (expected value, variance, etc.) are determined on the basis of à-priori information about the influence variables (such as expected mean value, upper/lower limit values). From the distributions thus defined, individual values for the influence parameters are then randomly drawn and the corresponding DCF is calculated. Repeat draws then provide an empirical probability distribution for the DCF which, for its part, enables a targeted statement regarding the probability for the capital value received to be within a certain bandwidth (for instance, less than zero). Our analysis uses this concept in order to deliberately show the diversity of uncertainty factors in deep sea mining.

3.4 Results of the commercial analysis

The real profitability calculation consists of the integration of prior revenue and cost estimates within the scope of the described DCF approach. The resultant capital value to describe the profitability of private deep sea mining is inevitably also a stochastic variable with a corresponding distribution. An empirical distribution of the capital value is determined through a large number of draws with a view to the exogenous influencing factors and by calculating the related capital values.

This provides information with regard to the average net revenue to be expected for investors and its scatter and hence the prevailing degree of uncertainty. The perspective is that of the overall project, i.e. the economic yield of the entire cash flow of the project is calculated that could be subsequently distributed among the different investor categories (equity investors, lenders, etc.) (entity approach).

Unlike the alternative calculation method of the equity approach, the profitability analysis can then be carried out independent of assumptions regarding concrete financing concepts and hence independent of the related uncertain parameters (capital shares, interest on loans, etc.).

Forecast-related uncertainty exists not just with regard to exogenous influencing factors, but also with regard to the general validity of the model setup. It is, for instance, not certain that the long-term correlations used for price forecasts will also be valid in the future. Technological progress and changes in the competitive situation can lead to other ways in which exchange prices will respond to future fluctuations of raw material mining activities and demand. Since changes like these are by their very nature difficult to predict, our profitability analysis is supplemented by further scenarios where the profitability of deep sea mining is determined independent of our price projection model. Instead, the average values of the most recent exchanges prices are used as metal prices.

Since – as described earlier – it is in fact the more recent past that has been characterised by strong price fluctuations on the metal exchange, the length of the period over which the average value is calculated is a very important factor. We therefore deliberately distinguish between three sub-scenarios as follows: average prices for the last ten years, the last five years, and last year (last measuring point: July 2016). These are assumed to be constant at future points in time, so that profitability is determined on the basis of today's prices. It then remains to be determined whether prices should be assumed to be constant in real or nominal terms. In the case of constant prices in real times, future prices would first be inflated on the basis of assumptions regarding the general rate of inflation. Since the same procedure was also chosen for the development of costs, this concept is therefore consistent within the model. In conjunction with the presentation of the results, it will be pointed out in the following that prices which are constant in both real and nominal terms are definitely realistic with a view to historical price developments (the results with the assumption of prices remaining constant in nominal terms are mentioned in footnote 1).

Our calculations therefore differentiate between two upper scenarios, i.e. the model with price projections (upper scenario 1) and the model with constant (in real terms) prices (upper scenario 2). Fig. 3-18 shows the distribution of the capital value in upper scenario 1, in each case differentiated according to two investment cost scenarios (see section 3.2.2). The diagrams on the left show the empirical frequency, those on the right the adjusted density function under the assumption of a normal distribution. As expected, the differences between the results of the two investment scenarios are small. The expected value of the distribution is clearly in the positive range in both cases. With the 'Primary German Supply' scenario, it totals 1.538 billion USD, in the 'Primary International Supply' scenario 1.618 billion USD.

The probability of ending up in the negative value range under the given distribution assumptions is almost zero in both cases.

As described, these revenue values apply to an assumed project term of 16 years (including a four-year investment phase). Such a time span could go beyond the planning horizon of some investors. It is therefore helpful to additionally examine the cumulative discounted cash flows in order to determine the time of break-even, for example. Fig. 3-19 shows the time structure of the cash flows for the example of the 'Primary International Supply' scenario, with the expected values used in each case for the stochastic influence variables. It can be seen that with the given metal price scenario the cash value of the investment will enter the positive value range in or about 2028, i.e. eight years after the project starts. It then continuous to rise further due to the simulated continuous price increases. However, uncertainty also increases as the forecasting horizon moves further into the future, so that the estimated cash flows also become increasingly uncertain as time advances.

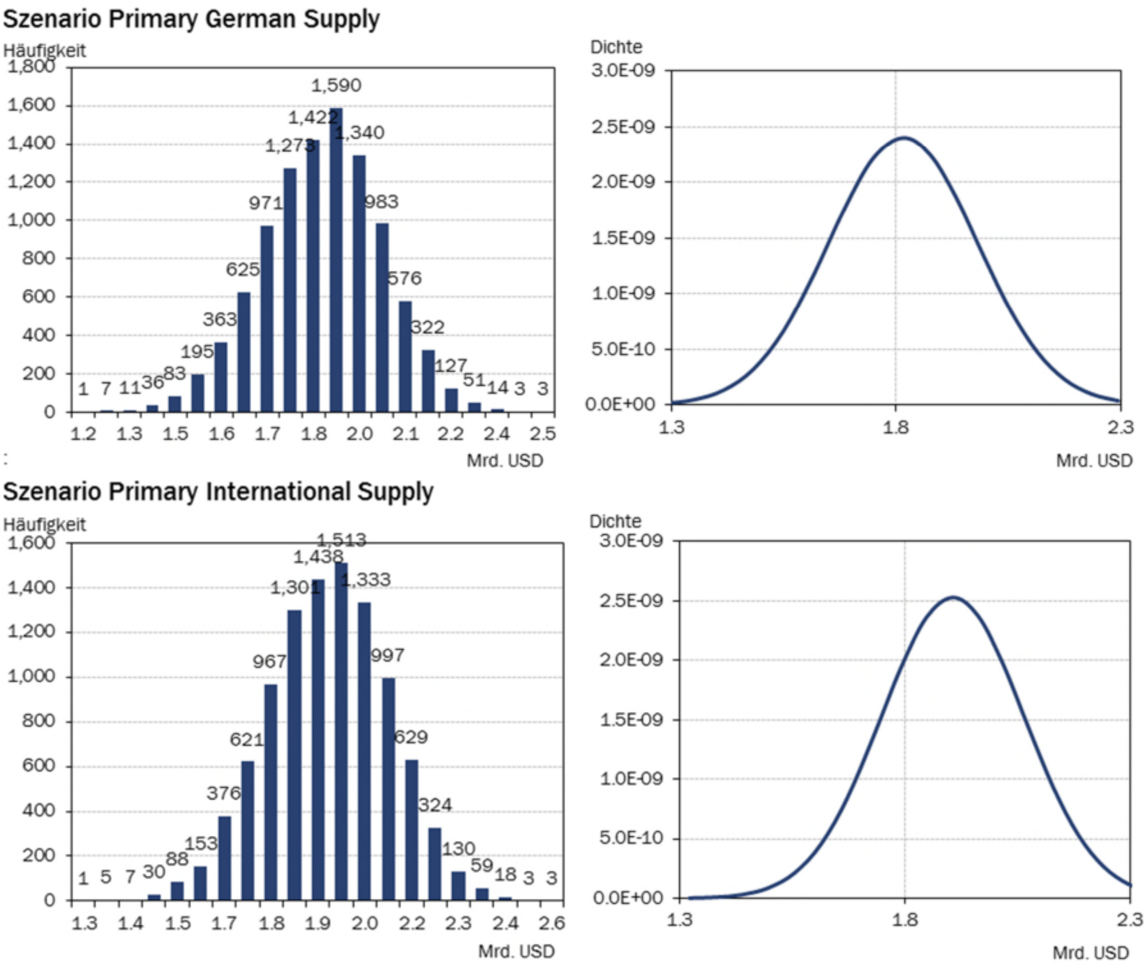


Fig. 3-18: Capital value distribution (upper scenario 1)

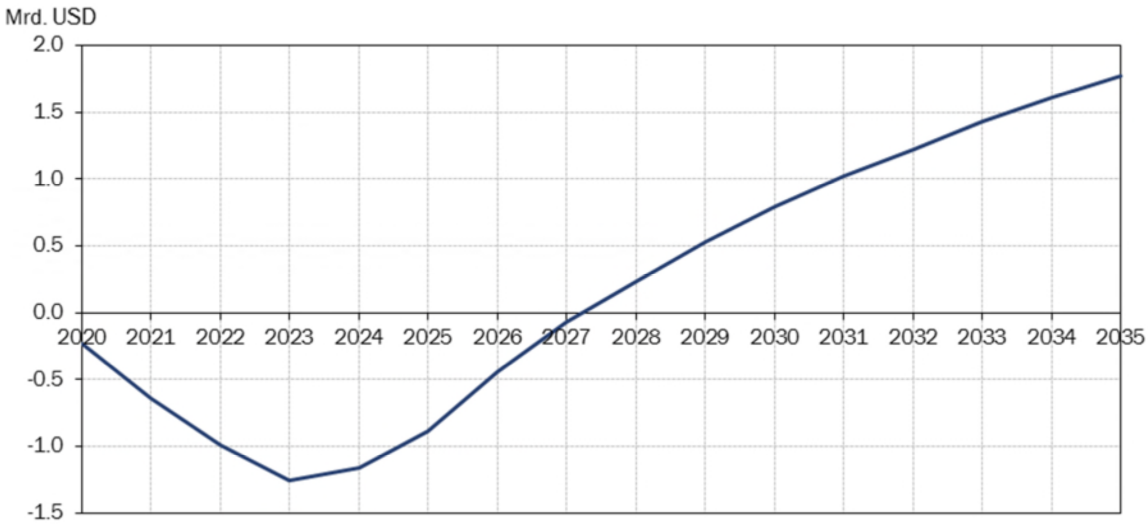


Fig. 3-19: Cumulative DCF in the expected value:
Upper scenario 1, Primary International Supply

Should, however, current long-term price trends fail to materialise in the future with the present rather low price levels on metal exchanges continuing, the expected revenue situation will look completely different. This can be seen from the simulation results under upper scenario 2 (today's average prices). Fig. 3-20 shows the distribution of the capital value under the assumption of future real (i.e. general inflation-adjusted) price levels in terms of average prices for the last ten and five years and for the last year. A clearly negative capital value can be seen in the expected value in the most recent period (i.e. average prices from August 2015 to July 2016) independent of the respective investment cost scenario. With the given distribution, the probability of achieving a positive capital value is almost zero.

The picture is slightly different with longer-term price averages because recent price declines then have a lesser impact. With the 'Primary International Supply' scenario, the expected capital value for five-year averages is therefore slightly positive. The revenue situation would be much more positive if future prices were based on the average level of the last ten years, especially due to the high-price phase in 2007/08. The expected capital value in the 'Primary International Supply' scenario then amounts to 1,050 billion USD. [2]

It can hence be seen that a medium-term price recovery is an absolute precondition for the commercial profitability of the deep sea mining project with its given specifications. Fig. 3-21 finally shows the cumulative discounted cash flows. Whilst positive profitability as shown in the price projections could already be achieved after eight years in the ten-year price average, this will not be achieved with the one-year average even after a long time.

[2] The revenue situation would be even less favourable with nominally constant prices. Both under the one-year and the five-year price average, the distribution of capital values is clearly negative for all investment scenarios. Positive values of 391.926 million USD are only expected under the ten-year average in the 'Primary International Supply' scenario.

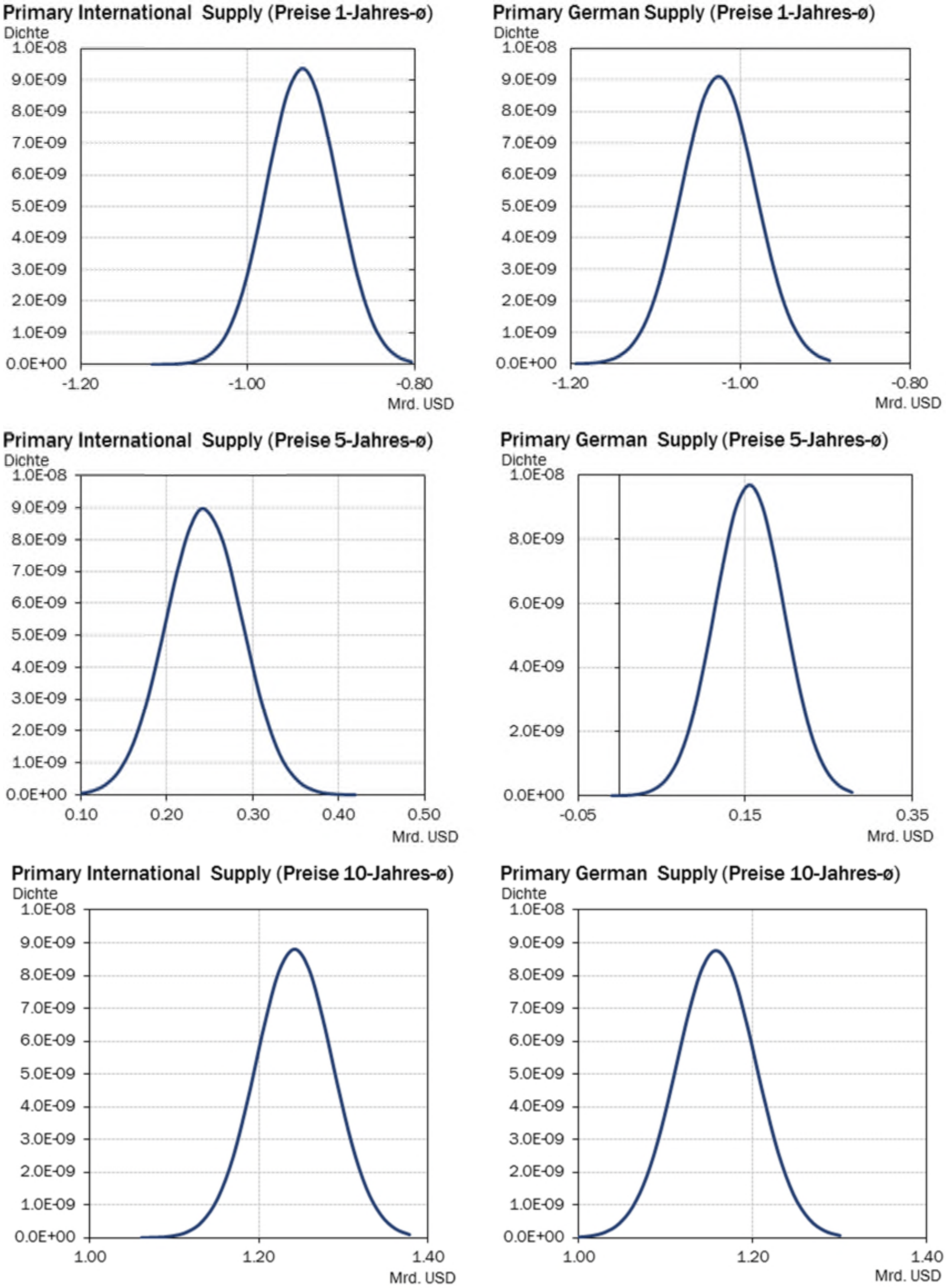


Fig. 3-20: Capital value distribution (upper scenario 2)

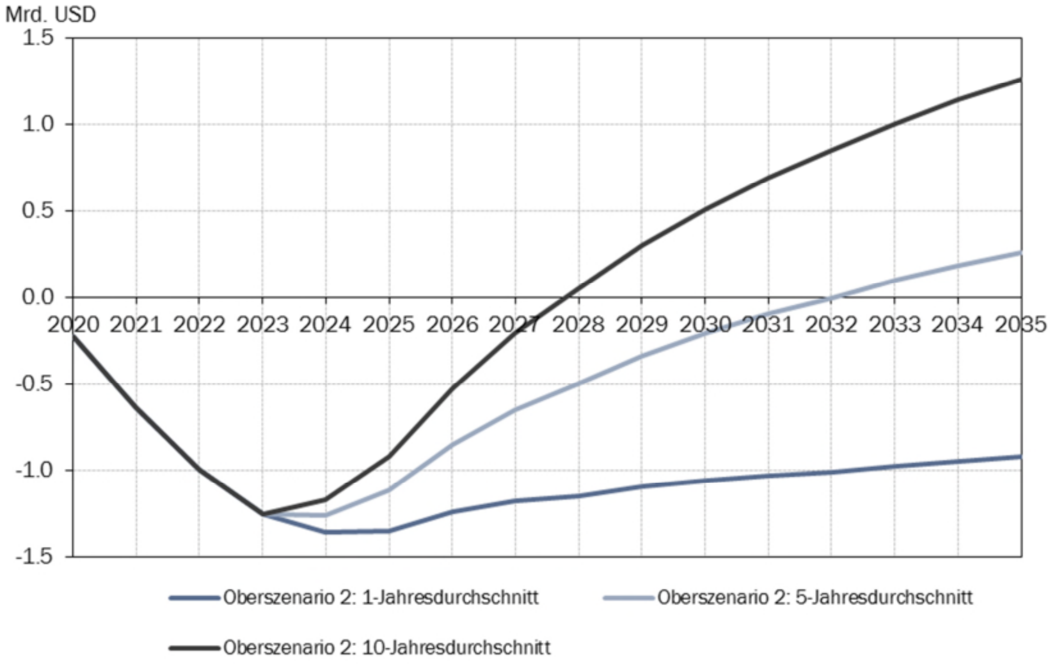


Fig. 3-21: Cumulative DCF in the expected value:
Upper scenario 2, Primary International Supply

The interest rate chosen for discounting future revenues and disbursements is obviously an important factor for the profitability assessment. A 15% discount rate was chosen as the baseline case primarily due to the large number of risks and uncertainties which exist along the value chain of deep sea mining (see section 4.1). However, since the importance of individual risk factors is very difficult to quantify in the form of concrete risk premiums, an exact quantification is of course not possible. The calculations are therefore repeated with a wide range of discount rates in order to show the influence of this parameter on our profitability analysis.

Fig. 3-22 summarises the results by showing the expected capital value distribution vs. the range of discount rates and price scenarios. As expected, profitability declines as discount rates increase. In the case of the projection scenario, however, it can be seen that even high discount rates of 25 to 30% still lead to a positive profitability assessment. This still applies, albeit to a less extent, if future prices settle at the average level of the past ten years.

A discount rate of more than 18% would be prohibitive if the five-year price average were adopted. The present price scenario (one-year price average), however, shows a general insensitivity of the resultant positive/negative sign to the discount rate: Even without any discounting of future payments, the result of a negative capital value would persist. The sensitivity analysis hence shows that the fundamental result of the profitability analysis remains: Developments on commodity markets will strongly influence the future profitability of deep sea mining.

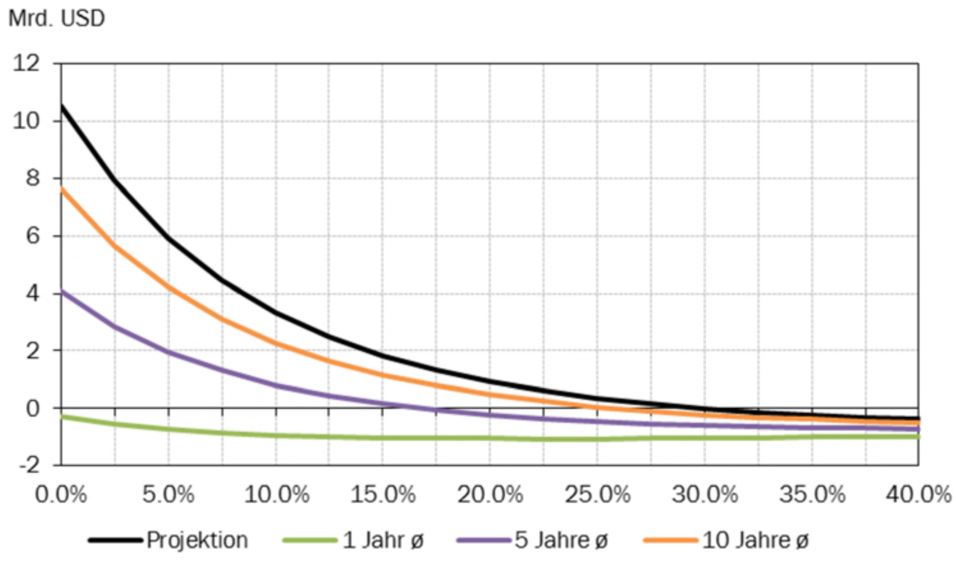


Fig. 3-22: Sensitivity of the expected capital value to the discount rate

4 Economic benefits for Germany

A key motivation factor for the public sector in favour of or against (further) deep sea mining activities is their potentially beneficial effect for the German economy. Setting aside any commercial benefits, it must be determined whether the potentially positive effect for the common good can justify the costs of supporting deep sea mining operations with government funds. Or, put simply: How will Germany benefit from spending government money on deep sea mining?

This section therefore analyses the various potential benefits for Germany that can result from commercial manganese nodule mining operations in the German licence territory of the Clarion-Clipperton Zone. This includes value chain, industry and technology effects, aspects of raw material availability and secured supply, aspects of regulatory intervention and involvement in the drafting of international rules as well as prospects of generating revenue from royalties. The analysis of the value chain shows that, depending on the share of German companies, gross added value of between €335m and €1,011m can be expected for the German economy. Depending on the respective scenario, the corresponding positive employment effect will range between 5,400 and 16,100 employee equivalents.

4.1 Industry analysis

The assessment of the value chain effects of deep sea mining covers the identification of potential technologies and their manufacture in Germany, on the one hand, and value adding and employment effects for Germany on the other. The following analyses are based on national and international publications from the field of deep sea mining, publicly available business and economic statistics, as well as assessments by the members of the consortium.

In Germany, there are several ways in which deep sea mining can generate value chain effects. One aspect is demand for products and services from German companies. This includes the provision of technologies and materials as well as planning and execution services as well as operative services in the field. Direct demand effects will additionally lead to indirect effects in upstream industries as a result of additional incomes.

The input-output analysis is a method commonly used to determine the correlations between input services by industries and the effects on value chains and employment. The basis for this are the tables of the input/output accounts which are part of the national accounts of the Federal Statistical Office. The national accounts map the interdependencies between production and goods in Germany including flows of goods between Germany and other countries. In this context, groups of products and their origins are assigned to economic activities (Federal Statistical Office 2015).[3]

4.1.1 Industry structure and value chains

In order to determine these effects, it is first necessary to identify the technology fields in deep sea mining. This value chain covers exploration and evaluation activities, production and mining, offshore and onshore logistics as well as processing and distribution and sales. This entire process, including the technologies used during the different phases, is supported by services in the field of manufacture of machinery and equipment, certification and management. Distribution and sales are not as important for the value chain in Germany because no direct demand for technologies and services will be generated here. However, many German companies are relevant in the fields of shipbuilding, mining equipment as well as certification services and manufacture of machinery and equipment.

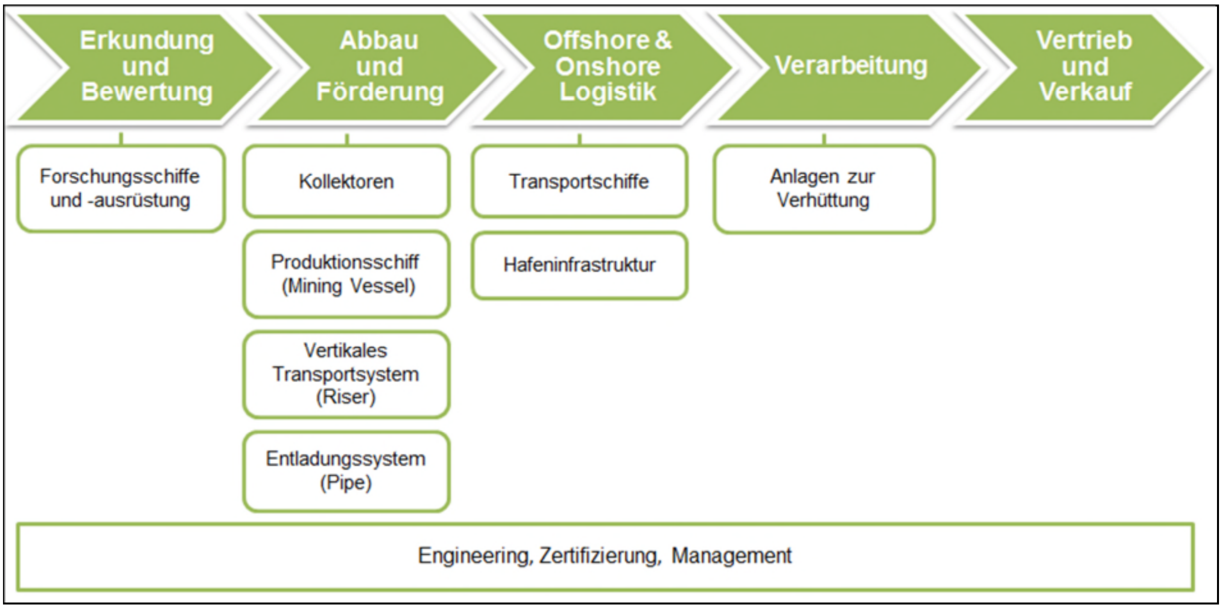


Fig. 4-1: Value chain in deep sea mining

Based on expert opinions, the members of the consortium first identify German companies and their international market position and estimate the expected capital costs for a technology set for manganese nodule mining. Three scenarios are distinguished here with ranges for possible capital costs and the shares of German production in each case.

[3] In the analysis, it must be noted that publication has been delayed by several years. The current input-output table for Germany refers to the year 2011. The analysis must therefore assume a relatively stable economic structure over the course of time. Furthermore, this method is based on the assumption of linear production functions, so that fixed factor and input coefficients are obtained. Accordingly, factor input quantities are therefore proportional to the respective output quantities.

The development of different scenarios reflects the fact that German companies are unable to offer the technologies needed for each and every step of the mining chain and/or that European or international competitors can offer these technologies at more favourable terms. This leads to three possible scenarios:

In the international scenario, the technology set is sourced from suppliers from everywhere in the world, so that both prices and the share of German companies will be lower. The European scenario assumes a European consortium that will buy mainly European equipment which means higher prices and a greater share of German production. The scenario of a German consortium with primarily German production leads to even higher costs, but also to a greater share of German products.

The smelting plant for the polymetallic nodules mined accounts for the financially largest share in total investments, ranging from €1,098m (international scenario, lower limit, second-hand bulk carriers) and €1,525m (German scenario, upper limit, new bulk carriers). Although this plant will not be erected in Germany, German companies will account for significant shares in manufacturing and fitting-out activities, depending on the respective scenario.

The situation is similar for the different vessels which will probably not be built completely in Germany, but which can be fitted with German products for monitoring purposes and special deep sea mining equipment. A high share of German production can also be expected for production and mining equipment, which also constitutes another important cost item, as well as for services throughout the entire value chain process, however, with sometimes significant variations in the share of German production between the German and international scenarios.

Table 4-1: Investment cost breakdown (in million euros according to scenarios)

Inventory	Primary German Supply			Primary European Supply			Primary International Supply		
	lower	upper	Share of German production	lower	upper	Share of German production	lower	upper	Share of German production
Mining vessel	155.0	187.4		145.9	178.4		123.4	155.9	
- Hull	52.3	58.6	20%	43.2	49.5	10%	27.0	32.4	0%
- Vessel-Specific Equipment	49.5	64.9	75%	49.5	64.9	53%	45.0	61.3	30%
- Mining-Specific Equipment	40.5	49.5	75%	40.5	49.5	63%	40.5	49.5	50%
- Yard Costs	12.6	14.4	50%	12.6	14.4	25%	10.8	12.6	0%
Vertical transportation system (riser)	187.4	220.7		187.4	220.7		170.3	220.7	
- Riser Sections and Flexible Joints	103.6	112.6	60%	103.6	112.6	43%	94.6	112.6	25%
- Pump or Airlift Systems	45.0	54.1	80%	45.0	54.1	65%	40.5	54.1	50%
- Buffer	13.5	16.2	90%	13.5	16.2	60%	12.6	16.2	30%
- Flexible Hoses to Collector	18.0	25.2	60%	18.0	25.2	30%	16.2	25.2	0%
- Monitoring & Control Systems	7.2	12.6	65%	7.2	12.6	53%	6.3	12.6	40%
Collectors	64.9	79.3		64.9	79.3		57.7	75.7	
- Carriage with Propulsion System	14.4	18.0	90%	14.4	18.0	55%	12.6	18.0	20%
- Collector, Crusher & Pump System	30.6	37.8	90%	30.6	37.8	55%	27.0	34.2	20%
- Navigation, Monitoring & Control Systems	19.8	23.4	65%	19.8	23.4	53%	18.0	23.4	40%
Discharge System (Pipe)	62.2	76.6		62.2	76.6		54.1	76.6	
- Riser Sections and Flexible Joints	37.8	45.0	50%	37.8	45.0	35%	31.5	45.0	20%
- Pump Systems	21.6	27.0	80%	21.6	27.0	65%	19.8	27.0	50%
- Monitoring & Control Systems	2.7	4.5	65%	2.7	4.5	53%	2.7	4.5	40%
Carrier Vessels / Transportation	92.8	114.4		92.8	114.4		91.0	114.4	
- Purchasing of newbuilt Supramax Bulk C.	76.6	85.6	0%	76.6	85.6	0%	76.6	85.6	0%
- Equipment for Transshipment	16.2	28.8	40%	16.2	28.8	33%	14.4	28.8	25%
Carrier Vessels / Transportation	71.2	91.0		71.2	91.0		67.6	91.0	
- Purchasing of secondhand Supramax Bulk C.	49.5	58.6	0%	49.5	58.6	0%	49.5	58.6	0%
- Conversion for Transshipment	21.6	32.4	60%	21.6	32.4	45%	18.0	32.4	30%
Harbour Infrastructure	40.5	54.1		40.5	54.1		36.0	54.1	
- Facilities & Equipment	31.5	40.5	60%	31.5	40.5	43%	27.0	40.5	25%
- Site (50000 sqm)	9.0	13.5	0%	9.0	13.5	0%	9.0	13.5	0%
Plant - Metallurgical Process	549.5	657.7		549.5	657.7		504.5	657.7	
- Plant & Equipment	495.5	585.6	70%	495.5	585.6	50%	450.5	585.6	30%
- Site	54.1	72.1	0%	54.1	72.1	0%	54.1	72.1	0%
Survey Vessel for Environmental Monitoring	63.1	72.1		58.6	72.1		49.5	63.1	
- Purchasing of new Survey Vessel	40.5	45.0	50%	36.0	45.0	38%	31.5	36.0	25%
- Monitoring Equipment	22.5	27.0	75%	22.5	27.0	63%	18.0	27.0	50%
All Disciplines on behalf of Owner	38.7	63.1		38.7	63.1		35.1	63.1	
- Engineering	18.0	27.0	75%	18.0	27.0	63%	14.4	27.0	50%
- Certification	7.2	13.5	75%	7.2	13.5	63%	7.2	13.5	50%
- Management	13.5	22.5	90%	13.5	22.5	83%	13.5	22.5	75%
Total (New Bulkcarriers):	1254.1	1525.2		1240.5	1516.2		1121.6	1481.1	
Total (Secondhand Bulkcarriers):	1232.4	1501.8		1218.9	1492.8		1098.2	1457.7	

4.1.2 Quantification (input-output analysis)

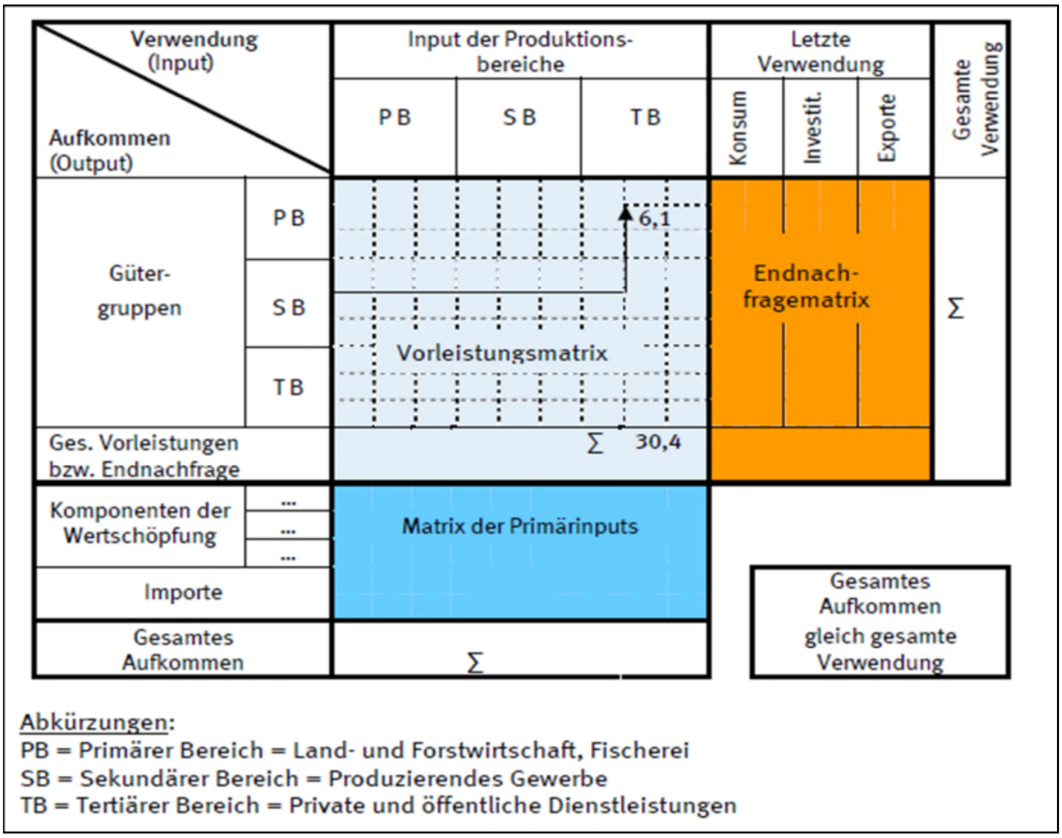
The input-output analysis is a method of empirical economic research which can be used to analyse delivery relations between different economic activities (see Leontief, 1936). The method presents the economic structure of a country or region on the basis of the input-output table which maps the delivery relations between different economic activities for a given year and shows value chain and final demand components with a high sectoral resolution (see Fig. 4-2).

In detail, the input-output analysis is used to estimate to what extent the economy as a whole will be impacted by the economic effects of changes in final demand against the background of interconnections between upstream inputs in one or more economic activities. The direct effect in this case results from the initial effect, i.e. the change in final demand for products and services for deep sea mining. This change in demand indirectly generates additional production for suppliers in the economic activity affected by final demand (first-round effect). Increased production at direct upstream suppliers, for its part, has a positive effect on demand for input products and services, so that further indirect effects occur along the value chain.

The analysis further assumes that an increase in employment leads to an increase in incomes, generating additional consumer spending by private households. The resultant increase in final demand leads to further increases in production, so that another effect chain is generated. The effect of this chain is called 'induced effect'.

The total effect is made up of the direct, indirect and induced effects. Altogether, the importance of an industry for the production, added value and employment components of an economy can exceed the direct industry effects by a multiple (multiplier effect).

The presentation of direct effects starts from the sectoral production account. However, deep sea mining is not a production area in its own right, so that the products of the above-described value chain are assigned to the product groups of the input-output table on the basis of expert assessments.



Source: Statistisches Bundesamt [Federal Statistical Office] (2010)

Fig. 4-2: Structure of an input-output table

In Germany, the initial effect will be felt strongest by the following economic activities: manufacture of machinery and equipment and plant equipment, electrical engineering as well as installation of machinery and equipment; see also Table 3-13. Engineering services which are linked to a large part of German production are less relevant because their share in total investment is small.

All in all, the production value in Germany ranges between

- €305.2m (international scenario, lower) and
- €924.7m (German scenario, upper).

This corresponds to around 20 or 60% of total investments.

This direct effect for the different economic activities, again, generates the indirect and induced effects mentioned earlier. For the German scenario, this therefore means an indirect production value of €636.1m or €772.9m, respectively, as well as induced effects of €542.4m or €664.4m, respectively. The total effect thus amounts to 2.6 times the initial sum invested in the German economy, i.e. direct demand of €1.0 translates into a total production value of €2.6. Furthermore, effects on gross added value and employment can be calculated from the employment, gross added value and income coefficients which can be taken directly from the input-output tables of the Federal Statistical Office. With gross added value of €824.0m or €1,011.2m as well as an employee equivalent of 13,200 or 16,100[4], respectively, the multipliers are slightly higher than the production value (see Table 4-2).

Table 4-2: Economic effects of the 'Primary German Supply' scenario

Effects	**Production value (in million euro)**		**Gross added value (in million euro)**		**Employment (1,000 employees)**	
	Lower	Upper	Lower	Upper	Lower	Upper
Direct	755.0	924.7	286.3	353.3	4.4	5.4
Indirect	636.1	772.9	270.3	330.4	4.3	5.2
of which:						
First-round effect	*350.2*	*427.0*	*153.0*	*187.6*	*2.5*	*3.0*
Induced	542.4	664.4	267.4	327.6	4.5	5.5
Total	1933.5	2362.0	824.0	1,011.2	13.2	16.1
Multipliers	2.6	2.6	2.9	2.9	3.0	3.0

In view of the small share of German production, the results with the European and international scenarios are below those of the German scenario, with the multipliers being relatively similar. Deviations are due to the different shares of German production under the different scenarios.

Table 4-3: Economic effects of the 'Primary European Supply' scenario

Effects	**Production value (in million euro)**		**Gross added value (in million euro)**		**Employment (1,000 employees)**	
	Lower	Upper	Lower	Upper	Lower	Upper
Direct	544.0	670.9	207.4	257.9	3.2	3.9
Indirect	456.9	558.8	194.6	239.5	3.1	3.8
of which:						
First-round effect	*251.9*	*309.2*	*110.3*	*136.2*	*1.8*	*2.2*
Induced	391.2	482.3	192.9	237.8	3.3	4.0
Total	1392.1	1712.1	594.9	735.2	9.5	11.7
Multipliers	2.6	2.6	2.9	2.9	3.0	3.0

[4] This corresponds to the number of employees who are, at a given productivity level, needed to produce the production value shown in one year.

Table 4-4: Economic effects of the 'Primary International Supply' scenario

	Production value (in million euro)		Gross added value (in million euro)		Employment (1,000 employees)	
Effects	Lower	Upper	Lower	Upper	Lower	Upper
Direct	305.2	414.8	117.6	161.6	1.8	2.5
Indirect	254.6	343.0	109.0	148.0	1.7	2.3
of which:						
First-round effect	*140.7*	*190.3*	*62.0*	*84.5*	*1.0*	*1.4*
Induced	219.8	298.7	108.4	147.3	1.8	2.5
Total	779.6	1056.5	335.0	456.9	5.4	7.3
Multipliers	2.6	2.5	2.8	2.8	3.0	2.9

The results shown above apply to the mining of manganese nodules in the German licence territory. Exports for further international mining projects could generate further positive demand and the resultant effects. No separate scenarios were developed for the mining of massive sulphides because the costs and value effects would be similar due to the similarity of the technology fields. Technological spill-over effects to other industries are disregarded because their relevance is limited to certain sub-areas of the value chain process and because reliable quantification of these effects is almost impossible.

4.2 Raw material policy

4.2.1 Availability and supply security of raw materials

Securing the supply of raw materials is a key element of assessing German involvement in deep sea mining. In order to assess the importance of the resource potential of the deep seas, the availability of resources that can be accessed onshore should be analysed first. Without supply risks and without essential cost advantages of deep sea mining, Germany's established raw material import supply channels would be superior to supplies from deep sea mining. The overall assessment should therefore address not only commercial aspects, but also strategic resource issues. From the perspective of the German government, the question must be answered as to whether Germany's onshore supplies of metals mined in the deep seas are threatened in any way whatsoever so that German involvement in deep sea mining can be justified as a strategic measure to secure raw material supplies.

In the following, the most important aspects of raw material security will be examined, discussed and put into the perspective of deep sea mining.

Germany has limited resources and is completely dependent on imports of those metals that can be potentially mined in the deep seas.

This dependency makes Germany, as a modern industrialised nation, particularly susceptible to supply security issues. High-price phases, in particular, are a recurrent reason for concern regarding the threat of commodity supply bottlenecks. High prices are initially an indicator of economic scarcity, i.e. high demand at times of limited supply. All of the metals analysed in this study are non-renewable, mineral resources. Scarcity of this group of resources can be due to two root causes that should be distinguished, i.e.:

- *absolute* scarcity because resources are exhausted

  or

- *relative* scarcity because of other supply bottlenecks (trade restrictions, institutional risks, etc.).

Both dimensions of resource scarcity can have severe repercussions on a country's raw material supply. The terminology as well as the related risks will be discussed below against the background of deep sea mining (BGR 2006, BGR 2015).

Absolute scarcity

Mineral raw materials are a finite resource. Geological reserves in the earth's crust are limited, and their physical availability will be exhausted at some time if mining continued. In terms of resource economics, exhaustion of reserves refers to the absolute dimension of resource scarcity.

In light of this triviality – resources are finite – it was and still is often wrongly concluded that raw materials will inevitably become increasingly scarce and hence more expensive. This common certainty often led to scarcity scenarios that forecasted declining availability and continuously rising prices for all kinds of raw materials. The most familiar example is certainly the predictions by the Club of Rome regarding the disappearance of oil. In fact, however, such scenarios have always proven to be wrong. Up to now, no long-term trend towards rising commodity prices has been observed in real terms; for some commodities, prices were even found to decline in real terms (Cashin et al., 2002).

Regarding absolute scarcity, it must therefore be determined from a German perspective whether exhaustion of a relevant raw material is already foreseeable from a geological perspective. The complete deposits of a raw material, which are proven in terms of geographic occurrence, quantity and quality, are called resources. This includes all deposits where exploitation is both economically viable and not viable. Reserves are defined as any subset of resources where mining is economically viable with the current state of the art at current prices.

Static range

A commonly used and easy to calculate measure for assessing absolute scarcity is the so-called static range. It is defined as the quotient of proven reserves and current exploitation rate:

$$\frac{\text{Reserves (in tonnes)}}{\text{Production (in tonnes per annum)}} = \text{static range (in years).}$$

The range thus indicates when the currently known reserves will be exhausted at current exploitation rates. The trivial measure is often misunderstood, so that any interpretation must be made with caution for a number of reasons.

The static range is a dynamic parameter that can change in either direction, i.e. both the numerator and the denominator change over the course of time. When a raw material is extracted, reserves will inevitably decline and, ceteris paribus, drop to 0 over the range period. Furthermore, the range of reserves is to a major extent dependent on future consumption and mining trends. If mining volumes were to increase in the future, the pace of this process would pick up accordingly and reduce the range faster. However, reserves can also increase over the course of time. Technical progress, exploration activities and changes in market prices can turn deposits, where mining was previously economically not viable, into deposits that are economically worth exploiting [see Fig. 4-3]. Part of the resources can therefore become reserves if new mining methods are developed or if prices rise. Reserves and hence also the static range increase accordingly.

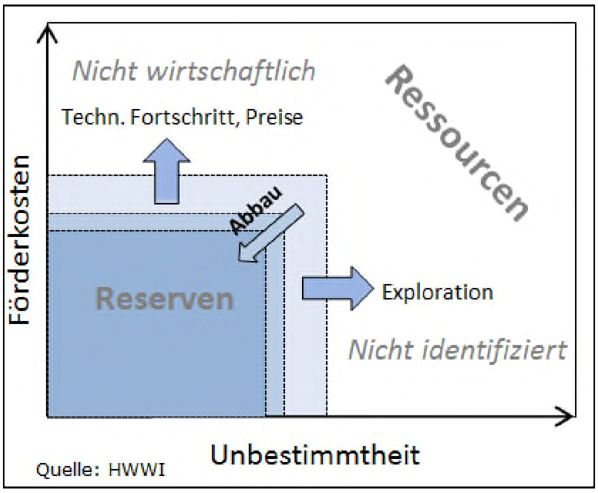


Fig. 4-3: Dynamic development of reserves and resources

An assessment of static ranges must therefore always consider the opposing processes of 'reserves declining due to mining' and 'reserves increasing due to exploration and technical progress'. In the past, reserves and ranges of many raw materials followed a rising rather than a declining trend. The corresponding static ranges (calculated in the past) therefore failed to adequately reflect the absolute scarcity of the respective raw materials. This means that the ranges which are determined today should be interpreted with caution. This is chiefly due to the following factors:

- As prices increase, the extent of reserves tends to increase too because mining of part of the resources that were previously economically not viable can become attractive at higher prices.
- A small range and higher prices increase the need for exploration activities which, for their part, can lead to increased resources and reserves.
- Technical progress: Improved mining technology can help to lower costs and therefore make mining of certain resources possible which consequently become part of the reserves.
- Recycling and substitution: Technical progress can enable higher recycling rates and increase the importance of potential substitutes. Both processes can restrict or even reduce mining volumes.

Although, for the reasons discussed above, the static range "is unsuitable as an early warning indicator for the absolute scarcity of raw materials" and "[constitutes] only a snapshot" (BGR, 2006, p. 16), Table 4-7 can provide at least a first impression of potential absolute scarcity. The static resource range, i.e. the ratio between proven resource and current exploitation rates, is shown there as an alternative measure for assessment.

Just like the static (reserve) range, this measure must also be interpreted with caution. On the one hand, it is conceivable that economically viable exploitation of part of the identified resources will never be possible so that these resources will remain in the ground. Furthermore, the resource basis and therefore also the resource range can increase as a result of newly discovered deposits. Given a cautious interpretation, the two parameters – the static reserve range and the static resource range – describe a time corridor during which the threat of absolute scarcity of the raw materials concerned could materialise.

Table 4-5: Mining, reserves and ranges of selected metals (in 2016)

Metal (ore)	**Production in 2015*** **(thousand tonnes)**	**Proven reserves** **(million tonnes)**	**Resources** **(million tonnes)**	**Static (reserve) range (years)**	**Static (resource) range (years)**
Bauxite	274,000	28,000	55,000	102	201
Lead	4,710	89	2,000	19	425
Chromium	27,000	> 480	>12,000	>18	>444
Iron (ore)	3,320,000	190,000	800,000	57	241
Gold	3	0.056	0.0	19	No data

Cobalt	124	7	27	57	218
Copper	18,700	720	2,100	39	112
Manganese	18,000	620	>5,100	34	>283
Nickel	2,530	79	130	31	51
Rare earths	124	130	No data	1,048	No data
Silver	27	0.57	No data	21	No data
Titanium (ilmenite)	5,610	740	No data	132	No data
Zinc	13,400	200	1,900	15	142
Tin	294	5	No data	16	No data

Source: USGS (2016); BGR (2006); HWWI (own calculations). *
USGS estimates for 2015

Absolute scarcity of the metals contained in manganese nodules

The static (reserve) ranges for cobalt, copper, manganese and nickel (as well as rare earths with reservations) as the relevant metals in manganese mining suggest that there is no threat of absolute scarcity is threatening at least over the next three decades. The reserve range of rare earths totals more than one thousand years, so that exhaustion of rare earth deposits can be ruled out in the foreseeable future. The static reserve range of the relevant metals in deep sea mining is shortest for nickel at 31 years. In conjunction with its resource range, nickel is the only metal that can be potentially exploited by deep sea mining and whose resources could be exhausted in the 21st century. The reserve and resource ranges of cobalt, copper and manganese do not suggest absolute scarcity in this century.

Relative scarcity

Besides the total volumes of proven onshore reserves and resources shown earlier as well as the related implicit ranges, relative scarcity is another key element in the assessment of supply risks. Relative scarcity describes potential situations in which a raw material can be (temporarily) in short supply for the most varied reasons, i.e. not as a result of exhausted reserves, but, for instance, due to other bottlenecks, such as lack of capacity, disruption of supply or trade restrictions. This condition is hence in principle of a temporary nature and reflects a supply deficit which has nothing to do with scarcity in terms of resource economics.

The most relevant aspect in this case is the geographic distribution of deposits and mining activities. Strong geographic concentration of production on a few countries implies, at least in the short to medium term, a corresponding geopolitical dependency of raw material importing countries, such as Germany. This dependency could be reduced by alternative metal mining methods, such as deep sea mining. Besides the general risk of geographic concentration, country-specific risks related to mining areas are also potentially relevant. These risks primarily concern the political and institutional level. Political instability is a particular risk: Political unrest can affect raw material export activities, and a country's new government can drastically change its trading orientation. In order to address such risks within the scope of a country comparison, the different dimensions of country risks must first be compiled in the form of comparative indicators. The World Bank's governance indicators provide a basis for this that is both unobjectionable and reliable from a methodological perspective.

With a view to the geographic concentration of metals, a list of the world's largest producing countries and their production shares of the different metals provides an overview. Table 4-8 shows a number of other important metals in addition to those metals (marked green) of which significant shares are contained in manganese nodules according to the above analysis. This highlights the relative importance of the geographic concentration of deep sea metals. The largest concentration of production volumes is currently seen for rare earths where China accounts for a global share of 90%. The shares of the largest producing countries are relatively small for the precious metals gold and silver. This applies specifically to nickel as one of the metals contained in manganese nodules. On the other hand, cobalt that is also contained here is a metal where a single country, i.e. the Democratic Republic of the Congo, currently accounts for more than half of global production.

Table 4-6: Most important producing countries in 2014

Metal (ore)	Rank 1	Produc-tion (thou-sand tonnes)	Global share (%)	Rank 2	Produc-tion (thou-sand tonnes)	Global share (%)	Rank 3	Produc-tion (thou-sand tonnes)	Global share (%)
Bauxite	Australia	78,632	30.27	China	65,000	25.03	Brazil	35,410	13.63
Lead	China	2,700	50.34	Australia	728	13.57	US	355	6.62
Chromi-um	South Africa	14,038	46.77	Kazakh-stan	5411	18.03	Turkey	4,100	13.66
Iron	China	1,514,240	44.84	Australia	745,735	22.08	Brazil	345,800	10.24
Gold	China	452	14.98	Australia	274	9.09	US	210	6.97
Cobalt	Dem. Rep. of the Congo	76	59.45	China	9	6.61	Canada	7	5.11
Copper	Chile	5,750	31.29	China	1,635	8.9	US	1,370	7.46
Manga-nese	China	16,000	29.27	South Africa	13,830	25.3	Australia	7,587	13.88
Nickel	Philippines	363	17.67	Russia	264	12.84	Australia	245	11.90
Rare earths	China	95	90.03	US	4	3.98	Australia	4	3.76
Silver	Mexico	5,766	21.02	Peru	3,778	13.77	China	3,568	13.01
Titanium (ilmen-ite)	Canada	2,500	20.24	Australia	1,340	10.85	South Africa	1,105	8.95
Zinc	China	5,200	38.01	Australia	1,561	11.41	Peru	1,319	9.64
Tin	China	160	45.12	Indonesia	70	19.80	Burma	35	9.87

Sources: BGS (2016); HWWI (2016).

Fig. 4-4 illustrates even better the extent of the global concentration of onshore mining as a whole. The individual countries are shown there in different colours according to their respective shares in global production in as far as such shares exceed 1%. The pattern clearly shows regional concentrations. Australia and China, for instance, achieve the corresponding production shares for all the metals concerned. Brazil and Russia also produce significant amounts of a wide range of metals. Europe, in contrast, has a minor role to play at a global level. Production in Africa – except South Africa – is limited to the production of specific metals in individual countries.

Sources: BGS (2016); HWWI (2016).

Fig. 4-4: Geographic distribution of production concentration

In order to enable a comprehensive assessment of the relative concentrations of the individual metals, the distribution of production will be translated in the following into a unidimensional concentration measure. Many such concentration measures have been developed in the field of regional economics, such as the Gini coefficient for spatial concentration, the Theil dissimilarity index and the Hirschman-Herfindahl index.

The latter's advantage in our case is that this index is an absolute (rather than relative) measure for concentration. This means that the concentration value measured depends not just on the relative distribution of production but also on the absolute number of producing countries. The index value is specifically calculated as the sum of the squared production shares of the individual countries for the respective metal. The maximum value with full concentration on a single country hence totals one. Fig. 4-5 shows the values for our metal selection on the basis of production data in 2014. It comes as no surprise that rare earths are currently rated as highly concentrated. Cobalt is the only metal of special relevance in manganese nodule mining that features an above-average concentration level. Nickel even shows a clearly below-average concentration.

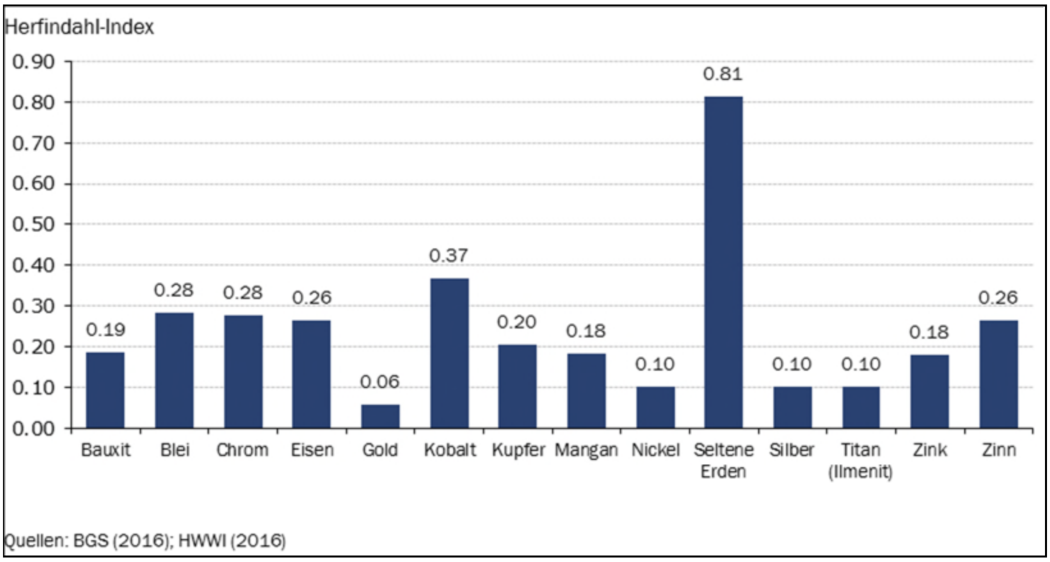


Fig. 4-5: Herfindahl index of global production concentration in 2014

In order to compare the institutional risks in conjunction with access to the different metals, we will, as mentioned earlier, use a selection of those governance indicators that are applied by the World Bank.

These indicators are based on many surveys among companies, citizens and experts and in each case reflect different dimensions of governance quality.

We have selected three sub-indices which cover important aspects of resource mining, i.e. political stability, rule of law and regulatory quality. Political stability reflects the probability that the ruling government could be destabilised or overthrown by non-constitutional or violent measures. Rule of law is a measure for the degree to which stakeholders can trust in and follow social rules, especially with a view to contract execution and ownership rights. Regulatory quality measures the perception of the government's ability to implement a decent regulatory policy that permits and facilitates the development of the private sector.

The indices cover a range from -2.5 to +2.5. In order to derive the mining risks of individual metals from these country indices, we use a simple average value calculation concept: In each case, we weigh the index value of the producing countries with their share in global production and calculate the average value. Table 4-9 shows the results according to sub-indices. Among the metals in question, titanium (in the form of ilmenite ore) is rated as the metal with the currently lowest institutional mining risk according to all three categories. This follows directly from the fact that Canada and Australia, i.e. two industrialised nations, serve important parts of the global market. Cobalt clearly marks the opposite end of the scale. The Democratic Republic of the Congo, the by far most important producing country with a very unfavourable political climate, contributes significantly to this result. The other deep sea metals (nickel, manganese) range more or less mid-field and to some extent also occupy leading positions. The latter applies especially to copper and (with the exception of the 'political stability' category) to zinc.

Table 4-7: Degree of institutional risk regarding access to raw materials

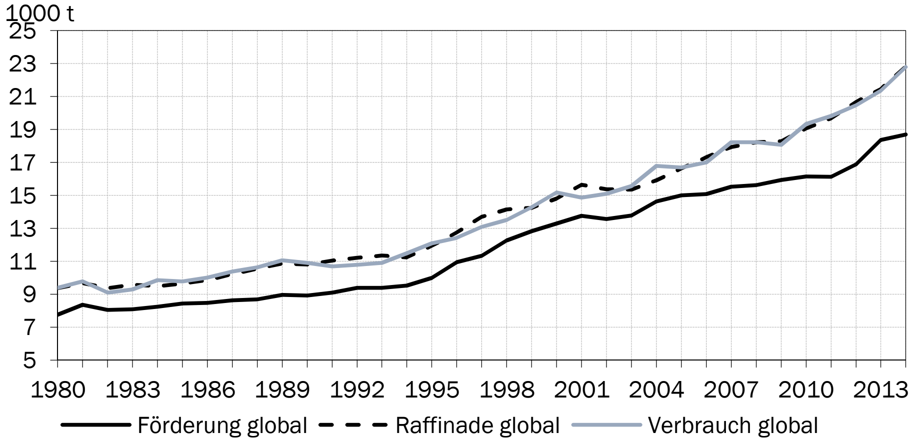
	Political stability		**Rule of law**		**Regulatory quality**	
Rank	Metal (ore)	Value	Metal (ore)	Value	Metal (ore)	Value
1	Titanium (ilmenite)	0.147	Titanium (ilmenite)	0.551	Copper	0.632
2	Copper	0.055	Copper	0.506	Titanium (ilmenite)	0.513
3	Nickel	-0.051	Iron	0.277	Silver	0.380
4	Iron	-0.056	Bauxite	0.216	Nickel	0.331
5	Bauxite	-0.091	Nickel	0.201	Bauxite	0.331
6	Manganese	-0.104	Zinc	0.159	Zinc	0.302
7	Zinc	-0.122	Manganese	0.115	Iron	0.298
8	Silver	-0.188	Gold	0.047	Lead	0.198
9	Gold	-0.194	Lead	0.012	Manganese	0.174
10	Lead	-0.238	Silver	-0.014	Chromium	0.172
11	Chromium	-0.340	Chromium	-0.054	Gold	0.166
12	Rare earths	-0.368	Rare earths	-0.177	Rare earths	-0.125
13	Tin	-0.462	Tin	-0.421	Tin	-0.281
14	Cobalt	-1.288	Cobalt	-0.727	Cobalt	-0.683

Sources: World Bank (2016)

4.2.2 Political and strategic interests

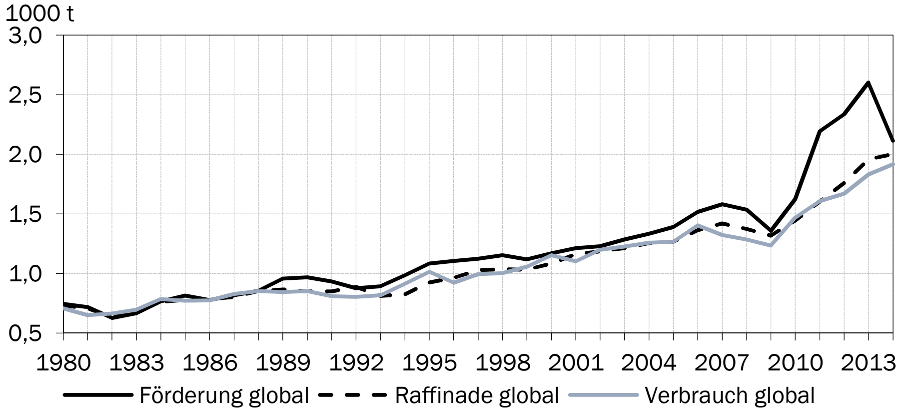
One important aspect of political and strategic interests is the consumption trend for the metals relevant within the scope of deep sea mining. Certain data limitations must be considered in this context. Although geological information services provide data concerning production volumes and refinery production for all metals, longer time series data regarding consumption levels is only available for certain metals. It is, for instance, not possible to map manganese and cobalt consumption. Fig. 4-6 compares the production and consumption trends for nickel and copper as other relevant metals on the basis of BGR data. Raw material consumption increases almost continuously in the long term, along with increased mining and refinery production in each case. Developments have been particularly dynamic since the beginning of the 2000s. Over the past five years, this can be seen especially for nickel, with nickel consumption growth picking up significantly, also in conjunction with booming mining activities.

Copper



Sources: BGR (2016); HWWI (2016).

Nickel

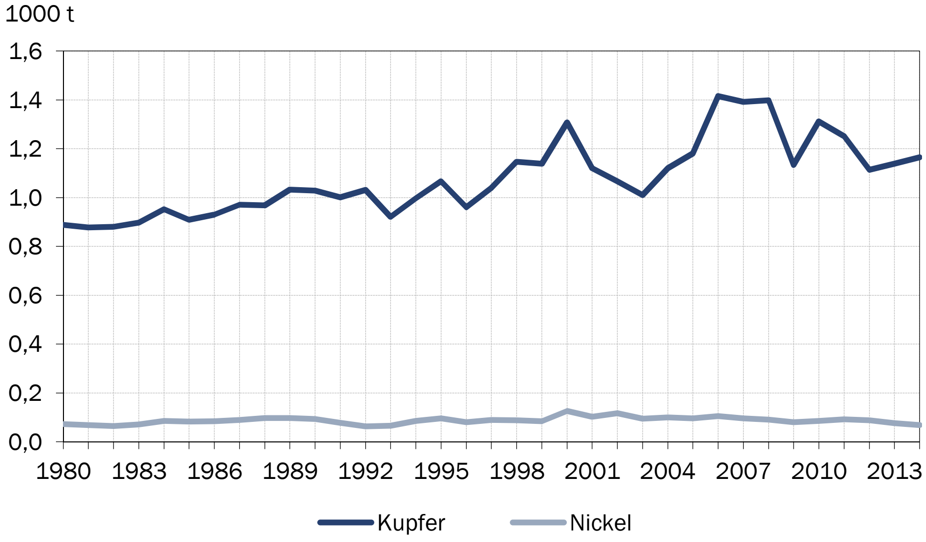


Sources: BGR (2016); HWWI (2016).

Fig. 4-6: Historical supply and demand trends, globally

Economic growth of the newly industrialised countries is an important driver behind growing resource demand, whilst western industrialised countries record a correspondingly significant decline. Against the background of considerations of national demand, the question regarding demand trends in Germany as shown in Fig. 4-7 becomes particularly important. Zinc and nickel consumption levels have been relatively flat over the past 30 years, with copper being the only metal to show a slightly positive trend, however, in an environment of generally stronger fluctuations. Since Germany, as a resource-poor country, depends on imports of ultimately all the metals in question, this will mean a certain level of import dependency even in the nearer future. The degree of import dependency can be seen best in a comparison with Germany's market shares for the other metals. This should be based on import data because – unlike consumption data – import data is monitored by the British Geological Survey (BGS) for all the metals so far considered.

Table 4-10 compares German and European imports for the year 2013. What is immediately obvious is Germany's high import share of pure copper: According to BGS data, more than half of European imports in 2013 went to Germany. German import activity is also strong in the case of nickel. Among the deep sea metals, only German imports of cobalt account for a relatively small share of total European demand. That being said, Germany's demand for metals contained in manganese nodules appears to be relatively high even in an international comparison.



Sources: BGR (2016); HWWI (2016).

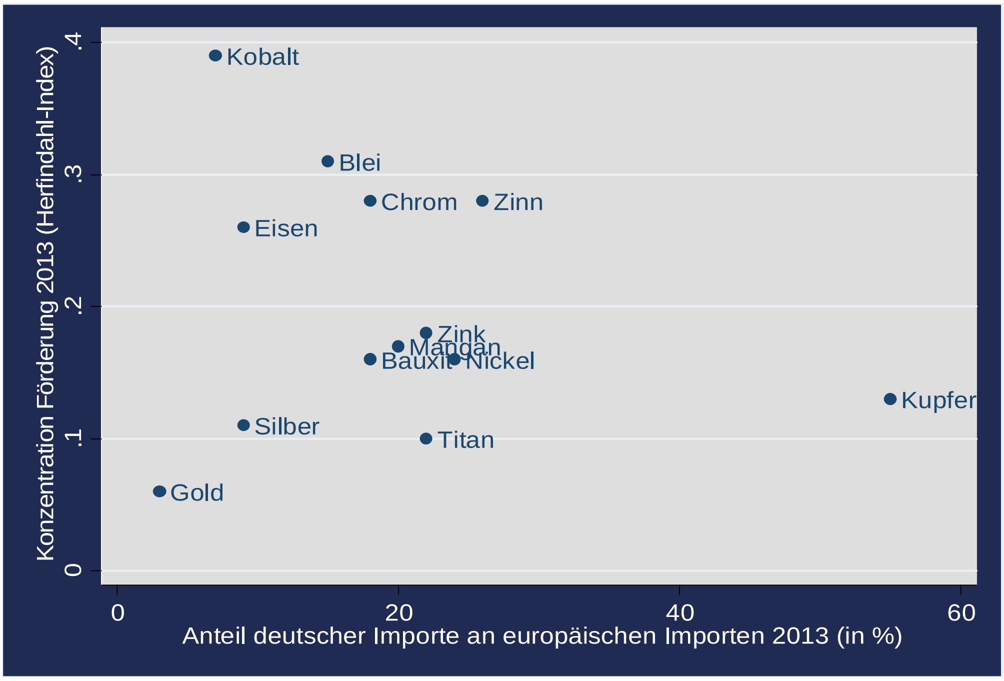
Fig. 4-7: Historical consumption trend, Germany

Table 4-8: German and European metal imports

Metal (ore)	Form(s)	Imports by Germany in 2013 (tonnes)	Imports by European countries in 2013 (tonnes)	German share
Bauxite	Ore	2,407,688	13,528,299	17.80%
Lead	Pure	149,465	1,018,943	14.67%
Chromium	Pure + ferrochromium	336,833	1,893,101	17.79%
Iron	Pig iron + ingots	2,066,234	23,502,454	8.79%
Gold	Pure	149,337	4,575,503	3.26%
Cobalt	Pure	4,309	59,113	7.29%
Copper	Pure	685,731	1,254,499	54.66%
Manganese	Manganese + fer-romanganese and silicomanganese	439,294	2,195,055	20.01%
Nickel	Pure + alloys (including ferro-nickel)	158.,674	673,521	23.56%
Rare earths	Pure + cerium/ cerium iron compounds + other compounds	7,004	26,434	26.50%
Silver	Pure	2,203,529	23,729,240	9.29%
Titanium (ilmenite)	Pure + oxides + ferrotitanium	335,513	1,543,441	21.74%
Zinc	Pure + oxides + ferrotitanium	435,610	2,008,739	21.69%
Tin	Pure + alloys (including ferro-nickel)	19410	73,895	26.27%

Sources: BGS (2016); HWWI (2016).

Finally, German import dependency can also be compared to the concentration of global production as determined in the previous section in order to assess how critical the respective level of import dependency is with a view to supply-side concentration (see Fig. 4-8). Copper, as the element with the highest German import share, shows a relatively low concentration level, whilst the German import share is relatively small in the case of metals with a particularly high concentration, such as cobalt.



Sources: BGS (2016); HWWI (2016). Rare earths outside sensible scaling

Fig. 4-8: Global raw material concentration and German import dependency

Annex 2 provides a specific market overview for certain metals relevant in deep sea mining.

4.3 Regulatory framework

Financial rules form an important part of any mining legislation. These rules consist of differentiated financial levies and can offer incentives for investors and/or contractors whilst at the same time acting as a cost factor. The fiscal regime for deep sea mining constitutes a system of fees, royalties and taxes, supplemented by insurance costs and a liability trust fund.

At its 22nd session on 15 July 2016, the International Seabed Authority published its first draft Mining Code (with wording yet to be finalised in certain parts). Among the 59 regulations, "Part V – Financial Terms of a Contract" sets forth 25 regulations with financial rules (Reg. 20 to 45). Further regulations are contained elsewhere in the draft document and its nine annexes. However, the proposed wording is limited to the formal structure of the different charges and levies. The amount of such charges and levies as well as the methods for their determination are left open. The description as "working draft" and the introduction to Part V of the draft expressly show that all the regulations are provisional because further discussion regarding the structure and amounts is needed. According to the so-called "building block" approach, the draft is the first phase with procedural regulations. The final design of the financial regulations as well as the comprehensive environmental protection regime and the transformation of ISA to a mining administration must be prepared in a separate move before a decision on the final mining code as a 'package' will be made. This work is a high-priority task. ISA has commissioned experts on four individual aspects who, in the first half of 2016, submitted discussion papers for ISA's internal opinion-forming process. These papers are confidential and therefore cannot be cited here.

Financial regulations up to now were limited to exploration licenses with a 15-year term. The basis is UNCLOS Annex III Art. 13 (2) and the three Mining Codes for the Exploration of Manganese Nodules, Sulphides and Crusts. Their regulations (abbreviated 'Reg.') provide for a uniform:

- once-off fee for application to cover administrative costs: 500,000 USD
- annual processing fee for annual reports: 47,000 USD.

From 1994, the once-off fee for application was temporarily reduced from 500,000 USD to 250,000 USD in order to offer an incentive to first licensees, but was again raised to 500,000 USD in 2013. The fee can vary in individual cases within a narrow band depending on lower or higher processing costs to be verified. The amount must be regularly revised by the council.

The annual processing fee was introduced in 2013 by an ISA resolution when the workload for examining and auditing the annual reports of the more than 20 licensees increased significantly. In 2015 (21st session), the extension fee of 67,000 USD was added for applications for a 5-year extension of the exploration phase. These examples illustrate ISA's policy for adjusting existing and introducing new fees. There has been no reason up to now for royalties or other charges in conjunction with the exploration licenses.

With regard to responsibility and liability (see section 5 below) even after completion of exploration activities, the general liability provisions of the UNCLOS continue to apply requiring proof of third-party liability insurance. Prior to commencing extraction system (collector) testing, a financial guarantee must be provided in order to secure payment of emergency measures that may become necessary.

4.3.1 Financial regulations for mining licences – draft exploitation regulations

The discussion on financial regulations for industrial mining operations started in 2012 in conjunction with the preparation of the exploitation regulations for manganese nodules. A first workplan of the Secretary-General[5] repeated familiar criteria, such as royalties that should be simple, equitable and orientated towards onshore mining. A new concept was that costs and revenues are subject to economic

[5] ISBA/18/C/4, para 5-6.

cycles over the course of a project lasting several years and that adequate compensatory measures have to be considered. Furthermore, this workplan is also important because its sections 15 et. seqq. contain for the first time proposals for cost models for the commercial mining of manganese nodules and for equipment testing.

A more detailed document from March 2013[6], which is based on an external study[7], very clearly calls for an equalisation of interests between the economic incentives for investors and protection of the environment, safety of operations and benefits for mankind as a whole. The financial regulations should be robust, acceptable and transparent.[8] This clearly shows the determination to generate incentives for deep sea mining because this is the key prerequisite for any revenues to be distributed at all.

The next step was a 60-page working paper titled "Developing a Regulatory Framework for Deep Sea Mineral Exploitation in the Area – Version II" dated 15 July 2015[9] that was based on a survey of 41 stakeholders10 and an ISA study from March 2015.[11] The report on the "Development and Implementation of a Payment Mechanism in the Area"[12] specifically addressed the financial regulations. After these preparations, the 21st ISA session adopted in July 2015 a type of roadmap[13] for developing the context of the Mining Code and commissioned the preparation of a list with seven priority deliverables, including the financial regime. Work on the content of the financial regulations began in 2015 in three workshops, i.e. in May 2015 in Singapore[14], in October 2015 in Bellagio (World Economic Forum)[15] and in May 2016 in La Jolla/San Diego[16], with the latter being considered to be an opinion-forming event thanks to its comprehensiveness. Furthermore, ISA Technical Study No. 15 contains several contributions even though it focuses more on compensation payments in the Outer Continental Shelf[17].

6 ISBA/19/C/5 "Towards the development of a regulatory framework for polymetallic nodule exploitation in the Area"; see also ISBA/19/C/18.

7 ISA Technical Study no. 11 of 26 February 2013. www.isa.org.jm/files/documents/.../DiscussionPaper-FinMech.pdf

8 ISA Technical Study no. 11, p. 47, refers to a "defensible" scheme.

9 http://bit.ly/1K4Bmrc; see also ISBA/21/C/16 of 15 July 2015, Annex III.

10 https://www.isa.org.jm/survey/March-2014/stakeholder-responses; including a German contribution.

11 Developing a Regulatory Framework for Mineral Exploitation in the Area. A Discussion Paper on the Development and Implementation of a Payment Mechanism, published March 2015, 29 pp. www.isa.org.jm/files/documents/.../DiscussionPaper-FinMech.pdf.

12 www.isa.org.jm/files/documents/.../DiscussionPaper-FinMech.pdf

13 ISBA/21/C/16 of 15 July 2015, Annex III, and ISBA/21/C/20 of 21 July 2015

14 Joint CIL-ISA Workshop 16-17 June 2015, Singapore; see ISA Briefing Paper 04/2015.

15 Workshop World Economic Forum 07.-09.10.2015 in Bellagio/Italy, available at: Toward_Transparency_Best_Practices_Deep_Seabed_Mining_Bellagio_report_2016_0501

16 San Diego Workshop. Conference Report: Deep Seabed Mining Payment Regime Workshop, May 17-18, 2016, La Jolla/San Diego, containing recommendations, presentation of facts and individual issues as well as tabular headings of open issues. https://www.isa.org.jm/files/documents/EN/Pubs/2016/DSM-ConfRep.pdf.

17 ISA Technical Study No. 15, June 2016, concerning compensation payments pursuant to Art. 82 UNCLOS.

As an intermediate result of all these preparations, ISA published on 15 July 2016 the above-mentioned Draft Mining Code[18] with 59 pre-formulated regulations, including "Part V – Financial Terms of a Contract" with 25 articles concerning financial regulations (Reg. 20 to 45) and further regulations set forth elsewhere in the draft and its nine annexes.[19] Details regarding levies and charges as well as the complete (royalty-relevant) section on environmental protection provisions are still missing[20].

The current draft hence only contains the structure of a combined remuneration system that comprises guarantee payments, fees, royalties, plus future profit-sharing payments and potentially an environmental liability trust fund; see section 4.3.3 below). In detail:

Fee for applications

Reg. 5 provides for a fee for applications, but does not specify a precise amount. Due to the involvement of the general public and possibly of experts too, the amount will be higher than the 500,000 USD for exploration applications.
Any deviations from the amount to be fixed must be compensated for.

Performance guarantee

As part of the procedure of applying for a mining licence, Reg. 10 provides for the possibility to request that the applicant furnish a financial performance guarantee that will become part of the terms of contract of the workplan. Details must be determined in guidelines. It is also likely that another guarantee in the form of an environmental guarantee or environmental bond will be demanded.[21] This raises the question as to whether this is in fact necessary because insurance is also a tried-and-tested instrument to cover these risks (see section 5.4 below).

Use of exploitation contract as security

Reg. 16 provides for the possibility to mortgage or otherwise encumber the exploitation contract in order to finance the project. The contractor's contracts with the financing party must be submitted to ISA for approval. Additional costs can arise for independent evaluations of environmental assessments, environmental management plans, financing plans and other components of the application. Details are subject to further consultation.

18 Working Draft Regulations and Standard Terms on Exploitation for Mineral Resources in the Area; https://www.isa.org.jm/files/documents/EN/Regs/DraftExpl/Draft_ExplReg_SCT.pdf and http://bit.ly/29MBDSS .

19 The annexes contain the draft documents for mining applications and its parts, i.e. feasibility study, mining plan, financing plan, emergency plan as well as standard contract terms and tables for penalties and other fees.

20 Advice regarding environmental protection regulations by GLS-ISA workshop, Co-chairs Report, June 2016.

21 San Diego workshop, Conf Report, numbers 111 – 115.

Annual fees

An annual contract administration fee pursuant to Reg. 21 is payable from the date of the contract coming into effect in order to cover annual administration and monitoring costs. This item includes ISA's monitoring and marine research tasks. The amount is open and will be based on increased handling and processing costs for environmental protection and operating safety issues (100,000 USD?).

An annual fixed fee is additionally payable from the date of commencement of commercial production (Reg. 22). This fee depends on a fee to be determined annually by the ISA Council per square kilometre of the exploitation area and, in this respect, is similar to the German concession royalty ('Feldesabgabe'). The annual fee can be offset against royalties.[22] Information regarding the amount is not available. An initial sum of 1 million USD is being considered.

Royalties

Royalties are the charges and/or taxes customary in mining to be paid for the extraction of raw materials from the deposit. The 1982 UNCLOS uses the term "production charges"[23], whilst the implementation agreement uses the customary term "royalty"[24]. Royalties can also serve to cover administration costs so that there is a risk of competition with fixed fees.

The royalty pursuant to Reg. 23 et seqq. is to be charged from the beginning of commercial production irrespective of whether the minerals were sold. The Council revises the amount on an annual basis. The contractor may apply to ISA for written information relating to the calculation of his royalties or other payments (Reg. 25). As the basis for such calculation, the contractor is obliged pursuant to Reg. 27 and 28 to submit certain information on fixed dates regarding production volume and quality as well as information regarding contracts with his customers. Furthermore, certified audits must be performed and other information as requested by ISO submitted on an annual basis.

Reg. 24 simply states that the amount and calculation basis of the royalty (unit-based, ad valorem or profit-dependent?) are subject to further elaboration.

Pursuant to Reg. 30, overpayments can be refunded or carried forward.

Pursuant to Reg. 31, the contractor is obliged to maintain complete records and to archive these for certain periods of time. The contractor is obliged to accept inspections and audits by ISA's representatives and auditors (Reg. 32 and 33).

[22] See: Implementing agreement, annex, section 8, number 1 d.
[23] UNCLOS Annex III, Art. 13 para. 3-6.
[24] Implementing agreement, annex, section 8, number 1 c.

In the event of false statements, Reg. 36 provides for a special procedure for the exchange of opinions between the contractor and ISA.

Although data regarding royalties is protected, payments that have been effected are published (Reg. 35).

Royalty payments, when overdue, bear interest pursuant to Reg. 38. Penalty of up to twice the amount of amounts overdue can be charged (Reg. 39).

Penalties can also be charged in cases of failure to submit information or submission of false information (Reg. 40 and 41). However, such payments can be deducted from performance guarantees pursuant to Reg. 10 and 42.

The exploitation contract can be suspended pursuant to Reg. 43 if the contractor is in default with royalty or fee payments by more than six months.

Disputes regarding royalty calculations and payments can be formally settled by "appropriately qualified experts" to be paid by both parties (Reg. 44). As an alternative, the parties can by mutual agreement refer the case to the Seabed Disputes Chamber of the International Tribunal for the Law of the Sea (UNCLOS Art. 188 (2)).

New "Recommendations for the Guidance of Contractors" are announced in Reg. 50 similar to the rules which already apply to the exploration phase.

Pursuant to Reg. 45 and 59, all financial regulations must be reviewed after five years or more.

Other financial regulations and costs

Under the heading "Other Applicable Fees", Reg. 53 in conjunction with Annex IX sets forth rules for fees, for instance, for extension and modification requests as well as interruptions in production.

Pursuant to Reg. 55, compliance notices may involve penalties.

Pursuant to Reg. 56, the costs of remedial action taken in the case of the contractor's failure to act must be paid by the contractor.

Annex VIII of the draft – at present still a blank placeholder – announces a schedule of contract violations and monetary penalties.

4.3.2 Individual issues related to the design of fees and royalties

The following question will have a role to play in ISAS's forthcoming deliberations regarding the structure and amounts for fees and royalties. As mentioned several times in the documents and reports, two main problems exist when it comes to fixing financial fees and duties.

The first problem concerns the complex requirements for financial regulations which are increasingly also viewed as steering elements for environmental protection[25]. At the same time, they are also expected to generate high revenue, compensate for any damage to the environment, protect onshore producers, skim windfall profits, enable transfer payments and incentivise developing countries to engage in deep sea mining. One of the documents refers to "corporate social responsibility".[26] The royalty and fee regime becomes a package of administrative and environmental fees, royalties, guarantee payments, liability regulations, insurance obligations and compensation funds.

The second major problem – besides the volatility of commodity prices – is the lack of experience regarding fees, royalties and business models for commercial deep sea metal mining including the related risks and opportunities.[27] This intertwining of interests and problems creates considerable target conflicts for ISA in its attempt to generate adequate, permanent revenue, to skim profits and to consider aspects of fair and equitable distribution.

The design and amount of the royalty are of central importance. The role models proposed by the ISA documents do not offer any solutions because the UN system does not include an international mechanism for corporate taxation. A look at national models shows that each of these has its own history and reflects specific features in its fees and taxes. Adopting a royalty model of a highly developed offshore industry (for instance, from Norway) is as pointless as an attempt to copy financial regulations for onshore industries. The recently published comparative study of national royalties for the offshore oil and gas sector is of no help. It is limited to the issue of compensatory payments pursuant to UNCLOS Art. 82 and does not provide a homogeneous picture.[28] It is probably already difficult enough for an international expert body to develop a solution for deep sea mining.

Four options (see also above) remain for deep sea mining if onshore mining is used as a reference model:[29]

- Unit-Based: a simple volume and/or weight-based royalty (quantity x price) which is often used for bulk material, such as iron ore and coal.
  (Question: wet or dry tonnes?)

- Value-based (ad valorem): a value-orientated method used for more previous metals.

[25] San Diego workshop 2016, Conference Report, p. 6 and numbers 104 et seqq.
[26] ISA Technical Study no. 11, pp. 75 et seqq.
[27] This is clearly expressed in ISBA/21/C/16, number 32.
[28] ISA Technical Study No. 15: A Study of Key Terms in Article 82 UNCLOS, June 2016, 90 pp.
[29] RWTH Aachen University. Breakthrough Solutions for the Sustainable Exploration and Extraction of Deep Sea Mineral Resources. Stakeholder comments 2015, pp. 6 et seq.; http://www.mre.rwth-aachen.de/de/projektdetail?id=29

- Hybrid: Hybrid forms (depending on quantity/trade value and profit)

- Profit-based: profit-based royalties which are common for diamonds, precious stones and particularly expensive minerals.

In the interest of simple administration of the system, option 1 is a good solution because it is easier to administrate than any other form of profit dependency and because investors are able to calculate the costs in advance. As another advantage, ISA also shares the risk of a possible price slump. On the other hand, quantity-dependent royalties can generate incentives for concentrated high-grade resource exploitation and to break even as quickly as possible.

After a comparison of the pros and cons, the San Diego workshop developed a combined proposal for a fee and royalty structure (royalty rates left open) "[…] to start as simple as possible":[30]

- Fixed fee from the commencement of the contract to cover ISA's administrative costs during a phase in which first major investments are made

- After the start of production, additional (moderate) fixed fee for around 20 years

- Additionally after the start of production, a value-dependent royalty, initially with minimum payments "interim or light ad valorem royalty" and later "full ad valorem", with the break-even point of the change yet to be determined

- The profit-based model is rejected as inoperable.[31]

Royalty payments will start in any case when production starts.[32] In order to determine the start of production, a definition is needed because this marks the point in time from which higher royalties are payable. Contractors will tend to push this point in time as far as possible into the future. "Pilot projects" and exploitation trials will be carried out beforehand for which moderate royalties are justified. However, raw materials mined during exploitation trials, for which no royalties are payable, can also be sold. If this period of time is stretched excessively, this could trigger questions regarding misuse and undue subsidies.

If prices and/or profits are to be determined, problems arise with regard to the determination of the metal value and the production-related incidental costs because the economic efficiency of the marine production chain is largely unknown and comprehensive additional information is needed.

[30] San Diego workshop, Conference Report, numbers 57 et seqq., with reference to the report from the Bellagio workshop.
[31] San Diego workshop, Conference Report, number 76.
[32] UNCLOS Annex III, Art. 17 (g).

It would have to be decided upfront which metals have to be priced because not all metals can be used. A 'market' for polymetallic deep sea resources does not yet exist. Profitability and return on investment can only be identified over the course of several years. The first investors (first movers) will probably have to bear high costs and risks, a factor that should also be considered. It must be determined at which points of the production chain pricing must take place because several phases exist during which value is added, such as dry product, loading onto the barge (first loading of barge), onshore refining, sale of end products. With regard to the determination of the value, either metal exchanges or the concrete production plant can be used as a basis. This requires a particularly complex system in order to trace price developments and the contractor's rate of return with minimum delay. One possible solution could be 'corridors' with upper and lower limits for prices or profits. Furthermore, annual audits of the company must be carried out by independent bodies, and the royalty must also be reviewed on a regular (annual?) basis. In view of these problems, a flat concession fee, case-specific production contract or a deposit/security to be provided in advance (lump sum) are also proposed.[33]

The other problems that exist are due to the requested comparability with onshore mining. The consistency of manganese nodules is different from that of onshore products. They are polymetallic concentrates of many metals/rare earths in different mixture ratios. The value content (degree) is usually significantly higher than in the case of onshore deposits. This means that onshore references are hardly available. Conversely, the required comparability with onshore mining implies that sound competition between onshore and deep sea mining is absolutely conceivable. Caution should be used when onshore producers demand financial compensation in order to protect their onshore production after the production of deep sea metals has begun. However, this cannot be justified until deep sea mining starts to cannibalise on onshore mining. Any other measure would constitute a subsidy or a transfer payment for political reasons.

It is also conceivable that the amount of royalties should consider onshore processing activities because this would be the only way to achieve the requested comparability with onshore production. Tried-and-tested metallurgical processes are in place for the smelting of onshore resources. Corresponding processes for manganese nodules – requiring separation of the various metals and rare earths – are still at laboratory level.

The processes are in any case energy-intensive and require the use of acids and chemicals. Their share in total costs is extremely high and is estimated at more than 50%. There is a considerable need for development and improvement in this area. Furthermore, smelting operations are not carried out under ISA supervision, but are instead subject to the fiscal and environmental conditions of the country

33 San Diego workshop, Conference Report, number 17.

where the smelter is based because the deep sea mining company will typically sell its raw products to another contractor for further onshore processing. It remains unclear how ISA can monitor the value chain of the final products.

ISA's role as a trustee (common heritage of mankind) is expressed in the concept of benefit sharing. ISA must[34] (compulsory duty) ensure that a suitable mechanism is in place to distribute financial and economic benefits even though reliable data and methods are not yet available for this purpose. In this case too, differences exist compared to onshore mining where national fiscal interest is the dominant factor.

ISA, in contrast, represents the collective interests of the community of nations. It is expected to generate high revenue, compensate for damage to the environment, protect onshore producers, skim windfall profits, enable transfer payments and incentivise developing countries to engage in deep sea mining. Benefit sharing, thanks to its high relevance and because of the expectations of many nations, supports the trend towards high royalties. On the other hand, it should be clear to all the stakeholders that deep sea mining must first commence and prosper before funds will be available for distribution. This aspect must be expected to be the subject of controversial debates because the distribution of financial and other benefits is the de facto most important possibility for the principle of joint heritage to materialise[35], all the more so because the future of the 'enterprise' as the second instrument for involving developing countries is uncertain even though it remains on ISA's agenda.

ISA's determination to enable the "optimum" production of high-grade and lower-grade resources is part of the common good context. Otherwise, licensees, striving for profit, would exploit only the high-grade parts of deposits (high-grading) and leave lower-grade parts behind which could, however, also be beneficial from an environmental protection perspective. In any case, a royalty is demanded which considers the combination of population density, quantity and value of the complete concrete mining field ("a whole of the deposit"). In view of the dimensions and different population densities of manganese nodule mining fields (200 km²), this will require considerable administrative effort.

Finally, fundamental balancing of interests between the common good and the risk levels will be necessary. Risks exist not just for the common heritage and environmental protection. ISA, investors and sponsoring states also take different kinds of risks (key words: raw material prices, economic cycles, substitution options, recycling, environmental risks, public acceptance, etc.). The distribution of financial benefits (who takes what?) and burdens must consider this conflict

[34] Art. 140, and also emphasised in implementing agreement, annex, section 9 numbers 7 et seq.
[35] Jan Stefan Fritz. Deep Sea Anarchy: Mining at the Frontiers of International Law. IJMCL 2015, pp. 445-476 (469). Aline Jaeckel et al. Sharing benefits of the common heritage of mankind – Is the deep seabed mining regime ready? Marine Policy 2016 (in print) http://www.sciencedirect.com/science/article/pii/S0308597X16300744

area. Although proposals are still lacking in this field, it goes without saying that first movers should pay relatively low royalties during the initial phase, followed by higher royalties at a later stage and once again by moderate royalties during the renaturation phase. It is hence imperative to find a careful balance between investment incentives and financial burdens by introducing dynamic and/or graded royalty levels.

4.3.3 Liability and insurance

The overall view of the financial conditions of deep sea mining also includes the various liability and insurance obligations due to (mandatory) environmental protection. Liability for damage in conjunction with activities in the area is subject to the provisions of the law of the sea.[36] Pursuant to Art. 139 and 154, liability regulations and obligations apply for the following, jointly acting and jointly liable parties:

- contractors
- authorities (ISA) and
- the sponsoring state.

Up to now, liability provisions (including an insurance obligation) only applied to the exploration phase. Future liability regulations, which are not yet included in the draft mining code, are likely to be based on the exploration phase.[37]

Liability of the contractor

The liability of a holder of an exploration licence (contractor) covers any damage, including environmental damage, caused by the contractor's own unlawful activities in the area during the course of his work[38] or caused by his employees, subcontractors or agents with the exception of damage caused by force majeure.[39] This applies also to damages which third parties (for instance, neighbouring contractors) may suffer and for environmental damage after the exploration phase[40] without any limitation of time.

In 2011, the seabed disputes chamber of the International Tribunal for the Law of the Sea (ITLOS) published an advisory opinion (hereinafter: ITLOS advisory opinion) where it defines the term "activities in the area" and thereby clarified the extent of liability.[41] Activities in

36 Art. 134, Art. 139; RPEN Reg. 30; see also Marco Visser/Michael Dettmer. Tiefseebergbau und Haftpflichtversicherung – die Versicherungsklausel 16.5; in: PHi Haftpflicht International Recht und Versicherung No. 3, 2015, pp. 98-104 and No. 4, 2015, pp. 156-168.

37 RPEN Reg. 1.3 expressly also mentions "exploitation" (although RPEN applies to exploration only).

38 UNCLOS Annex III, Art. 22. RPEN Annex IV, section 16.1

39 RPEN Annex IV, sections 16 and 17.

40 RPEN Reg. 30.

41 ITLOS advisory opinion of 1 February 2011, ITLOS case no. 17: Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area; numbers 84-97. http://www.itlos.org/. See in detail: Jessen, Henning. Staatenverantwortlichkeit und seevölkerrechtliche Haftungsgrundsätze für Umweltschäden durch Tiefseebergbau. ZUR 2012, Nr.2, pp. 71-81; David Freestone. ASIL insights Vol. 15, issue 7 of March 9, 2011. Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Ac-

the area are accordingly: the exploration and mining on the seabed, the transport to the surface and the activities directly connected to these, i.e. the separation of production water as well its discharge and disposal into the sea as well as preparatory material separation activities on board. The contractor's sphere of responsibility thus covers all mining activities. Vessel transport of the resources and subsequent onshore processing activities do not form part of this action chain.[42] They are subject to the IMO conventions for maritime navigation and/or the laws of the state where processing is carried out. Liability-relevant activities outside the area continue to be subject to the general framework provisions of UNCLOs Part XII "Protection and Preservation of the Marine Environment" with state liability pursuant to Art. 235.

This is the background against which the liability and insurance clause must be interpreted which is a standard clause contained in any exploration contract and linked to the obligation to take out insurance.[43] It reads:

"The Contractor shall maintain appropriate insurance policies with internationally recognized carriers, in accordance with generally accepted international maritime practice."

This concerns third-party liability insurance with certain special, yet to be clarified elements. It remains to be seen which concrete safety and environmental standards, limit values, etc. will be determined by ISA for which insurance cover will be requested. Explanations regarding the liability and insurance clause are also lacking. It is unclear whether liability will be understood to be strict liability or negligence rule liability. Only internationally "recognized" insurance companies with the capacity to handle damage cases on a global scale will be accepted. Since the wording states "insurance companies", i.e. the plural, this suggests a multi-policy requirement. Furthermore, proportionality issues will arise depending on possible damage characteristics (ecological damage, damage prevention costs, subcontractor liability) as well as long-term damage after termination of activities. The cover amount is so far not limited, but could probably be agreed upon in negotiations between the contractor and ISA. Direct claims against the insurance company are not mentioned, so that there are (so far) no indications for this.

The outcome will ultimately be a new business field and a new type of insurance policy for deep sea mining which the insurance sector will have to address.

Liability of ISA

tivities in the Area. AJIL Vol. 105, 2011. pp. 755-760. Legal liability is subject to the provisions of ICLOS Annex VI, Art. 33 and 40.

42 In this respect, the wording in RPEN Reg. 1.3 is misleading.

43 Insurance obligation pursuant to RPEN Annex IV, section 16.5. Regarding the insurance aspect, see, in detail: Visser, Marco/Dettmer, Michael. Tiefseebergbau und Haftpflichtversicherung – die Versicherungsklausel 16, op. cit.

Liability on the part of ISA in its capacity as an authority results from the fact that it exercises control in the area as soon as a licence contract is signed. It is liable to the contractor and any third party for damage caused by its acts or omissions, including the protection of confidential data.[44] However, the jurisdiction of the Seabed Disputes Chamber of the ITLOS is subject to the restrictions of Art. 189.

Liability of the sponsoring state

Liability of the sponsoring state is foreseen within narrow limits only. Each licence application must be supported by the applicant's home country in the form of a certificate.[45] Pursuant to Art. 139, the sponsoring state is obliged to ensure and confirm that the sponsored contractor is financially and technically capable and that it will fulfil its obligations in conformity with the ICLOS and its contract. Pursuant to Art. 139 (2), the state is liable in this respect. Pursuant to Art. 153 (4) and Annex III Art. 4 (4), the state is obliged to adopt laws, regulations and administrative measures which are, within the framework of its legal system, reasonably appropriate for securing compliance by persons under its jurisdiction. This initially means that national deep sea mining legislation must be adopted and administrative measures implemented in order to enforce continuous supervision measures for national companies. The ISA regulations and standards contained, for instance, in the mining codes, constitute the relevant regulatory framework and the minimum standard that must be maintained.[46]

The 2011 ITLOS advisory opinion sets forth more detailed provisions for this relatively general due diligence obligation on the part of the state. The state fulfils its due diligence obligations if it requires adherence to the precautionary approach, the principle of best environmental practices as well as environmental compatibility analyses.[47] Developing countries are not entitled to a 'discount' on due diligence obligations.[48] The due diligence obligation is deemed to be met if these guiding principles are enshrined in the national legal system.[49]

The sponsoring state's liability is therefore limited by an "exculpatory option"[50]. The state is not liable for the contractor's culpable failure as long as the state meets its obligations in the form of some kind of quality control by ensuring that the contractor abides by all relevant rules of the international law of the sea. In Germany, these obligations are implemented in the form of the 'mining supervision authority' set forth in the German Seabed Mining Act (MBergG)[51] and by the

[44] Art. 168 (2), Annex III Art. 22; RPEN Annex IV section 16.3-4.
[45] Art. 139 and 153 Abs. 2 (b); Annex III Art. 4 (3) and (4); RPEN Reg. 11.
[46] Art. 208 (1) and (3); Art. 209.
[47] ITLOS advisory opinion, numbers 119, 122 et seqq., 131 et seq., 136 et seqq., 141 et seqq.
[48] ITLOS advisory opinion, numbers 158 et seq.
[49] Jessen, op. cit., p. 77. The state has further supporting obligations from UNCLOS and the implementing agreement as well as the mining codes, including the obligation to assist the authority (Art. 153 (4)), guarantees in emergencies, ensuring that recourse is available in respect of damage (Art. 235 (2)); for a detailed description, see ITLOS advisory opinion, numbers 122 et seqq.
[50] Marco Visser/Michael Dettmer, op. cit. p. 101.
[51] Sec. 8 MBergG [German Seabed Mining Act], BGBl. [Federal Gazette] I 1995, p. 778.

undelayed translation and publication of the three mining codes[52] which set forth the three above-mentioned principles as mandatory provisions.[53] The ITLOS advisory opinion expressly acknowledges the German and Czech legislation in this context.[54] The due diligence obligations of the sponsoring state are dynamic in nature. They must reflect the state of the art and the real development of the environmental risks of deep sea mining and have to be revised when necessary. More risk-prone activities require a more restrictive interpretation of the due diligence obligations in order to meet a state's active control and supervision duties.[55]

There is a potential for liability gaps to occur. If, for instance, the contractor is unable to pay compensation for damage in full or in part (or if the insurance company fails), residual responsibility of the sponsoring state to close this gap could be an option. This option is controversial and rejected by most of the states.[56] If sponsoring states were not liable, a liability gap would occur. Another liability gap can occur if it is not possible to identify the polluter (or if the polluter is identified too late). In order to address these (rare) cases, the ITLOS advisory opinion suggests setting up a liability trust fund[57] (see section 5.4 below).

On the one hand, this system of liability rules – in the interaction between contractor, ISA and sponsoring state – underpins the primary responsibility of the contractor as the main cause of the damage risk with the consequence of the obligation to take out third party liability insurance. However, certain questions still remain open, including the respective liability obligations of the three liable partners. Both ISA and the sponsoring state have an obligation to supervise the contractor. The contractor is hence subject to two controlling instances whose responsibilities may at time overlap and require a clear definition.

The overall concept of the sponsoring state and its liability ultimately serve to set up reliable national legislation and effective enforcement mechanisms in all states where companies are based. In states where the rule of law prevails, no additional risks or disadvantages have to be feared if the relevant authorities and institutions (Federal Ministry for Economic Affairs and Energy, BGR, LBEG Niedersachsen [Lower Saxony State Mining, Geology and Energy Authority]) ensure that ISA's regulations are transposed to national law and monitored. Since the state has a mere 'sponsoring' function for companies, the prerequisites for state liability are not fulfilled in this case because no "official authority is transferred".[58]

52 RPEN (manganese nodules) BGBl. II 2014, pp. 615 et seqq.; REPS (polymetallic sulphides) BGBl. II2015 pp. 162 et seqq.; RPEC (cobalt-rich crusts) BGBl. II 2014 pp. 570 et seqq.
53 See RPEN Reg. 31.2 and REPS Reg. 33.2 (precautionary approach and best environmental practices). A detailed discourse on the obligation to conduct environmental compatibility analyses is found in ISBA/19/LTC/8; see also ITLOS advisory opinion, numbers 145 et seq.; Jessen, op cit.
54 ITLOS advisory opinion, number 237
55 Jessen, op. cit., p. 76.
56 ITLOS advisory opinion, numbers 203 et seq.
57 ITLOS advisory opinion, numbers 205, with a reference to Art. 235 (3).
58 Marco Visser/Michael Dettmer, op. cit. p. 101.

Liability fund

Finally, Art. 235 (3) and Art. 304 expressly provide for the option to develop liability rules further under international law. New liability rules under the law of the sea are therefore possible, especially in the form of a liability fund, as suggested by the ITLOS experts, to cover large-scale damage or unknown risks.[59] Such a fund would have to be kept separate from ISA and could be financed by an environmental charge to be newly created.[60] It is likely that workshops to be held in the near future will address details of this issue.

A stakeholder survey additionally led to the proposal of a sustainability fund specifically geared to marine environmental research or technological development for developing countries, a proposal that has rarely been discussed up to now. The need, goals and financing are still unclear.[61] However, special ISA funds are not uncommon. The voluntary trust fund[62] was established in 2002 in order to enable delegates from developing countries to attend LTC and FC meetings, whilst the endowment fund[63], established in 2006, is financed from voluntary contributions for scientific research and development aid.

In view of widespread concerns regarding massive environmental damage that goes beyond the scope of insurance cover, liability funds focus on large-scale damage. International maritime transport can serve as guidance in this respect, with the International Maritime Organization (IMO) providing regulated access to liability and compensation rules, as well as the new EU Offshore Safety Directive.

Beginning in the 1970s, liability instruments were introduced in the field of maritime transport in response to the strong increase in transports of oil and hazardous substances and the growing number of spectacular accidents causing widespread environmental pollution. Shipping companies/owners are now obliged to take out compulsory insurance with liability limits for standard accidents and to provide certified proof of such cover.[64] As part of a multi-tier liability regime, these funds are organised as international organisations with their own administration structure. The International Oil Pollution Fund (IOPC FUND) covers liability gaps for large-scale tanker accidents involving oil pollution[65]. This liability model[66] is valid and accepted worldwide. Its elements are strict liability with compulsory insurance for standard damage (1st tier). The 2nd tier is a liability fund for large-scale damage which, for its, part, is supplemented by a voluntary

59 ITLOS advisory opinion, numbers 205 and 211; Jessen op. cit. p. 79;
60 San Diego workshop, Conf. Report numbers 106 et seqq. (118).
61 http://bit.ly/1K4Bmrc, p. 36; San Diego workshop, Conf. Report number 119
62 ISBA/8/A/11 and ISBA/12/FC/L.1, number 11.
63 Art. 143 (2) and ISBA/12/A/11.
64 Besides general shipowner's liability, special forms of compulsory liability exist for oil as cargo, fuel oil, passengers, wreck removal.
65 Convention on Civil Liability for Oil Pollution Damage (CLC 1992), supplemented by the International Oil Pollution Compensation Fund (IOPC Fund 1992) with a maximum cover of 203 million SDR = €227m, and a supplementary fund 2003 with a maximum cover of 750 million SDR = €840m; www.iopcfunds.com
66 Yuna Huang. Compensation of Damage to the Marine Environment; in: Ehlers, Peter/Lagoni, Rainer. Responsibility and Liability in the Marine Context. LIT Verlag 2009, pp. 19 et seq., 32 et seq. and 42.

supplementary fund[67] (3rd tier). Compensation for several accidents has been paid in the form of compensation for personal injury and damage to property including the costs for the removal of pollutants. However, cover does not include long-term environmental damage, such as degrading of the environment or restorative or rehabilitative measures. There are still no mechanisms to define and identify such forms of environmental damage in the sea.

Along the lines of the tanker accident compensation system, IMO also agreed on a yet to be adopted two-tier liability and compensation scheme (HNS FUND Convention 2010) for large-scale damage caused by liquid or solid hazardous substances.[68] Tier 1 provides for compulsory insurance to be taken out by shipowners with harmed parties having a direct claim against the insurance company. Tier 2 is the fund to be financed by contributions from the consignees of the hazardous cargo, i.e. "paid post incident". Contributions by governments are not foreseen. The maximum damage is limited to 250 million SDR (special drawing rights) = 380 million USD. These funds are an established instrument in international sea transport and could serve as a template for deep sea mining.

A second starting point could be the EU Offshore Safety Directive[69] which came into effect on 19 July 2015 with transitional periods.

The directive applies to the EU's around 1,000 offshore installations and its objective is to prevent major accidents and to limit their consequences. It provides, for instance, for the establishment of independent competent authorities, safety analyses, state-of-the-art safety management, health protection of workers, contingency plans, public participation as well as reporting and information obligations. The directive does provide for detailed liability rules. Although Art. 7 provides for the licensee's strict liability, and Art. 4 (3) additionally demands that the state ensures that insurance be taken out by licensees. However, all details are left to the individual member states and the directive needs to be transposed into national law. Pursuant to Art. 39, the European Commission is obliged to submit regular reports on application and implementation, including further analyses and more far-reaching proposals.

The first such report from 2015[70] finds that the licensee's liability continues to be subject to the Environmental Liability Directive from 1994[71] and/or national law. The report refers to national insurance companies and OPOL[72] as the voluntary liability association of the oil

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67 International Tanker Owners' Pollution Compensation Fund (ITOPF) since 1968; www.itopf.com
68 IMO brochure for liability funds for hazardous cargo transported by sea: http://www.imo.org/en/MediaCentre/HotTopics/Documents/HNS%20ConventionWebE.pdf
69 Directive 2013/30/EU on safety of offshore oil and gas operations. Official Journal L 178/66 of 28 June 2013.
70 Report from the Commission on liability and financial security, COM(2015)422 final, of 14 September 2015.
71 Directive 94/22, Official Journal L 164/3 of 30 June 1994.
72 The Offshore Pollution Liability Association Ltd (OPOL) is a mutual agreement of the industry that is open to operators of offshore installations and facilities. Member companies are protected by a guarantee that other member companies will cover liability claims which they are unable to satisfy themselves up to a maximum cover (125 million USD for rehabilitation costs and 125 million USD for pollution damage). Claims are not raised directly against OPOL, but against

and gas industry. According to the report, this was the basis for the development of a competitive market for "financial security instruments" with pools, insurance, bonds and guarantees. Despite a lack of financial security instruments to fully cover the more infrequent and costly accidents, an expansion of the liability provisions is at present not considered to be reasonable. The European Commission will continue issuing its reports and may also submit new proposals, for instance, regarding criminal liability for environmental damage. The offshore safety directive is hence, at best, the first step towards modern maritime safety management and strengthens the concept of absolute liability, however, (so far) without introducing any new or more restrictive cover instruments.

4.3.4 Next actions

At the 22nd session, a short exchange of opinions took place with regard to the draft mining code which is referred to as a "work in progress" and will probably take three to five years. The report by LTC chairman Dr. Reichert to the Council ended with a tabular overview of the different modules of the draft. The steps and time schedule are as follows:

- 2 November 2016: Deadline for stakeholder comments on the draft exploitation regulations
- 2nd workshop on the payment regime, if possible, before the end of 2016
- January 2017: Workshop in Berlin on environmental assessment and management
- February 2017: Revised draft version for discussion by the LTC
- Workshop to revise the environmental management plan, before July 2017
- July 2017: Discussions at the 23rd session
- Scientific workshop on areas of particular environmental interests (APEI)
- Workshop on impact reference and preservation zones (IRZ/PRZ)
- Establishment of a legal working group on responsibility and liability

the member company which is liable for the damage and loss.
OPOL is neither a compensation fund nor does it offer a guarantee that protects a member company against insolvency. This communitisation of insolvency risks, which are borne by third parties, helps to reduce insurance costs and to convince regulators of the licensees' financial capacity. Furthermore, the criteria for OPOL membership create an additional level of mutual control within the industry that supplements regulatory control of the financial standing of companies at the time the licence is issued.
OPOL membership imposes on operators strict liability for damage and losses and is a prerequisite for obtaining licences in the UK and Ireland. However, OPOL's maximum cover of 250 million USD on reimbursement and compensation per incident may not cover all damage and loss from the worst accidents. Details can be found in COM(2015)422 final, of 14 September 2015.

4.3.5 Evaluation and recommendation

Parts of the first draft mining code (number 3 above) read like a criminal code. In its attempt to achieve maximum transparency, it is characterised by mistrust of investors and contractors. The wording does not contain attempts to create incentives for investors and to implement a lean administration. Instead, the draft focuses on financial interests and comprehensive control instances. The forthcoming discussion regarding fee levels and the many necessary definitions and control procedures mean that there is a risk of excessive red tape. Observers may feel that ISA needs a highly professional 'fiscal department' in order to manage all of the above-mentioned evaluation aspects in conjunction with the taxation of deep sea mining. Workshops and their experts are currently setting the tone. It should also be pointed out that up to now the importance of tests was irrelevant for the clarification of open issues. Neither the draft nor the workshop reports mention any tests.

The background papers stress that a system that is easy to manage will offer many advantages during the initial phase of industrial deep sea mining. However, there will be voices among the states that favour elaborate systems and a very transparent distribution of profits though benefit sharing. On the other hand, the stakeholder survey confirmed that the ISA bodies do not yet have any reliable information for the development of detailed financial rules. Sound results from pilot mining studies and pilot mining tests are especially lacking. Planned annual production volumes remain unclear as long as estimates vary between 1 and 3 million tonnes (dry material), corresponding to daily production of between 3,300 and 10,000 tonnes (with 300 production days per year). This is worsened by the above-mentioned problems in finding models and criteria to achieve the ambitious goals.

Next practical steps will be stakeholder comments, ISA workshops, expert opinions and "ISA Guidelines to Develop Financial Terms" as a means for orientation. If desired, ISA can at any time request that the Seabed Disputes Chamber of the ITLOS submit an advisory opinion pursuant to Art. 191 in order to clarify open issues.

In the event that ISA fails to develop reasonable financial regulations for the area as its sphere of responsibility, potential investors will seek bilateral forms of cooperation with countries with rich mineral resources in the economic and continental shelf zones. At least 25 exploration projects are known in these marine zones.

The finance committee and the legal and technical commission (LTC) of ISA will have to work on this.

That is why participation in the stakeholder survey up until 2 November 2016 is so important, as is active collaboration in LTC, FC and supporting workshops by contributing proposals after prior consultation with the EU.

A mechanism should be adopted which slowly or gradually results in longer-term stable financial regulations, for instance, in the form of a startup phase of around ten years as a transitional financial regime with a flat fee and a 'light' ad-valorem royalty[73] as an incentive for investors according to the 'KISS – keep it simple and smart' principle. In other contexts, for instance, in Art. 82[74] or in conjunction with environmental protection requirements, ISA supports the "adaptive management approach"[75] as a concept for the gradual adaptation of concrete standards. This corresponds to the requirement for "[...] a more fluid legislation that can be adapted as knowledge grows ...]"[76].

This applies, in particular, to the financial regime. Further details of the rules must be defined in line with the development of the young deep sea industry. An initial phase with simple lump-sum fees (taxes) appears to be reasonable. Investment in exploitation operations can only be expected if investors can rely on dependable financial regulations, ideally for the entire term of their contract.
Unequal treatment of contractors would undermine trust in ISA. If financial adjustment mechanisms are considered to be necessary during the term of the contract, these mechanisms must be known from the very beginning.

A transitional regime of 10 to 15 years with financial stability (transitional phase/phased approach) and with easy to manage fees and royalties can offer reliable incentives for the first exploitation companies and generate regular revenue for ISA without prejudicing a future differentiated system. The term should be such that first exploitation investments can amortise. The end would be marked by a review to clarify the future system.

Priority should be given to answering the following questions, for instance:

- Transitional regime, its contents and duration
- Fee and royalty structure: equal treatment, fine-tuning of royalties (quantity-based and/or profit-based, gross or net), possible deductions, profit calculation, profit threshold, bandwidths/scaling, loss carryforward, invoice checking, role of commodity exchanges, payment in USD or SDR?
- Amount of fees: A value which is clearly but reliably above the corresponding fees for the exploration phase seems to represent a reasonable level for the fee for application and the annual fee.

73 San Diego workshop, Conf. Report, p. 10.
74 Compensation payments by coastal states for the exploitation of resources of the outer continental shelf, increasing annually after five payment-free years; see Art. 82.
75 ISBA/21/C/16 of 15 July 2015, Annex III. See Aline Jaeckel, Deep Sea Mining and Adaptive Management, in: Marine Policy (to be published soon), http://www.sciencedirect.com/science/article/pii/S0308597X16300756.
76 Seabed mining: about to start? Metals Insight, Vol.11/Issue 2/January 28, 2016.

- Amount of royalties: Royalties could start with a quantity-based (unit-based) amount, with ad-valorem elements being gradually added. The amount of royalties may not be prohibitive.

- Relationship with the tax and royalty system of the contractor's state

- Need for and scope of a liability fund and its financing

- Uniform system for all three resources or differentiated concept?

- Extent, reference basis and recipients of benefit sharing[77]

- Costs of the further development of ISA (general increase in the scope of tasks, establishment of a finance department and of a mining directorate)

- The complex bundle of liability, security payments, insurance and funds must be made more transparent and simple.

- The discussion on the future mining code must also address the aspect of an environmental liability trust fund which could, for instance, be financed with parts of the royalties paid to ISA.[78]
  It could be orientated towards the navigation example if damage due to a mining accident is similar to that caused by supertankers or oil platforms involving the release of pollutants which has, however, not yet been proven to date.[79] Whilst such a fund could be used to cover the decontamination and clean-up costs, the problem of identifying serious environmental and long-term damage remains unsolved. This requires further examination, with the precautionary approach probably playing an important role.

With regard to future negotiations, the legally established goals and principles (see number 1 above) must be upheld, at least from a German perspective, in order to counter possible watering-down tendencies. This applies, in particular, to reasonableness, equal treatment, simplicity, adherence to commercial principles and a step-by-step approach. The precautionary approach remains a meaningful basic concept underlying environmental protection goals in deep sea mining.

4.4 Royalties

The 1982 United Nations Convention on the Law of the Sea and the 1994 Implementing Agreement are the legal framework on which all further deep sea mining concepts and approaches must be based.

77 Discussions on this topic are still in their beginnings; see Aline Jaeckel et al. Sharing Benefits of the Common Heritage of Mankind – Is the Deep Seabed Mining Regime Ready? Marine Policy, March 2016, in print.

78 http://bit.ly/1K4Bmrc, see p. 36.

79 Massive releases of oil, gas, chemicals, etc. are very unlikely in the case of purely mechanical collection of minerals on the seabed. Damage caused by deep sea mining will primarily occur in the form of sediment clouds on the seabed and immissions during vertical transport.

This means that the design of practical deep sea mining operations should also be based on the theoretically advisable characteristics of a royalty system, such as simplicity, effectiveness, efficiency, fairness and flexibility.

Although a royalty concept can be designed in many different ways, it ultimately requires weighing up public interests and entrepreneurial incentives without neglecting social aspects. The pros and cons of the various design options will probably lead to a hybrid system of fixed and profit-based components. This is discussed not just in the working groups of the International Seabed Authority, but could also prove to be a possible compromise and a recommendable solution.

The implementation of national royalties will probably not be possible until the discussions at supranational level have been concluded. Without this basic knowledge, it will not be possible to reliably identify the remaining potential for revenue – setting aside the question of whether national royalties are generally permissible.

4.4.1 Legal basis

Before presenting the state of the discussion and possible solutions to the open issues, the principles of the 1982 United Nations Convention on the Law of the Sea[80] and the 1994 Implementing Agreement[81] should be mentioned as constituting a binding basis for the financial regulations and the related legislative process. Each mining code must respect these principles.

The 1982 UNCLOS and its annexes as well as the related implementing agreement from 1994 and its annex use different terms, including, for instance, "financial terms", "financial rules" or "financial arrangements". Both the convention and the agreement only contain the principles and types of royalties as well as issues of responsibility for future procedures. Close ties with measures to protect the marine environment[82] are always taken for granted. Most details remain open. The basic legal situation is as follows:

The ISA council is responsible for the development of financial rules based on recommendations by the 15 members of the finance committee (FC)[83] and the 30 members of the legal and technical commission (LTC). The assembly is responsible for final decisions on financial rules, regulations and procedures.[84] The financial regulations are (only) applicable to contractors who have entered into a licence agreement with ISA. Contractors are public and private mining compa-

80 BGBl. [Federal Gazette] 1994 II, pp. 1798 et seqq. All articles quoted below refer to UNCLOS, unless specified otherwise.
81 Agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea (implementing agreement), BGBl. [Federal Gazette] 1994 II, pp. 2565 et seqq.
82 Art. 145, 209.
83 Art. 162 (2) y (ii), and implementing agreement, annex, section 9 number 7.
84 Art. 160 (2) f, Art. 162 (2) o (i) and UNCLOS Annex III Art. 13 (1); implementing agreement, annex, section 9 number 7.

nies.[85] Under maritime law, their subcontractors are not obliged to pay royalties.

UNCLOS Annex III mentions the following objectives: [86]

- Optimum revenues for the authority
- Attractiveness (incentives) for investments and technology development
- Equal treatment of contractors
- Ban on substitution
- Incentives for joint agreements with enterprises and developing countries
- Disputes regarding financial rules arising under the licence agreement between ISA and the licensee can be resolved by arbitration. Recourse to the International Tribunal of the Law of the Sea (ITLOS) and its dedicated Seabed Disputes Chamber is also open under Art. 186 et seqq.

Since the area of the deep sea (the 'Area') and its resources constitute "common heritage of mankind" to which all mankind is entitled[87], equitable sharing of economic benefits is aimed at.[88] The implementing agreement limits these objectives to a certain extent stating that the use of resources must be carried out in accordance with sound commercial principles[89].

More importantly, the implementing agreement sets forth additional principles[90] which have the following meanings.

- Fairness: Payments must be fair and reasonable for both contractors and the authority. This relativates the above-mentioned objective of generating maximum revenue for the authority.[91]
- Comparability with land-based mining: Payments shall be "within the range" of those prevailing in respect of land-based mining of the same or similar minerals. In this case, it must be noted that onshore mining is faced with continuously fluctuating prices and volumes whilst at the same time being burdened with national royalties and taxes.
- Simplicity: The system should be "simple and easy to implement and to administer".
- It will have to be examined whether a system of royalties or a hybrid system encompassing royalties and profit sharing should be

85 Art. 153 (2) (b) in conjunction with UNCLOS Annex III Art. 13 (1).
86 UNCLOS Annex III Art. 13 (1) (a-f) and (14) - (15); Art. 17 (1) (c).
87 Art. 133, 136, 137 (2) and 150.
88 Art. 140.2, 160.2 f and 2 g, 162.2 o (i).
89 Implementing agreement, annex, section 6 ("production policy"), number 1.
90 Implementing agreement, annex, section 8 ("financial terms of contracts"), numbers 1 - 3.
91 UNCLOS Commentary, Vol. VI, p. 728.

implemented. In the event that an optional system is implemented, contractors will have a right to choose.

- A fixed annual fee is foreseen for commercial production which can be set off against other payments.
- The payment system must be revised and adjusted at regular intervals.
- Disputes concerning rules and regulations based on these principles are subject to the dispute settlement procedure (including referral to the Seabed Disputes Chamber under Art. 186 et seq.).

The principles supersede some very detailed[92] provisions in UNCLOS Annex III, Art. 13 (3) – (10) with regulatory rights of ISA regarding resource volumes and prices. The implementing agreement expressly states that the latter are not applicable.[93] These paragraphs, which are now invalid, provided for a right of choice between an annual fixed fee of 1 million USD or a production charge with a net share in production, the latter being supplemented by extensive rules for determining amounts, other costs as well as billing procedures. For the avoidance of doubt: The ratification of UNCLOS and the accession of important industrialised nations to UNCLOS and hence its coming into effect in 1994 only became possible after certain articles providing for centrally planned, interventionist measures had been eliminated from the implementing agreement and after principles of the free market economy were strengthened in the implementing agreement as a result of renegotiations.

The older idea of a right to choose between an annual fee and a production charge according to bureaucratic standards is therefore no longer on the table. Since 1994, ISA's bodies have been determining the details and the amount of the financial terms on a case to case basis. According to the leading UNCLOS commentary[94], ISA is also free to develop alternative financial regulations as long as the principles of the implementing agreement are adhered to.

Based on this, the ISA council will determine the royalties to be paid in future. One sub-aspect is the issue of consideration of the quite considerable research and development costs incurred during the prospecting and exploration phase as provided for in the mining codes.[95] Licensees would be well advised to document their development costs. The accounting requirements, which have to be confirmed by recognised auditors, were updated in 2015.[96]

92 UNCLOS Commentary, Vol. VI, pp. 718, 728, refers to Art. 13 as "the most complex article".
93 Implementing agreement, annex, section 8, number 2.
94 UNCLOS Commentary, Vol. VI, p. 728.
95 Provisions are included in the mining codes for nodules, sulphides and crusts, for instance, in RPEN Reg. 6 (2) and Annex IV para. 10.2 c.
96 Recommendations for Contractors …for the Reporting of Exploration Costs, ISBA/21/LTC/11.

4.4.2 Design options

With a view to the features of royalty systems, the following sections will briefly discuss the necessary characteristics before dealing with design options.

The central need to design a royalty system for potential deep sea mining can be summarised as follows: A royalty regime should be designed in such a manner that it does not prevent individual profitable projects whilst at the same time skimming off possible excessive profits that exceed a 'normal' return.

The International Seabed Authority (ISA 2015a) itself identifies a total of seven principles for the design of a royalty system, i.e.:

1) Effectiveness
   The ability of the system to generate the desired results, for instance, in terms of revenue

2) Fairness
   No preference for or discrimination against certain stakeholders

3) Efficiency
   Impartiality with regard to investment decisions

4) Simplicity, transparency, plannability
   These aspects, each of them individually and in aggregate, lead to lower administrative costs for both government agencies and private stakeholders

5) Coherence and consistency
   Identical facts and situations should also be treated the same.
   This applies not just to item 2), but also to the requirement that design options regarding the royalty/tax basis be ruled out.

6) Flexibility
   In the case of (major) changes in the market environment, it should be possible to quickly adapt the system, or the system should already include a corresponding mechanism.

7) Enforceability
   The administration must be able to generate revenue without any major effort and to impose effective sanctions on defaulting parties, for instance, for default in payments.

The implications of the fact that deep sea resources are not renewable have already been mentioned. This has mainly two consequences for the design of the royalty regime. First, a system must be available from the very beginning, i.e., all the necessary rules and regulations should be in place as soon as (commercial) exploitation starts or, even better, as soon as this is foreseeable. This means investment security on the one hand and smooth administrative operations on the other. Second, there is only limited leeway for retroactive changes in the system. This means that tried-and-tested principles from terrestrial mining should also be adopted specifically for deep sea mining. This does, however, not rule out adaptation measures if conditions change significantly.

In a broader sense, the revenue can also be used as a tool for designing the framework conditions. Especially aspects of intra-generation fairness must be considered here. The background is once again that both present and future generations are entitled to the revenues from deep sea mining so that a sustainable use of such revenues is mandatory. This also means avoiding all kinds of corruption and rent-seeking that can generally occur throughout the entire value chain.

These considerations imply a customary trade-off: On the one hand, governments should strive to optimise revenues and/or revenue flows. This does, however, imply significant administrative efforts which are only reasonable to a certain extent, i.e. as long as the additional administrative costs do not exceed potentially higher revenues. This is in most cases primarily relevant for determining the 'normal' return which investors can achieve, i.e. when it comes to calculating the economic return that can be skimmed off and/or the amount of (incentive-compatible) royalties. In reality, information asymmetry means that it is hardly possible to fully skim off returns so that they are usually effectively shared between governments and private investors.

Design options

Many options are available when it comes to designing a mining royalty system. The table below provides an overview of relevant taxes in the mining industry, while the next table summarises the purposes of these taxes (Otto et al. 2006, p. 32):

Table 4-9: Taxes in the mining industry and their basis

Type of tax	Basis
***In rem* taxes (unit or value basis)**	
Unit tax	Tax per unit
Value tax	Percentage of mineral value (the definition of value can vary)
Value-added and goods and services tax	Percentage of sales value
Asset and capital tax	Percentage of asset/capital value
Import tax	Percentage of import value
Export tax	Percentage of export value
Withholding tax on interest on loans	Percentage of the value of interest on loans
Withholding tax for imported services	Percentage of the service value
Value-added tax	Percentage of the value of the good or service
Licence fee	Fee per registration
Lease or usage fee	Fee per unit of area

Type of tax	**Basis**
Postage stamp tax	Fee per transaction or percentage of the transaction value
***In personam* taxes (net income)**	
Income tax	Percentage of income
Asset return or capital return tax	Percentage of the profit from the sale of capital assets
Additional tax on profits	Percentage of additional profits
Profit tax	Percentage of additional profit
Duties on net profit or net value	Percentage of mineral value minus deductible costs
Withholding tax on distributed profits or dividends	Percentage of distributed value

Source: Otto et al. (2006)

Table 4-10: Purposes and scope of validity of different tax types

Type of tax	Purpose	Scope of validity
***In rem* taxes**		
Unit tax	Ensures stable and reliable revenues (stable because fluctuations of commodity prices have no impact), payment on transfer of title	Frequently applied, especially for industry and bulkware
Value tax	To generate revenue in the first place; payment on transfer of title	Frequently applied
Value-added tax and goods and services tax	Revenue from economic activity, tax on investments	Value-added tax has replaced sales taxes in many countries
Ownership tax	Ensures stable revenues corresponding to the value of physical assets; often paid to municipal administrations	Frequently applied
Import tax	Ensures revenues in order to put national manufacturers at an advantage; historically a tax to finance port development and customs administrations	Most countries waive this tax or impose a zero tax on mining equipment.
Export tax	Generates revenue in order to maintain domestic demand	Tax on minerals abandoned by almost all countries
Withholding tax on interest on loans	Generates revenue in order to support equity and local financing	Frequently applied
Withholding tax for imported services	Generates revenue in order to support the use of local services	Frequently applied
Value-added tax	Generates revenues in order to tax part of sales	When a product is exported, most countries negate the effect of input and output through exemption or refund
Licence fee	In order to generate revenues of public administrations	Frequently applied
Lease or usage fee	In order to secure stable revenues, often for municipal administrations for land use	Frequently applied
Postage stamp fee	In order to secure revenues from transaction values	Often used in developing countries; does not apply to industrial nations
***In personam* taxes**		
Income tax	In order to generate revenue in line with financial solvency	Applied universally
Asset return or capital return tax	In order to tax profits from the sale of capital investments	Frequently applied in industrial nations, but not in developing countries
Additional tax on profits	In order to tax part of exceptionally high profits	Very seldom
Profit tax	In order to tax part of exceptionally high profits	Very seldom
Duties on net profit or net value	In order to generate revenue in line with financial solvency	Mainly applied in countries with strongly developed tax administrations
Withholding tax on distributed profits or dividends	In order to generate revenues in line with financial solvency in order to keep capital in the country	Frequently applied

Source: Otto et al. (2006).

In a more general form, the most relevant components according to Schönfelder (2016) are:

- Corporation tax
- Value-added tax
- Import/export taxes
- Customs
- Tax on returns and
- Royalties

An alternative classification is based on profit-based and production-based taxes. The former type includes, for instance, corporation taxes and taxes on returns, whilst the latter type covers, for instance, exploitation fees, import and export taxes as well as value-added tax (ICMM 2009, p. 37). However, several authors also use different classifications even though their contents are more or less in the same direction. These lists are sufficient for the purposes of this study. The following sections will focus on royalties only which are relevant in this context.

Otto et al. (2006, p. 50) define royalties as follows:

- The law creating the tax calls that tax a royalty.
- The intent of the tax is to make a payment to the owner of the mineral as compensation for transferring to the taxpayer the ownership of that mineral or the right to sell that mineral.
- The intent of the tax is to charge the producer of the mineral for the right to mine the minerals produced.
- The tax is special to mines and is not imposed on other industries.

In other words: This royalty is payable by mining companies (or the company selling the resource) in consideration of the right to exploit (and/or sell) the resource. In as far as the intent is to give the public a share in the exploitation profits and in the return from raw material exploitation, this can then also constitute an (additional) tax on returns.

Four obvious options are available for designing a royalty regime (see also above):

- Quantity-based
- Value-based (ad valorem)
- Profit-based
- Hybrid forms of the above variants

No matter which variant, the question remains regarding the reference variable and how it can be determined when it comes to administrating the royalty. The reference variable can be derived at different points of the value and/or exploitation chain. In theory, the reference variable should be located as close as possible to the real point of exploitation so that it is not necessary to subsequently eliminate further processing steps from the evaluation. However, this efficient solution may involve administrative costs, and a later evaluation point may be easier to handle, for instance, after market transactions have taken place (ISA 2014). This thus represents a classic case of a trade-off between efficiency and ease of administration.[97]

A detailed analysis of process and administration issues in conjunction with royalties can be found in Guj et al. (2013, section 3). In order to describe the above-mentioned options regarding possible valuation points (V0-6), see the illustration below (refer to Guj et al., 2013, p. 27):

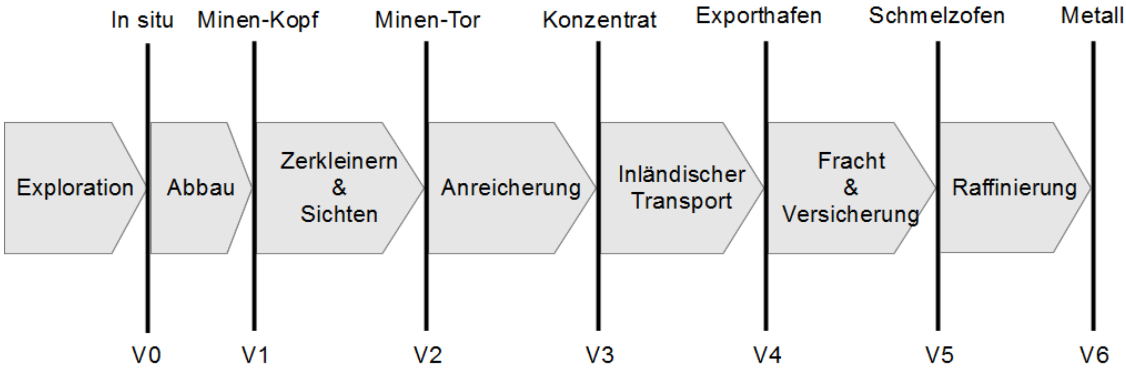


Fig. 4-9: Valuation points along the value chain

A royalty can serve several purposes. However, it must be introduced in such a manner that it is compatible with the overall mining taxation system. Both multiple taxation of identical facts and interaction with other taxes must be taken into consideration or avoided. However, the minimum goals should be reasonable compensation to be paid to the (original) owner of the resource for its exploitation in the first place and secondly recovery of the government's administration costs. Although additional elements of a tax on returns are conceivable, these would worsen the valuation problems mentioned earlier because skimming off of returns is only possible if information regarding the normal rate of a return of a project is available. Returns can only be skimmed off in as far as the components above and beyond this normal rate of return are concerned. It would be better to consider an additional fee or tax rather than to design royalties along these lines.

A royalty system must solve a central conflict of interests no matter what the assessment basis. The state has a keen interest in permanent, regular and plannable payment flows. Investors and companies, in contrast, are interested in progressive systems where payment is not due until a project has become profitable. There is also a general

[97] "Valuation points closer to the mine are more economically efficient and equitable, while those closer to the point of final consumption are more revenue-stable and potentially easier to administer." (Guj et al. 2013, p. 26).

risk that a royalty would increase the marginal costs of mining operations. This would also affect investment incentives, resulting in less-than-optimum production volumes or even in generally profitable projects not taking place at all. This conflict must also be considered before a royalty regime is introduced.

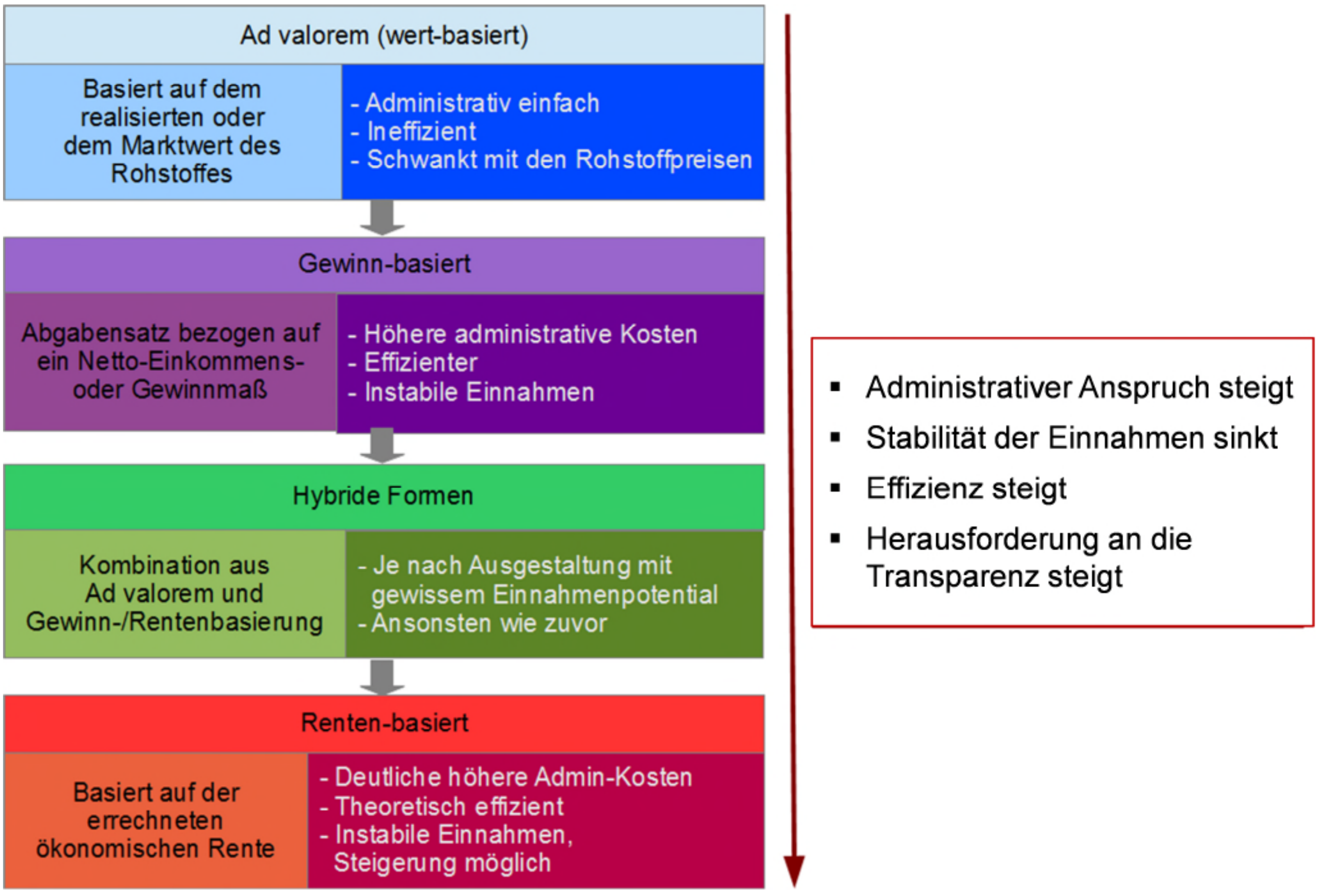
With regard to complete mining royalty systems, the conclusion drawn by Otto et al. (2006, p. 2) is still generally valid today: "The geological, economic, social, and political circumstances of each nation are unique, and an approach to royalty taxes that is optimal for one nation may be impractical for another. The answer to the central question of whether royalties are inherently good or bad depends on the circumstances of the parties involved, project economics, and one's point of view."

Pros and cons of certain royalty systems

Fig. 4-10 compiles the pros and cons of the different royalty systems according to the respective assessment basis (ISA 2014, p. 77). Administrative complexity increases, whilst plannability and/or stability of revenues decrease from top to bottom, whereas economic efficiency and challenges for transparency increase.

Whilst value-based royalties are therefore easier to implement, but economically hardly effective, return-based royalties are economically more effective, but hard to administrate. Profit-based and hybrid forms range between these two extremes with regard to these criteria.

Table 4-11 shows in this context how governments on the one hand and investors on the other evaluated different assessment bases according to relevant criteria. This underlines almost across the board that opinions are opposed in most cases. A royalty system must therefore inevitably constitute a compromise between public and entrepreneurial interests.



Source: ISA (2014)

Fig. 4-10: Pros and cons of the assessment bases for royalties

Table 4-11: Evaluation of royalty types by governments and investors (Y = yes, N = no, ? = questionable)

Government criteria						
Royalty type	Income generation	Stability of revenue flow	Revenue in early years	Administrative ease and transparency	Affects production decisions	Amenable to multi-party distribution
Unit based	Y	Y	Y	Y	Y	Y
Ad valorem	Y	Y	Y	Y, if gross revenue based ?, if market value based	Y	Y
Profit or income based	? only if profitable	N	N	N	N	Y
Hybrid (minimum ad valorem floor applies if profits are too low)	Y, stable minimum base plus additional profitable	Partial	Y, but modest	N	Y, slight distortion	Y
Investor criteria						
Royalty type	Reduces income	Responsive to profitability	Rapid payback	Responsive to market price	Impact on marginal price	Supports production efficiency
Unit based	Y	N	N	N	Y	N
Ad valorem	Y	N	N	Y	Y	N
Profit or income based	? only if profitable	Y	Y	Y	N	Y
Hybrid (minimum ad valorem floor applies if profits are too low)	Y, to a degree	Y, mostly	Y, mostly	Y	Y, modest	Y, mostly

Source: Otto et al. (2006)

Systems in terrestrial mining

One could generally believe that the tax – and hence also the royalty – systems implemented in terrestrial mining could provide good blueprints or at least guidance for a corresponding system in deep sea mining. However, one must say that this is hardly the case for a number of reasons.

First: "Currently, there are as many tax regimes as there are countries" (ISA (2014)). Although the typical elements can be identified (royalty, corporation tax, additional tax on profits), a comprehensive systematic comparison of all possible systems is thereby practically ruled out. An interval of around 40 to 55% applies to the tax burden for the mining sector. This is roughly made up of corporation tax (25 to 35%), additional taxes on profits (15 to 25%) and royalties (3 to 6%) (ISA 2014). The latter apparently have the least important role to play.

Second, although mines can be compared, their key features are never identical. This is probably also applicable to deep sea mining, albeit to a lesser extent. This means that the specific conditions of a given project must always be taken into account. Since this may generate sometimes prohibitively high administrative costs, these specific conditions may also render an efficient solution impossible.

Third, terrestrial mines often focus on a single resource whist both manganese nodules and massive sulphides are polymetallic, so that mining operations are only economically viable if as many of their constituents as possible can be extracted. This strongly restricts comparability with existing systems, all the more so because possible interaction between taxes and royalties must be considered for individual metals.

Fourth, all efforts in deep sea mining are first-time projects for which no experience is so far available. Although scientific results and empirical findings should be referred to, no system applied in terrestrial mining lives up to the theoretical ideal – not least due to political and economic reasons.

This is why this study will not investigate royalty systems in terrestrial mining in more detail, all the more so because this is not in the focus of this study. For a more in-depth analysis, see, for instance PWC (2012). The discussion regarding a royalty should be based on the available results of theoretical and empirical literature on the effects of certain royalty designs. An additional legal and economic analysis should examine to what extent the provisions of German mining law can be applied to deep sea mining. Section 31 of the Federal Mining Act [§ 31 BBergG] provides for a 10% royalty (of the average market value of the resource extracted). Although the federal states can determine the actual amount, this may not exceed four times the rate laid down in the Federal Mining Act. However, the federal states are entitled to the revenues which are considered within the scope of the fiscal equalisation scheme between the federal states. In contrast to this, it is obviously difficult to assign the resources from the deep sea to the federal states.

Specific features of a royalty in deep sea mining

The previous section has already addressed some of the specific features of deep sea mining which also influence the royalty regime. These are, in detail:

- UNCLOS Art. 136 lays down the principles for regulations for the seabed by stating that no national state is allowed to appropriate the resources from the deep sea and that these resources must be be applied to the benefit of all mankind because they constitute common heritage of mankind.
- Access to marine resources on the seabed is subject to strong restrictions and represents an activity controlled by the International Seabed Authority.
- Both manganese nodules and massive sulphides consist of a number of different metals. Due to minor deviations in composition

from deposit to deposit, the real percentages cannot be determined until the resources are in fact exploited. The polymetallic characteristic is a major obstacle to the definition of royalties. First, it must be defined which of the metals contained are to be subject to royalties. Second, the data collection and evaluation problems discussed earlier are particularly important here. This applies, in particular, to the underlying composition, i.e. the question as to whether a fictitious and theoretical composition or the real composition will be used. The latter, however, can only be determined after several process steps.

- Deep sea mining means breaking absolute new ground in many respects. This is because uncertainty is particularly great in this area, for instance, with regard to
  - the extent of resources
  - the actual composition of the resources mined
  - the industrial feasibility of the mining projects
  - open questions regarding smelting technology and
  - the environmental impact.
- It is hence also difficult to develop a royalty system that is both efficient and practicable in administrative terms. Supplementary national systems can only be introduced if all international challenges are overcome. Furthermore, the greater the uncertainty, the more reason to demand higher royalties. The International Seabed Authority will probably be the first institution to have this privilege.

In analogy to terrestrial mining projects, ring fencing could also be an option in deep sea mining. Project-specific fiscal treatment is possible in cases where the individual project can be clearly distinguished from other projects. Although this once again means specific administrative requirements, it also means that inefficient approaches can be prevented in individual cases. At the same time, the effect of uncertainty can be reduced with regard to the composition of the reserves.

ISA's current concept provides that the revenues (economic benefits) from deep sea mining can be applied, for instance, via a royalty, to the benefit of mankind and in particular to that of the developing countries. It is, however, remarkable that the developing countries are not referred to because of the prosperity gap in relation to the industrialised nations, but because of their lacking technical possibilities to engage in deep sea mining themselves. The wording regarding the use of revenues goes in the direction of a sustainable preservation of capital as mentioned earlier, so that this goal should hence be welcomed.

The International Seabed Authority generally favours a simple, easy-to-audit system that should be designed along the lines of terrestrial mining schemes. As already discussed, the latter can only be implemented to a limited extent, whilst the former attaches greater importance to ease of administration than economic efficiency. Components of the royalty system so far discussed were an annual fee, a royalty and a profit share. According to the motto of 'KISS – keep it simple and smart', a 10-year transitional phase was discussed which could be limited to a unit fee and a royalty. This is seen as an incentive for investors to venture into deep sea mining. Although this corresponds to the argument that a royalty system should not stifle investment, it contradicts the requirement that a functional royalty system should, if possible, be implemented before exploitation starts. This then means a risk that investors could generate windfall profits, that – contrary to be previous paragraph – no sustainable capital preservation takes place and that the resource would be exploited too quickly. Furthermore, it is not possible to rule out future adaptation of the royalty system for political and economic reasons.

In July 2016, the International Seabed Authority commented for the first time in more detail on the design of the "Financial Terms of an Exploitation Contract" (see section 4.3 for details). The important elements mentioned there – however, without any statements regarding their amount or reference basis – are (ISA 2016, pp. 28-36) the following:

- Annual contract administration fee
- Annual fixed fee
- Royalty

The fee is payable annually as soon as commercial production commences, and must be paid for all metals mined in the area and/or subsequently sold. The basis has not yet been specified, so that both the volume and/or the value can be chosen during the further negotiation process. In view of the pros and cons discussed earlier, a compromise, i.e. a hybrid form, can be expected.

4.4.3 Recommendations

With a view to recommendations for Germany's future position in relation to issues of the royalty system, two aspects should be distinguished. First, it must be determined how Germany can engage in forthcoming discussions at ISA and which arguments Germany will put forward. Second, the question must be raised regarding Germany's leeway for a national royalty regime.

Regarding the first aspect, it should be noted that the question regarding sensible and necessary design characteristics was already sufficiently dealt with in recent years. With regard to the characteristics of the royalty system, comprehensive literature on terrestrial mining is available which is also considered in existing ISA documents. In summary, the system to be supported must be effective, efficient, fair, simple, transparent as well as flexible and enforceable. In this context, the precautionary principle to protect the deep sea should be given priority over other considerations, not least because commitment to the environment and sustainability is one of Germany's explicit strengths. Moreover, the application of the revenue generated is so far only marginally dealt with in ISA's documents. Germany should advocate sustainable investments to the benefit of all mankind.

Regarding the second aspect, i.e. an independent German royalty, an analysis would be pointless without knowing the precise design of the royalty system at international level. Moreover, the leeway for a national German royalty will probably be limited, all the more so, because it would be levied secondary to an international royalty. Attempts should hence first focus on a precise definition of the purpose of a German royalty. Assuming that the international royalty regime aims at an incentive-compatible skimming off of returns from resource exploitation, the goal of an additional German solution can only be to finance previous investments, such as exploration projects, as well as future research and development activities. The obvious solutions will then be to sell German exploitation rights by auction. Given an appropriate design, it will also be possible to identify and skim off the willingness of interested companies or syndicates to pay. On the one hand, this would not prevent investments and it would also generate revenue for the German government on the other. For a more detailed discussion of design options – which would go beyond the scope of this study – see Schönfelder (2016, pp. 34-53) and, for short recommendations, IMF (2012, p. 38).

5 Pilot mining test

5.1 Introduction

The pilot mining test (PMT) has a central role to play in regulations of the International Seabed Authority (ISA). The pilot mining test is conducted at the end of the exploration phase and constitutes the transition to a possible exploitation phase.

The licensee (called "contractor" in the terminology of the International Seabed Authority) can be a state, a state institute or a public or private company. The procedure provided for by the International Seabed Authority assumes that the contractor is interested in commencing industrial exploitation operations on the deposit after the successful exploration phase which, for its part, ends with the pilot mining test. In other words, the International Seabed Authority assumes that the contractor, at the time of acquiring an exploration licence, has already developed a commercial strategy for commencing the exploitation phase. However, the discussion of the implementation prospects in section 6 shows that this does not yet currently apply to any of the contractors.

The International Seabed Authority assumes a period of 15 years for the exploration phase, with the pilot mining test planned for the third 5-year phase of exploration activities.

The International Seabed Authority defines the purpose of the pilot mining test as follows: "In a mining test, all components of the mining system will be assembled and the entire process of test mining, lifting materials to the ocean surface and discharge of tailings will be executed."[98] The International Seabed Authority thus determines that the pilot mining test is to integrate the operations of mining the material from the seabed, its lifting to a platform on the surface as well as the treatment and discharge of process water. However, the International Seabed Authority also demands in another document that a pilot mining test to be performed include verification of the metallurgical processes.

[98] International Seabed Authority, Legal and Technical Commission:
Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area.
ISBA/19/LTC/8, Paragraph 23, Page 8

5.2 History and technical background

Since the 1970s, relevant experts have been thinking about the risks and opportunities of deep sea mining. Components for deep sea mining have been developed and tests carried out since then. These tests focus on the collector and the mining system as the key components of the new technology.

The most important past activities are described below:

1978 OMI (Ocean Management Inc.): Pilot mining test the CCZ
- INCO US Inc.
- Metallgesellschaft AG, Preussag, Salzgitter AG
  AMR (Arbeitsgemeinschaft meerestechnisch gewinnbarer Rohstoffe [Consortium for Raw Materials from the Deep Sea])
- Deep Ocean Mining CO. (DOMCO, Sumitomo, Japan)
- SEDCO

1979 OMCO (Ocean Minerals Company): Pilot mining test the CCZ
- Lockheed Martin
- Amoco
- Shell Billiton

1985 PREUSSAG/GEOMONOD: Collector test with the 'Sonne' research vessel
- PREUSSAG
- CEA
- Technicatome
- Ifremer

2006 NIOT (National Institute of Ocean Technology, India)
in co-operation with the University of Siegen:
development of a manganese nodule collector

2003 KIOST (Korea Institute of Ocean Science & Technology):
2013 Collector tests at a depth of 1,370m
2015 Tests of a conveyor pipe with buffer, riser and pump system at a depth of 1,200m

These tests are described here not only because they are of historical interest, but also in order to provide an understandable description of the components involved in a pilot mining test.

5.2.1 OMI (Ocean Management Inc.) Pilot mining test in the Clarion-Clipperton Zone, 1978

Fig. 5-1 is a schematic diagram of OMI's pilot mining test. The major components of the system are the mining vessel (the modified drilling vessel SEDCO 445), the conveyor pipe (rigid riser with integrated pump and airlift system and a flexible hose system) as well as the collector.

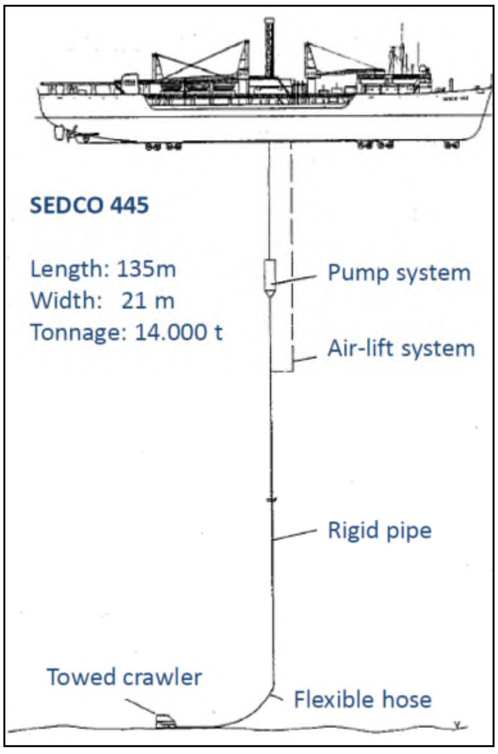


Fig. 5-1: OMI's pilot mining test, 1978
system sketch

Two different collector systems were tested:

- 'Berlin' collector
  Hydraulic/mechanical collector system
  Developed at the Berlin Shipbuilding Test Institute
- AMR collector
  (Arbeitsgemeinschaft meerestechnisch gewinnbarer Rohstoffe [Consortium for Raw Materials from the Deep Sea])
  Hydraulic collector system
  Developed by Orenstein & Koppel

The pump system, which is integrated into the conveyor pipe, consists of submersible motor pumps with a capacity of 40 to 60 tonnes per hour through an 8-inch riser. The airlift system, which works parallel, has a capacity of 80 tonnes per hour and injects air into the riser with a diameter of 6 inches at a depth of 2,000m.

520 tonnes of polymetallic nodules in total were pumped to the vessel.

Fig. 5-2 shows the drilling vessel SEDCO 445 as modified for the test whilst Fig. 5-3 shows the collector with the hydraulic collection system.

Fig. 5-2: OMI pilot mining test
Modified drilling vessel SEDCO 445

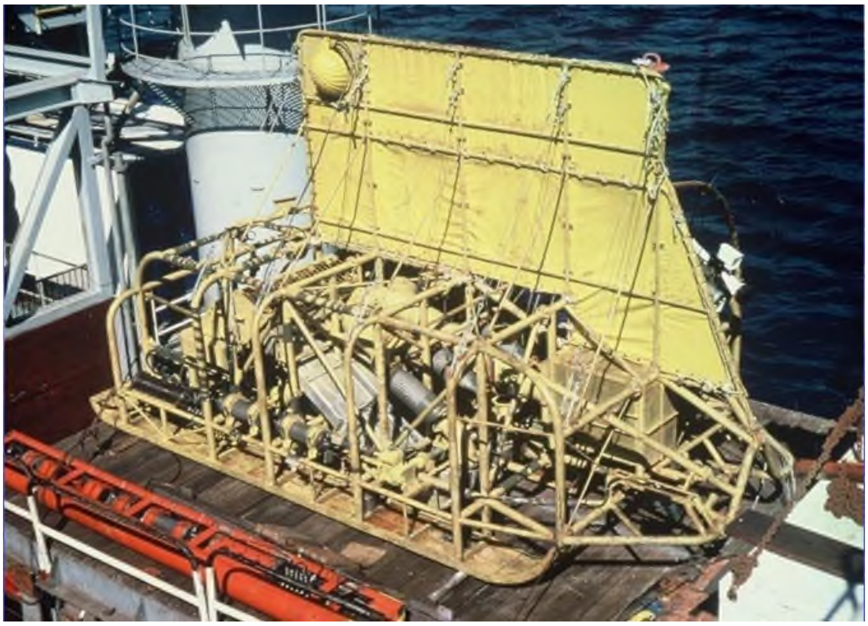


Fig. 5-3: OMI pilot mining test
Dragged collector with hydraulic collection system

5.2.2 OMI (Ocean Management Inc.) Pilot mining test 1979

This test was also conducted in the Clarion-Clipperton Zone at a depth of around 5,000m with the modified drilling vessel Glomar Challenger. This test used an extraction system with a collector and conveyor pipe developed by Lockheed.

The costs of this test totalled around 500 million USD (in 2016 figures). However, it should be noted that the focus of this campaign was probably the inspection of a sunken Soviet submarine and the attempt to salvage it.

Fig. 5-4 shows the collector that was used in this test.

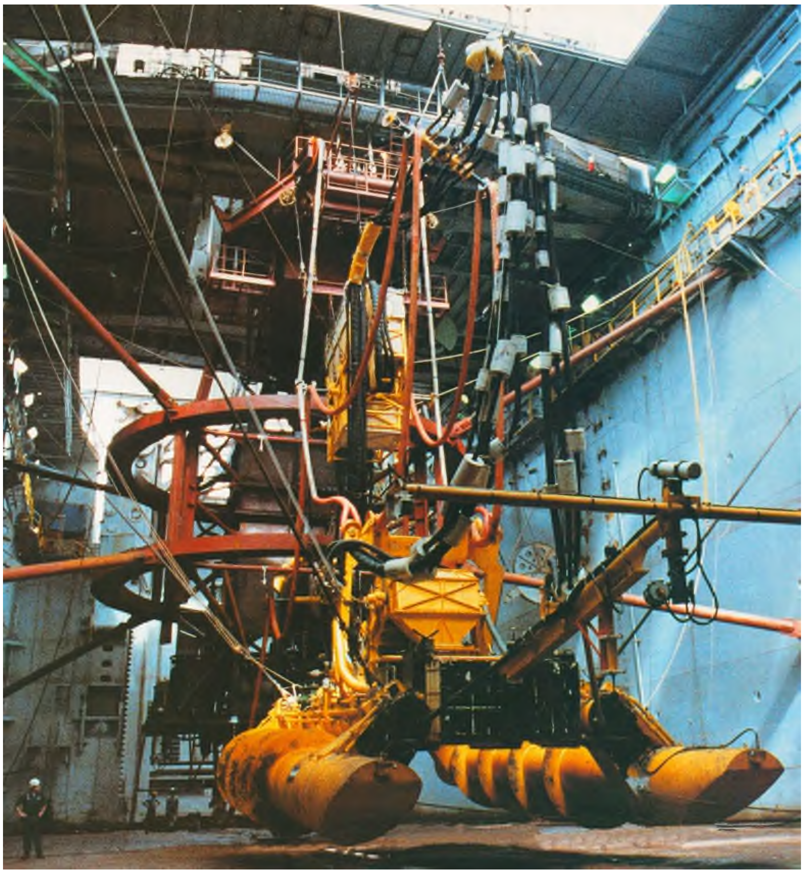


Fig. 5-4: Collector of the OMCO project on board the Glomar Explorer (1979)

5.2.3 Performance of impact experiments 1989 to 1996

As part of the DISCOL and ECOBENT projects, tests were conducted in order to simulate the influence of the collector on the seabed and the benthos and to analyse this in long-term observation studies.

Fig. 5-5 shows the test equipment, i.e. a mechanical harrow with solid bodies which is placed onto the seabed and towed by a vessel.

This harrow was used in February (baseline study).

In two other instances in 1989 as well as in 1992 and 1996, the location in question was studied (post impact studies) in order to document the reversion of the furrows and the development of the benthos.

Fig. 5-5: Experiment for researching the raising of sediment on the seabed using a mechanical harrow

5.2.4 German/French collector, 1985

Within the scope of a joint German/French project, a scalable deep sea collector test was planned in 1985 and the following years, but was not carried out.

Fig. 5-6 shows a system sketch of the then plans for the collector and monitoring equipment. The collector vehicle was designed as a self-propelled vehicle, and the nodule collection process was to be tested. Tests with a conveyor pipe were not planned.

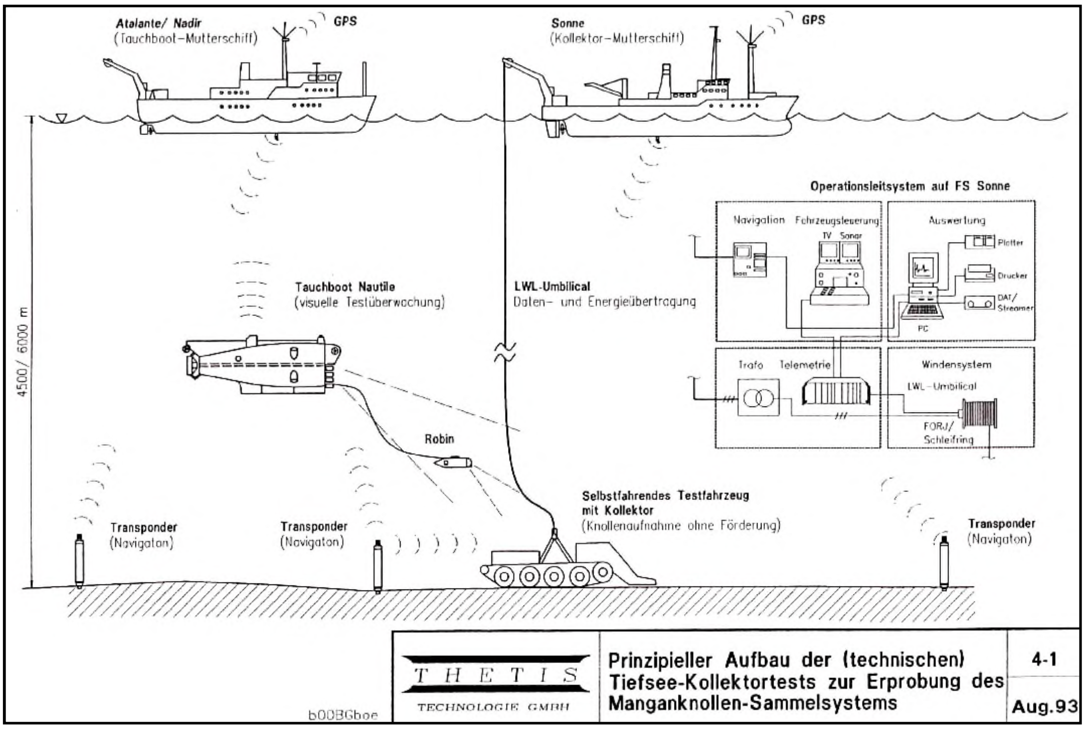


Fig. 5-6: Sketch of the test of the German/French collector, 1993

Fig. 5-7 is a sketch of the collector. This system was to be used for workshop, shallow-water and deep sea function tests. It was also planned to collect nodules.

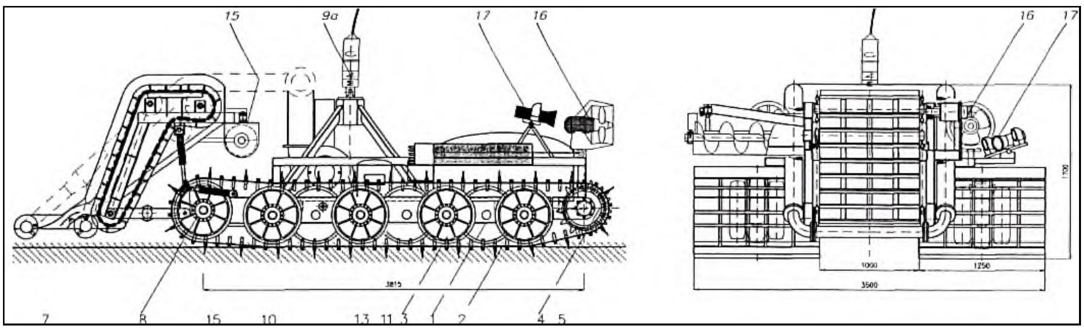


Fig. 5-7: Sketch of the German/French collector, 1985

5.2.5 National Institute of Ocean Technology (NIOT), India Collector tests 2005 to 2010

This collector was developed in co-operation with the University of Siegen.

In 2006, first tests with the collector were carried out at a depth of 500m using the research vessel 'ORV Sagar Kanya' that had been modified for the test.

In 2009, another test was conducted with a remote-controlled vehicle at a depth of 3,000m with artificial nodules. In 2010, the water depth was increased to 5,280m.

Also in 2010, a new collector design with a nodule crushing system was tested at a depth of 500m.

Fig. 5-8 shows the collector developed at NIOT in a German/Indian co-operation project.

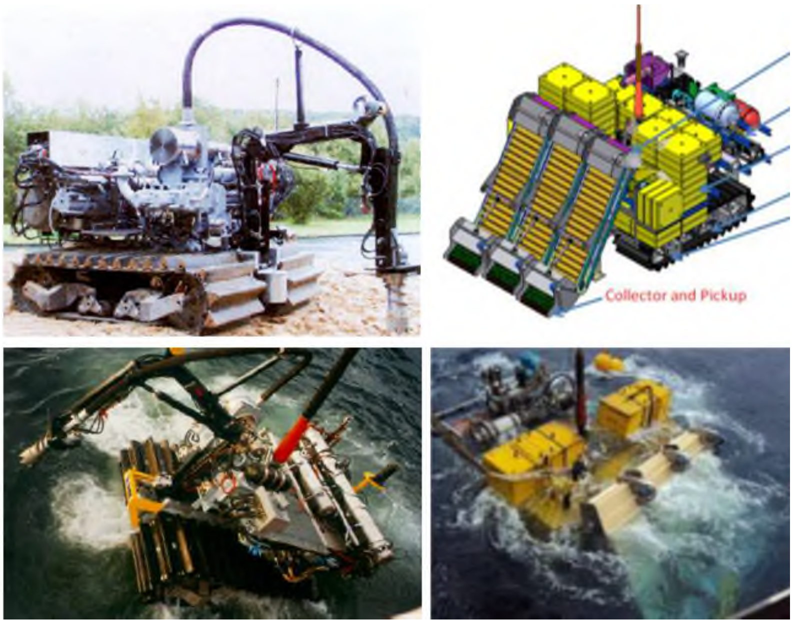


Fig. 5-8: NIOT collector

5.2.6 Korean Institute of Ocean Science and Technology (KIOST) Korean Research Institute of Ships and Ocean Engineering (KRISO) Test series with collector, buffer and conveyor pipe 2003 to 2015

South Korea pursued a very systematic approach in order to develop systems for mining polymetallic nodules.

The first collector test with a nodule collection system in the form of a single module was carried out in 2003. On this basis, a collector that was fitted with four modules was successfully tested at a depth of 1,370m in 2013.

Another test was conducted at a depth of 1,200m with the buffer developed as well as a riser with an integrated pump system.

Although this test series does not yet fulfil the requirements for a pilot mining test because a complete, integrated mining system was not tested, the tests are nevertheless an excellent basis for the next development steps and the performance of a pilot mining test.

Fig. 5-9 shows a system sketch and photos of the tests.

Fig. 5-9: Collector, buffer and riser with pump system (KIOST/KRISO)

5.3 Requirements for the pilot mining tests

5.3.1 Regulations and recommendations by the International Seabed Authority (ISA)

ISA pursues the following aims with the pilot mining test:

- Assessment of technological and ecological risks
- Acquiring concrete results for the development of requirements for the granting of mining licences
- Facilitation of the development of the most eco-friendly technologies possible

Besides information regarding impacts on the marine environment and technical results, ISA is also eager to generate further information with a view to fees, royalties and taxes to be charged, the implementation of liability and insurance rules and regulations as well as the requirements for liability funds to be set up as well.

Describing the impacts of deep sea mining on the marine environment is a very important part of a pilot mining test. In this respect, ISA demands comprehensive environmental monitoring in the test area and in a reference area to be conducted before, during and after the pilot mining tests. The purpose of this is to generate an in-depth knowledge basis regarding possible environmental impacts, and the subsequent comparison between the test and reference areas is to enable a better assessment of environmental impacts. Furthermore, a comprehensive environmental impact assessment must be part of planning procedures and the basis for approving the respective pilot mining test applied for.

ISA has not yet answered all the questions related to the performance of the pilot mining tests nor issued the corresponding regulations. The following issues are, for instance, still open:

- How is the completed pilot mining test to be evaluated?
  Will this be carried out by ISA itself, or will additional external bodies or scientific experts be employed?
- To what extent must plans, technical details, measuring results and the further results of a pilot mining test be documented to ISA?

5.3.2 Assessment of environmental impacts by monitoring

In order to assess the impact and possible long-term effects of potential manganese nodule mining operations on the marine environment, the pilot mining test must be accompanied by an environmental monitoring process. The results of small-scale experiments like those conducted in the early DISCOL project (see section 5.2.3) and studies in the current JPI Oceans project can be transferred to a limited extent only to the large-scale mining operations to be expected.

Biological and geochemical effects as well as impacts on the marine environment can occur in three zones (see also Fig. 5-10):

- The area around the collector on the seabed
- The benthic turbidity cloud (caused by the collector)
- The turbidity cloud in the water head (caused by material discharged by the vessel)

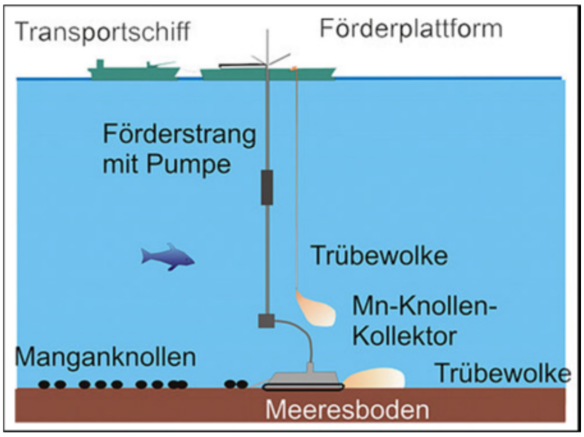


Fig. 5-10: Environmental impacts of a pilot mining test (in three zones)

The pilot mining test can generate the following environmental impacts:

<u>Collector:</u>

The movement, power and active work of the collector in the seabed can directly kill both sessile and mobile fauna. Furthermore, light and noise caused by the collector can disturb or frighten away organisms living in the otherwise dark and quiet habitat. Since most of the material extracted is hard substrate in the form of nodules, the sessile organisms living there would be deprived of their existence basis. Changes in the biodiversity and occurrence of species would be one of the consequences to be expected. There is a risk that mobile species would flee to unaffected reference areas and live there.

However, nodule mining would affect not just the macrofauna, but also microorganisms that live mainly in the upper sediment layers. Experience from projects, such as 'MIDAS', 'JPI Oceans' or 'DISCOL', shows that the number of organisms and species in an affected area is much lower than in unaffected areas. Changes in the shares of the different species as well as reduced microbiological activity were also observed.

Benthic turbidity cloud:

The benthic turbidity cloud is caused mainly by the movements of the collector on the seabed and leads to an increased sedimentation rate with the consequence that organisms can be buried and their filter organs obstructed, for example. Further possible consequences of sediments raised from the seabed can be an increased rate of release of trace metals, reduced oxygen content as well as the release of nutrients into water near the seabed.

Turbidity cloud due to sediments discharged from the vessel:

The turbidity cloud caused by sediments discharged from the vessel into the water leads, amongst other things, to greater particle concentration in the water head which leads to obstruction of gills and other organs of organisms living in the water head. Furthermore, potentially toxic trace metals can be released which can be taken up by plankton and other organisms and thereby concentrate in the food chain. Released nutrients, for their part, lead to greater primary production in the water head.

Parameters to be monitored

In order to describe the biological and geochemical changes in the ecosystem during and after manganese nodule mining, monitoring of the following parameters in the water head, surface sediment and pore water is essential:

- Number and type of fauna species
  (including video recordings and photos of the macrofauna)
- Measurement of noise and light effects
- Sink rate and distribution of particles in the water head
- Concentrations of and changes in trace metals and nutrients
- Changes in oxygen and pH
- Changes in pore volume in the sediment

This requires the use of a lander with oxygen and pH sensors for measurements in the sediment and the water head over longer periods of time. Furthermore, sensors must be developed to measure particles, nutrients and certain trace metals in the water head. Moreover, sediment samples for physical, geochemical and (micro)biological analyses must be taken before, during and after a pilot mining test because 90% of sediment organisms live in the upper, 10cm thick layer. During a pilot mining test, benthic chambers should be used to measure biological and chemical conversion (such as oxygen consumption).

A pilot mining test, along with parallel environmental monitoring before, during and after the pilot mining test, is urgently needed in order to enable reliable conclusions regarding long-term and large-area repercussions of potential manganese nodule mining on the marine ecosystem. At the same time, the pilot mining task offers an opportunity to influence, especially via the environmental monitoring process, the determination of guidance and limit values for future exploitation and to ensure that high standards are adhered to. The results of a pilot mining test are also important for the further development of mining equipment in order to establish technical systems and technologies that ensure maximum protection of the environment. A pilot mining test can also offer German manufacturers the opportunity to take on a leading role in the development of sensor, control and instrumentation as well as sampling systems, as well as in the fields of data collection, transmission, processing and presentation.

5.4 Technical elements and cost estimate

The previous sections referred to the tests carried out so far in order to describe the technical elements to be tested as part of a pilot mining test. These elements are the collector system, the conveyor pipe to transport the nodules to the surface, as well as the system to discharge the purified process water.

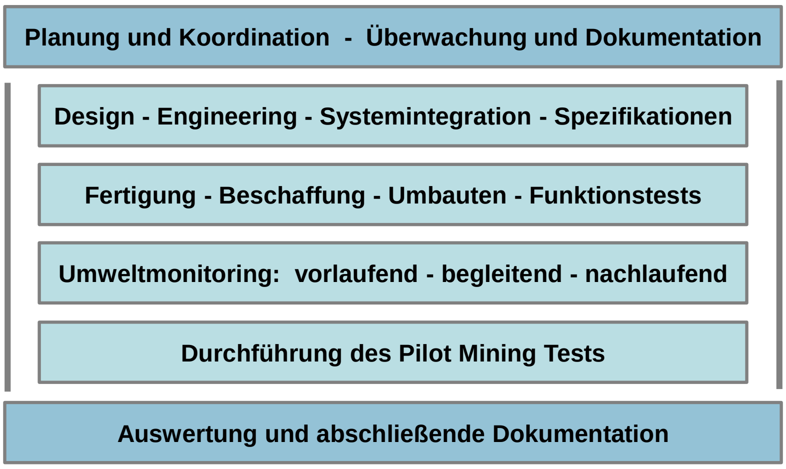


Fig. 5-11: Sketch of the phases of the pilot mining test

Fig. 5-11 is a sketch showing the elements and phases of a pilot mining test. In order to perform the test, higher-level planning and co-ordination efforts are required in order to organise co-operation between the various stakeholders, supervise and monitor the pilot mining tests, and document the results.

Within this organisation, system specialists must calculate and design the components to be manufactured, purchased or modified, and function tests must be conducted.

Environmental monitoring must be organised in such a manner that the required measurements are carried out in due time before, during and after the pilot mining test. The real pilot mining test as such is then carried out as a campaign. The higher-level planning and co-ordination organisation is responsible for monitoring, supervising and supporting the test at the test site and for evaluation and the necessary documentation.

Tests of the technical equipment are often carried out at a reduced scale. This is not suitable for pilot mining tests because scale effects would especially influence the physical processes in the conveyor pipe and collector so that the results could be distorted to a unacceptable degree. Testing directly in the future mining area, at full water depth and with full scaling of the system component, is also necessary in order to identify the impact on the environment.

It is, however, certainly possible to choose a capacity for the collector and conveyor pipe significantly below that of the equipment to be used in future exploitation operations because a narrower collector and a reduced cross-section of the conveyor pipe will not influence the results of the test.

Besides a reduced exploitation rate, the following measures can also be implemented in order to reduce the cost of the pilot mining test:

- Instead of a special mining vessel, a suitable drilling vessel can be chartered, retrofitted by relatively simple measures in order to perform the pilot mining test, and subsequently restored to its original condition after the test.
- Since many collectors have already been tested, a tried-and-tested collector could be purchased and used for the pilot mining test, or a new collector can be manufactured on the basis of a design that has already been tested.
- Second-hand riser sections from the oil and gas industry are sufficient for the rigid pipe elements of the conveyor pipe and the process water return pipe.

A total time of around five years is assumed for the pilot mining test. See Fig. 5-12.

<table>
<tr><th>Jahr 1</th><th>Jahr 2</th><th>Jahr 3</th><th>Jahr 4</th><th>Jahr 5</th></tr>
<tr><td colspan="5">Planung und Koordination - Überwachung, Dokumentation und Auswertung</td></tr>
<tr><td colspan="2">Design und Engineering
Systemintegration</td><td colspan="3"></td></tr>
<tr><td></td><td colspan="2">Beschaffung und Fertigung
Umrüstung und Funktionstests</td><td colspan="2"></td></tr>
<tr><td colspan="3"></td><td>Durchführung
Test</td><td></td></tr>
<tr><td colspan="2"></td><td colspan="3">Umweltmonitoring
vorlaufend - begleitend - nachlaufend</td></tr>
</table>

Fig. 5-12: Phases of a pilot mining test

The pilot mining test begins with the planning and design phase for the different components and their system integration, with the environmental impact analysis to be conducted before the test also taking place during this phase. Procurement and manufacture of the components can start during the course of the 2nd year. In the 3rd year, manufacturing should continue, second-hand and/or chartered equipment should be modified and function tests as well as environmental monitoring to be performed prior to real testing should be carried out. The test is scheduled to take place during the 4th year. In the 5th year, the tests are finally evaluated and documented on completion of the environmental monitoring process.

Fig. 5-13 shows the estimated costs of the pilot mining tests including cost bands.

Disziplin	Mio. EUR	Mio. EUR
Planung und Koordination, Überwachung, Dokumentation und Auswertung	6.1	5 – 8
Umrüstung Bohrschiff zum Förderschiff	17.2	15 – 22
Förderstrang	49.4	45 – 63
Kollektor	15.0	13 – 20
System zur Rückführung der Tailings	9.6	8 – 12
Durchführung Pilot Mining Test (90 Tage)	43.2	40 – 55
Umweltmonitoring vorlaufend - begleitend - nachlaufend	15.3	14 – 20
Summe:	155.8	150 – 200
davon Leistungen für Design, Engineering und Systemintegration:	7.3	6 – 9

Fig. 5-13: Estimated costs of the pilot mining tests

Altogether, the costs total around €150m to €200m, including around €6m to €9m for planning and co-ordination as well as component design. Given the present exploitation volume of deep sea mining in Germany, the pilot mining test will therefore generate considerable costs which constitute a new order of magnitude in the development of deep sea mining technology.

However, progress in deep sea mining is not possible without the pilot mining test which marks the obvious end of the exploration phase. The information generated through the test is vital for a mining licence to be issued.

For investors, the pilot mining test means crucial proof of the technical and economic feasibility and functionality of the components tested. The test also warrants the correct and reliable assessment of the impact on the delicate marine ecosystem which is so far untouched by human intervention.

6 Strategies for implementing industrial deep sea mining

6.1 Introduction

An analysis of the strategies for implementing industrial deep sea mining should be based on an examination of the activities so far undertaken in this sector by companies and institutions. The result is an overview of different business goals and company strategies that can be divided into the following three categories:

1. Investors in mining operations:
   The business model of these companies is in fact the extraction, smelting and, in particular, the marketing of resources. As the following analysis will show, only a few or even no companies of this type are currently active at an international level.

2. Project developers:
   The business purpose of individual companies with special technological know-how is to obtain licences to be sold to companies in the raw material sector at a future point in time. This business model can be compared to that of project developers, for instance, in the real estate sector or, for instance, in the offshore wind power industry. These companies hope that their investment in exploration operations and, if applicable, also in the performance of a pilot mining test can be re-financed and a corresponding profit generated through the sale of mining rights.

3. Equipment manufacturers and service companies:
   The business model of these companies is the sale of suitable services and technologies/equipment for deep sea mining.
   As will be shown later in this document, most German companies interested in deep sea mining belong to this group. They will not be able to exploit their opportunities until investors and project developers or even governments invest in exploration or mining activities.

6.2 Status and prospects of current implementation activities in deep sea mining

Table 6-1 is a list of current deep sea mining licensees. All of the licences shown are exploration licences. The table indicates which licensees (or contractors as they are called by the International Seabed Authority) are government institutions and which are companies.

Table 6-1: List of contractors for deep sea mining in the Clarion-Clipperton Zone

	Contractor	Vertrag	Sponsoring State	Vertragsende
Staatliche Einrichtungen	Interoceanmetal Joint Organization	29.03.2001	Russland, Polen, weitere Staaten	28.03.2016
	Republic of Korea	27.04.2001	Korea	26.04.2016
	COMRA China Ocean Mineral Resources	22.05.2001	China	21.05.2016
	DORD Deep Ocean Resources Development	20.06.2001	Japan	19.06.2016
	Ifremer	20.06.2001	Frankreich	19.06.2016
	BGR Bundesanstalt für Geowissenschaften und Rohstoffe	17.07.2006	Deutschland	18.07.2021
Unternehmen	Nauru Ocean Resources	22.07.2011	Nauru	21.07.2026
	Tonga Offshore Mining Limited	11.01.2012	Tonga	10.01.2027
	GSR Global Sea Mineral Resources	14.01.2013	Belgien	13.01.2028
	UKSR UK Seabed Resources I	08.02.2013	Vereinigtes Königreich	07.02.2028
	Marawa Research and Exploration	19.01.2015	Kiribati	18.01.2030
	OMS Ocean Mineral Singapore	22.01.2015	Singapur	21.01.2030
	UKSR UK Seabed Resources II	29.03.2016	Vereinigtes Königreich	28.03.2031
	Cook Islands Investment Corporation	16.07.2016	Cook Inseln	15.07.2031
	China Minmetals Corporation	(noch 2016)	China	(2031?)

It can be clearly seen that from 2001 to 2006 exploration licences were applied for exclusively by government institutions. This includes the Federal Republic of Germany through its Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) [Federal Institute for Geosciences and Natural Resources] which applied for its licence in 2006. The licence will expire in 2021.

The licences issued between 2011 and today were granted solely to private companies backed by very different states (so-called sponsoring states). The companies include, for instance, Global Sea Mineral Resources NV (GSR) from Belgium, a member of the Belgian DEME group, whose business model will be described below as an example.

The fact that only private companies applied for exploration licences in recent years suggests that deep sea mining is becoming increasingly attractive in commercial terms. The companies listed belong to categories 1 and 2 of the roles described in section 6.1.

Table 6-1 also shows the various states that have applied for licences since 2001. All of these countries – China, Japan, South Korea and Russia – are countries where close ties exist between big industry and government and where subsea mining is supported due to strategic interests and at times even without any economic justification.

Activities by the European Union

The European Union has tendered and awarded research projects as part of several promotional programmes that address the further development of various sub-aspects of deep sea mining. The projects currently underway are:

- MIDAS
  Managing Impacts of Deepsea Resource Exploitation
  research project 7, €12m, EU funds of €9m, 2013 to 2016
- BLUE MINING
  Breakthrough Solutions for Mineral Extraction and Processing in Extreme Environments
  research project 7, €15m, EU funds of €10m, 2014 to 2018
- BLUE NODULES
  Deep Sea Mining Concept Design for Polymetallic Nodules
  Horizon 2020, €12m, EU funds of €8m, 2016 to 2020
- Study to investigate the state of knowledge of deep-sea mining
  Client: EC – DG Maritime Affairs and Fisheries
  August 2014

Furthermore, ecological aspects of deep sea mining are investigated as part of the intergovernmental initiative 'JPI OCEANS – Joint Programming Initiative Healthy and Productive Seas and Oceans'. The programme is scheduled to run from 2015 to 2017.

Similar to the German government, the European Union is determined to exploit the opportunities that deep sea mining has to offer for the European economy and the protection of its raw material supplies. Support focuses on closing information gaps regarding deep sea mining technology and on research into the related environmental impacts.

Many German commercial enterprises are involved in the European research projects. The Belgian DEME group will be described below as an example because it can be used to describe the typical business model of a project developer.

The DEME group is involved in the European 'Blue Mining' and 'Blue Nodules' research projects. Furthermore, the DEME group holds an exploration licence for its subsidiary Global Sea Mineral Resources NV (GSR) for which Belgium acts as the sponsoring state (see Table 6-1).

The DEME group belongs to the construction sector and has a strong focus on construction projects in and at the water and particularly strong expertise in dredging works. In the field of deep sea mining, the company focuses on its core expertise, i.e. the collector, the conveyor pipe, transshipment and transport to the shore, as well as its strengths when it comes to winning and implementing projects on the international market. These qualifications also enable the group in technical terms to perform the required pilot mining tests which are a central building block on the road to a mining licence.

In line with the typical business model of a project developer, the DEME group expects that – given a sufficient economic attractiveness of mining operations – raw material companies will be willing to buy the licence belonging to the DEME group, thereby generating a reflow of capital to the DEME group.
Furthermore, the DEME group could in future act as a service company for the mining company and perform the activities of mining and transporting the polymetallic nodules right through to their smelting onshore.

<u>Range of activities by German companies:</u>

Many companies in Germany have expressed their interest in deep sea mining and some of have joined the Deep Sea Mining Alliance (DSMA).

Table 6-2 is a list (without claiming to be exhaustive) of these companies including differentiation thereof according to business fields.

Table 6-2: German companies planning to become active in deep sea mining

Company	**Scope/expertise**
Environmental monitoring: before – during – after:	
Center for Biotechnology, Bielefeld University	Biodata mining
GEOMAR, Kiel	Monitoring of the marine ecosystem
Hydromod, Hanover	Field measurements and laboratory analyses, measuring trips
MARUM, Bremen	Use of autonomous underwater vehicles
Atlas Elektronik, Wedel	Measuring systems
Evologics, Berlin	Measuring systems for long-term monitoring
Kongsberg Maritime Contros, Kiel	Subsea monitoring platforms
Oktopus, Hohenwestedt	Planning in the field of deep sea environmental protection
Sea & Sun Technologies, Trappenkamp	Sensor systems for in-situ measurements
DNV GL, Hamburg	Certification
Lloyd's Register, Hamburg	Certification

Company	Scope/expertise
Planning and co-ordination – monitoring and documentation:	
Heinrich Drilling Consultant, Erkelenz	Procurement
IMPAaC Offshore Engineering, Hamburg	Planning of underwater systems
MC Consulting	General consulting, documentation
Oktopus, Hohenwestedt	Planning in the field of deep sea environmental protection
Ramboll IMS, Hamburg	Planning, co-ordination, risk management, monitoring, documentation
Logistics for a pilot mining test	
Harren & Partner, Bremen	Ship management
Siem Offshore Contractors, Leer	Contractor, operator
Design – engineering – specifications:	
BAUER Maschinen, Schrobenhausen	Systems for deep sea mining (mining equipment)
Bosch Rexroth, Lohr am Rhein	Underwater drive and control systems
Conti-Tech. Hanover	Flexible conveyor hoses
ImPAC, Hamburg	Underwater systems
KSB, Frankenthal	Pump systems for underwater use
LEISTRITZ, Nuremberg	Pump systems for underwater use
MHWirth, Erkelenz	Specification of the complete system and conveyor pipe
Neptun Ship Design, Rostock	Modification of the drilling vessel
Ramboll IMS, Hamburg	System analysis and simulation, FMECA
Technolog. Hamburg	Modification of the drilling vessel
ThyssenKrupp Industrial Solutions, Essen	Separator system
ThyssenKrupp Marine Systems, Kiel	System integration and collector engineering
DNV GL, Hamburg	Certification
Lloyd's Register, Hamburg	Certification
Procurement – manufacture – modification	
BAUER Maschinen, Schrobenhausen	Systems for deep sea mining (mining equipment)
Bosch Rexroth, Lohr am Rhein	Underwater drive and control systems
ContiTech, Hanover	Manufacture of conveyor hoses
Enitech, Bentwisch	Pressure-resistant electronics
Evologics, Berlin	Measuring systems, navigation and communication
GISMA, Neumünster	Underwater plug connectors
Krauss-Maffei Wegmann DST, Remscheid	Crawler system and chassis
KSB,Frankenthal	Pump systems for underwater use
LEISTRITZ, Nürnberg	Pump systems for underwater use
Lloyd Werft, Bremerhaven	Modification of the drilling vessel
MacArtney MBT, Kiel	Qualification of the underwater systems
MHWirth, Erkelenz	Manufacture of the conveyor pipe
Neptun Ship Design, Rostock	Supervision of construction and modification
NSW Norddeutsche Seekabel Werke, Kiel	Umbillicals
Sandvik, Düsseldorf	Systems for deep sea mining (mining equipment)
Technolog, Hamburg	Supervision of construction and modification
ThyssenKrupp Marine Systems, Kiel	System integration and crawler manufacture
Vallourec, Düsseldorf	Manufacture of risers
Yokogawa, Düsseldorf	Integrated vessel control system

The business models can be described as follows:

- Monitoring before, during and after the deep sea activities as such
- Planning and project management of the pilot mining tests as well as of the future real deep sea mining activities
- Logistics services for the pilot mining test and the future real mining activities
- Development of machines and equipment needed for deep sea mining
- Manufacture and supply of machines and equipment needed for deep sea mining

The last two categories often include the same companies because development and design of machine and equipment components are usually carried out together with manufacturing by the same companies.

A look at these categories and companies shows that German companies are primarily service and mechanical engineering companies. What can be seen is a wide range of different characteristics, so that an integrated approach is not easy, for instance, by integrating the deep sea mining process from mining on the seabed right through to shipments to smelters. This diversity of sub-disciplines is probably also the reason why no German company has so far issued a letter of intent for developing a licence, for instance, in the role as project developer.

Another remarkable aspect is the fact that the list of companies designing and manufacturing machines and equipment does not contain any companies that manufacture ore smelting/metallurgical equipment. This is surprising because Germany, with its traditionally strong position in mechanical engineering, has quite a number of companies that manufacture equipment for these operations. This corresponds to the knowledge gaps in the field of smelting processes for polymetallic nodules described earlier in this study. The companies concerned obviously do not yet sufficiently see deep sea mining as an opportunity.

This similarly also applies to raw material companies which are not represented at all in the above table. In this case too, it seems that German raw material companies have not yet understood the opportunities that deep sea mining has to offer.

<u>A model for implementing the pilot mining test</u>

As already described in section 5 and elsewhere in this study, the major obstacle on the road to a mining licence is the pilot mining test which is necessary at the end of the exploration phase in order to verify the functioning of the technologies planned for industrial mining operations and to determine the environmental impact of exploitation operations.

Compared to the funds so far invested, investment in a pilot mining test totalling around €150m to €200m is considerable (see also Fig. 5-13).

In order to distribute the tests to as many parties as possible, an organisation structure was developed under the European 'Blue Mining' project whereby a pilot mining test was carried out with funds from the European Union as a kind of temporary common task of the licensees and contractors involved.

Fig. 6-1 illustrates this structure. The underlying idea is that all interested contractors with a shared interest join forces in order to conduct a pilot mining test on their way to the mining licence.

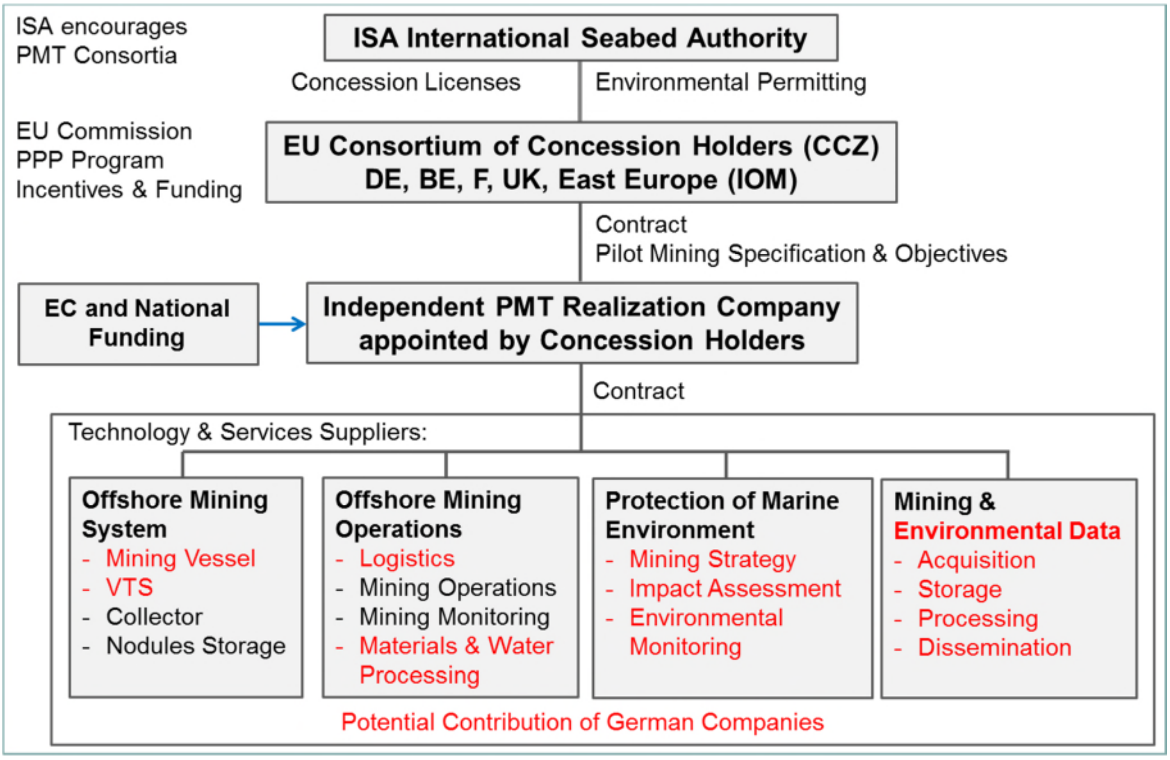


Fig. 6-1: Structure of a European joint initiative for performing a pilot mining test

These companies establish a joint venture in the form of a so-called pilot mining test realisation company to which the licensees contribute proportionate funds for the performance of the test. This joint venture also applies for funds from the European Union and, if applicable, also from national states.

This company then conducts the pilot mining test as described in section 5 and commissions companies to perform the different activities, so that these companies generate the desired additional know-how. This could also be an opportunity for German companies (see the work categories shown in red in the lower part of the illustration in Fig. 6-1).

6.3 Options for the further development of the German licence in the Clarion-Clipperton Zone

Compared to other licensees, Germany has already made quite considerable progress with the exploration of the licence for manganese nodules. The next step will be the pilot mining test as a precondition for a mining licence. As explained in section 5, around four to five years will be needed to perform and evaluate the pilot mining test.

The analysis in section 3 shows that, given the current level of raw material prices, it is very unlikely that any private company will invest in mining. Even if a company were to make this decision today, it would take around ten years until first raw materials are mined because, put simply, around five years would be needed for the pilot mining test and another five years for the final development, manufacture and testing of the complete equipment and machinery. This is a very long period of time.

Any forecasts of raw material prices in ten years from now will be very vague, as shown in the historical analyses of raw material markets in section 3. Raw material price levels will ultimately be strongly dependent on demand which, for its part, is subject to major fluctuations depending on the economic development of the different regions of the world as well as technological progress.
Historical changes took place on time scales that are shorter than 10 years. Such a long mining preparation time can therefore be characterised as a major obstacle to commencing deep sea mining.

In order to offer the German licence in the Clarion-Clipperton Zone to really interested mining companies, a pilot mining test makes sense because it reduces the time between the investment decision and the commencement of mining operations to the investment lead time which we estimate to be around four to five years.

If funds are now invested in pilot mining tests, there is, of course, a risk that raw material markets will not yet have reached a sufficient level to commence exploitation operations after the pilot mining test. This uncertainty regarding the future development of raw material markets is a natural component of this industry and explains the different business models of the companies that are active on this market.

However, our analyses of the historical developments of raw material markets and of the forecasts regarding future developments in section 3 suggest that a sufficient increase in raw material prices is more likely than a continuation of the currently low level.

It therefore makes sense for German to conclude the exploration of its licence territory in the Clarion-Clipperton Zone by conducting a pilot mining test and investing the funds that are needed for this.

<u>Options to exploit the licences</u>

Bundesanstalt für Geowissenschaften und Rohstoffe [Federal Institute for Geosciences and Natural Resources] is currently the owner of the exploration licence. Up to now, exploration activities were financed by the German government which can assign the licence to third parties. From today's perspective, this assignment should take place at the end of the exploration phase at a time when companies have clearly expressed their interest in commencing exploitation operations.

The type of rights exploitation must be compatible with procurement law. This may require further analyses from a procurement law perspective. However, the German government will retain its function as sponsoring state.

6.4 Necessary contributions by German industry

According to the definition of categories of business models of German companies (section 6.1), it should first be noted that no German companies have so far stated any interest in acting as mining companies or project developers. Such a statement of interest would constitute a strong signal with regard to deep sea mining.

In other countries, however, there are companies (see, for example, the DEME group mention in section 6.2) that have issued such statements of intent, making it clear that they consider the economic prospects of deep sea mining to be more positive than German companies do.

For Germany, the next step towards the implementation of deep sea mining is to finance and perform the pilot mining test. German service and mechanical engineering companies have a keen interest in this pilot mining test because, by developing the related technologies, they could consolidate their opportunities as suppliers for project developers and mining companies even outside Germany. This possibility should generate willingness to finance at least part of the pilot mining test from the companies' own means.

6.5 Options for actions of the German government

In view of the structure of the German companies (see section 6.2) that have so far expressed an interest in deep sea mining, and in view of the costs of a pilot mining test, it is unlikely that the pilot mining test can be conducted without significant government funding. This is in the first place a major option for government action. However, several other fields of action exist parallel to this.

Given a sufficient high raw material price level and a functioning market, deep sea mining could also get underway without further government funding. Otherwise, this would be due to partial market failure. In the case of deep sea mining, this can be due, for instance, to negative external effects:

- Insufficiently researched environmental impacts of deep sea mining
- Insufficiently defined legal framework conditions for exploitation operations (lacking mining rules and regulations)
- Insufficient availability of technologies

Market failure can also be a consequence of scale effects.
This means that the volumes of deep sea mining projects are too small so that only a few companies or syndicates world-wide have the necessary means for these activities. The German companies – irrespective of the fact that their business field focuses primarily on services and mechanical engineering – that are currently interested in deep sea mining are too small and therefore restricted by the above-mentioned scale effects.

However, the government has always an option to reduce the negative external effects.

Research and development

Research and development can help to close knowledge gaps. Over the past decades, relatively comprehensive research and development work has been carried out for the collector and the conveying pipe. On the other hand, however, knowledge in the field of smelting/metallurgy of polymetallic nodules on an industrial scale is still limited. Research and development are especially needed in order to expand the range of extractable metals. This is the special challenge with polymetallic nodules. Conventional smelting processes exist for ores that typically contain a limited range of metal compounds. However, the structure of polymetallic nodules is very complex due to their genesis so that special processes for their industrial-scale extraction have yet to be developed.

For instance, no process is yet available for extracting rare earths the presence of which in polymetallic nodules is often mentioned as a major advantage of deep sea mining. The analysis of operating costs in section 3 also showed that known smelting processes require considerable amounts of energy which therefore becomes the dominant cost factor of deep sea mining. Technological improvement at this point would directly influence the economic efficiency of deep sea mining which would then also be possible at lower raw material prices.

In the case of massive sulphides, considerable uncertainty still exists with regard to the deposits themselves. The third dimension is lacking here in exploration efforts so that it is not yet possible to determine the thickness of deposits. Exploration drilling technologies for deep sea projects are currently being tested, for instance, as part of the 'Blue Mining' project.

The pilot mining test is the best way to close knowledge gaps with regard to environmental impacts.
In this context, it may also become necessary to drive further developments in the field of environmental monitoring technologies.

Legal framework

Thanks to Germany's comprehensive and perfectly documented exploration activities in the licence territory of the Clarion-Clipperton Zone and its active participation in the work of the International Seabed Authority, Germany has gained an internationally recognised position. Germany should use its possibilities to take part in the design of the framework conditions for the pilot mining test and the exploitation code (mining) at the International Seabed Authority.

Context of the European Union

In order to distribute the burden to many stakeholders, Germany could also consider driving the pilot mining test as a European cooperation project (see section 6.2).

If, after a pilot mining test, no German companies are interested in engaging as investors or project developers in industrial deep sea mining, one could also consider offering European companies the use of the German licences.

7 Summary and recommendations

This study examines the economic benefits of commercial deep sea mining for Germany. Our profitability analysis shows that deep sea mining is not commercially viable at current price levels on raw material markets.

At the same time, historical developments on raw material markets show that influence factors, such as political change and economic developments in the regions of the world strongly influence price developments. Although reliable forecasts of such influence factors are not possible, many indicators – including, for instance, the growing world population and the economic catching-up process of newly developed and developing countries – suggest growing demand for raw materials and an increase in raw material prices, so that deep sea mining would be profitable in the future.

The policy and strategy of individual companies is characteristic for these cautiously positive expectations for the future economic prospects of deep sea mining in that these companies drive investments in pilot mining tests in order to be prepared to enter field of industrial exploitation.

German companies that have voiced interest in the business field of deep sea mining belong exclusively to the service and mechanical engineering sectors. Government support for research and development activities is particularly interesting for these companies as a way to develop their technology portfolio further and to thereby improve their opportunities on the market. However, these market opportunities can only be exploited if other companies (currently no German) invest in pilot mining tests and in commencing industrial exploitation operations.

Our analysis of the value chains shows that, even with a scenario of international partnership of investors, the German economy could reap substantial benefits in the form of greater added value and employment.

The German government has reached a development level far above that of other licensees thanks to its funding of exploration activities. In view of the long time of around five years needed to prepare and implement the pilot mining test, this should be carried out with co-funding by German companies even though it is not possible to predict with certainty that the pilot mining test will be immediately followed by the commencement of the exploitation phase because raw material prices have reached a sufficient level.

In any case, the German government should close knowledge gaps through technology development, These gaps exist, in particular, with regard to the smelting of polymetallic nodules. The currently known processes permit only part of the raw materials contained in the nodules to be recovered. It is, for example, not yet possible to extract the rare earths from the nodules, even though rare earths are often quoted as an important argument for deep sea mining. Furthermore, the known smelting processes are extremely energy-intensive so that energy costs, besides the development of raw material prices, are becoming a decisive factor in deep sea mining.

Whilst the exploration of deposits of polymetallic nodules has already reached a very advanced level, there is still high demand for exploring massive sulphide deposits which should also be promoted.

At European level, there are many research activities taking place parallel with funds from the European Union. It should hence be examined whether synergies exist with European activities.

The licences held by Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) [Federal Institute for Geosciences and Natural Resources] can be exploited by assigning them to interested companies after the pilot mining test has been completed and when prices on the raw material markets have reached a sufficient level. The framework conditions set by European awarding law must be taken into consideration if such an assignment is to take place.

Hamburg, 6. March 2017

Expert group Ramboll IMS & HWWI

Annexes

Annex 1	**Econometric forecasting model for price projections**
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Annex 1: Econometric forecasting model for price projections

Annex 1.1: Model variables

Description	Explanation	Unit	Source
Macroeconomic variables			
Global GDP	Global gross domestic product of the respective year	US dollar	World Bank
Interest	US 3-month treasury bill rate	Percent per annum	Federal Reserve
Y	Calendar year	-	-
Raw-material related variables			
Copper			
Produktion_Kupfer	Annual global copper production	Megatonnes	BGR
Produktion_Kupfer_kum	Cumulative global refinery production of copper over time	Megatonnes	BGR
Verbrauch_Kupfer	Annual global copper consumption	Megatonnes	BGR
ΔLager_Kupfer	Annual change in US copper stock	Megatonnes	USGS
P_Kupfer	Real (inflation-adjusted) copper price	US dollar per tonne	BGR; LME
P_Alu	Real (inflation-adjusted) aluminium price	US dollar per tonne	BGR; LME
Nickel			
Produktion_Nickel	Annual global refinery production of nickel	Megatonnes	BGR
Produktion_Nickel_kum	Cumulative global refinery production of nickel over time	Megatonnes	BGR
Verbrauch_Nickel	Annual global nickel consumption	Megatonnes	BGR
ΔLager_Nickel	Annual change in US nickel stock	Megatonnes	USGS
P_Nickel	Real (inflation-adjusted) nickel price	US dollar per tonne	BGR; LME
P_Stahl	Real (inflation-adjusted) stainless steel price	US dollar per tonne	BGR; LME

Appendix 1.2: Model equations

Markt für Nickel

$$\mathbf{Produktion_{Nickel;t}} = \beta_0 + \beta_1 P_{Nickel;t-1} + \beta_2 \mathbf{Verbrauch_{Nickel;t}} + \beta_3 Y_t + \beta_4 \mathbf{Zins_t} + \beta_5 \mathbf{Zins_{t-1}} + \beta_6 \mathbf{Produktion_{Nickel;t-1}} + \epsilon_t$$

$$\mathbf{Verbrauch_{Nickel;t}} = \beta_0 + \beta_1 P_{Nickel;t-1} + \beta_2 \Delta \mathbf{Lager_{Nickel;t-1}} + \beta_3 \mathbf{BIP_{Welt;t}} + \beta_4 \mathbf{BIP_{Welt;t-1}} + \epsilon_t$$

$$P_{Nickel;t} = \beta_0 + \beta_1 P_{Nickel;t-1} + \beta_2 Y_t + \beta_3 \Delta \mathbf{Lager_{Nickel;t-1}} + \beta_4 \mathbf{BIP_{Welt;t}} + \beta_5 P_{Stahl;t-1} + \epsilon_t$$

Markt für Kupfer

$$\mathbf{Produktion_{Kupfer;t}} = \beta_0 + \beta_1 \mathbf{Verbrauch_{Kupfert;t}} + \beta_2 Y_t + \beta_3 \mathbf{Zins_t} + \beta_4 \mathbf{Zins_{t-1}} + \beta_5 \mathbf{Produktion_{Kupfer;\,;t-1}} + \epsilon_t$$

$$\mathbf{Verbrauch_{Kupfer;t}} = \beta_0 + \beta_1 \Delta \mathbf{Lager_{Kupfer;t-1}} + \beta_2 \mathbf{BIP_{Welt;t}} + \beta_3 \mathbf{BIP_{Welt;t-1}} + \epsilon_t$$

$$P_{Kupfer;t} = \beta_0 + \beta_1 P_{Kupfer;t-1} + \beta_2 Y_t + \beta_3 \Delta \mathbf{Lager_{Kupfer;t-1}} + \beta_4 \mathbf{BIP_{Welt;t}} + \beta_5 P_{Alu;t-1} + \beta_6 \mathbf{Produktion_{Kupfer\_kum;t}} + \epsilon_t$$

Appendix 1.3: Estimation results

Copper		**Nickel**	
Coefficient	**Estimated value**	**Coefficient**	**Estimated value**
	Production		
β_0	-21,255.83	β_0	6,846.19
β_1	0.2549	β_1	-0.1136
β_2	11.0204	β_2	0.6692
β_3	54.0627	β_3	-3.4999
β_4	-86.6951	β_4	3.2565
β_5	0.7306	β_5	-7.4339
		β_6	0.5479
	Consumption		
β_0	-260,107.30	β_0	-21,481.14
β_1	-0.4887	β_1	0.4351
β_2	34,555.52	β_2	0.1719
β_3	-25,799.98	β_3	3,948.24
		β_4	-3,230.93
	Price		
β_0	2,122.14	β_0	4,140.843
β_1	0.4619	β_1	0.1556
β_2	-1.8257	β_2	-3.7361
β_3	-0.0046	β_3	-0.1311
β_4	47.5841	β_4	105.5534
β_5	1.2159	β_5	18.85
β_6	0.0001	β_6	0.0016

Appendix 2: Raw material synopses

Appendix 2.1: Cobalt

In brief:

Is cobalt important for the German economy?	Yes. Although absolute volumes are small, cobalt is important for many key (German) industries.
Is cobalt rare world-wide?	No. Statistics suggest that the proven reserves will last for more than 50 years.
Is cobalt a critical resource with threatened supply security for Germany?	Yes. Due to political uncertainty in the major production countries, the supply situation is very risk-prone.
Global production concentration: *[0 (evenly distributed) to 1 (concentrated in a single country)]*	0.368 ≙ high country concentration (see section 2.2.2)
Weighted governance indicators of the production countries [-2.5 (very poor) to +2.5 (very good)] *(Germany as a reference country: +0.93; +1.85; +1.69)*	Political stability: -1.29 (poor) Rule of law: -0.73 (poor) Regulatory quality -0.68 (poor)

Cobalt is a hard, shiny grey, brittle metal. It is known best for its blue colour in glass products and colouring materials. Cobalt's economic importance is chiefly due to its properties as a steel stabiliser and alloying metal. Cobalt increases, for instance, the strength, corrosion resistance and magnetic properties of alloys at high temperatures, so that cobalt is an important metallurgical element for high-strength special steels.

Element group 27, atomic number 27, group of transition metals, bluish-greyish colour, solid, ferromagnetic.

Use and economic relevance:

Cobalt is used and consumed in many different industries and economic areas. Cobalt is mostly used in alloys and rarely in its pure metal form. The two most important uses of cobalt are steel stabilisers as well as rechargeable batteries. It is also used as a pigment and dye, as a chemical catalyst and for magnetic applications. As an alloying metal, cobalt helps to significantly increase the strength, corrosion resistance and hence the life of steel. Many alloys in applications with extreme material requirements at often high temperatures therefore contain cobalt. Examples include aircraft engines, gas turbines or equipment for space applications. Cobalt is also used as a cathode material in the three most common types of rechargeable batteries (nickel cadmium, nickel metal hydride, lithium ion) and is therefore relevant for a wide range of technological products, such as smartphones, laptops and electric vehicles. Thanks to its corrosion resistance and magnetism, which cobalt retains even at very high temperatures, it is also an important component of magnets, for instance, for electronic devices, computers and electric motors. In view of its many different uses and its importance for many industries, cobalt is considered to be a strategically important metal. (Bertau 2013)

Table 1: Most important uses of cobalt

Use	Share in total consumption
Alloys	28%
Batteries	25%
Hard materials	12%
Pigments/paints	10%
Catalyst	9%
Magnets	6%
Other	10%

Industries:
Metal industry, aerospace, mechanical and electrical engineering, renewable energies, ceramic industry, chemical industry.

Products:
Batteries, superalloys, chemicals, permanent magnets, aircraft turbines, tools.

Source: Bertau (2013)

Substitutes:

Substitutes exist for certain uses, however, with inferior product properties. Potential substitutes are barium or strontium ferrites, neodymium iron boron or nickel alloys in magnets; cerium, iron, lead, manganese or vanadium in paints. Cobalt iron copper or iron copper in diamond tools, iron phosphorus, manganese, nickel cobalt aluminium or nickel cobalt manganese in lithium ion batteries; nickel alloys or ceramics in aircraft engines; nickel as a catalyst in oil refineries (USGS 2016).

Occurrence and production

Although cobalt as such is not a rare element in the earth's mantle, it is seldom found in concentrated form. The global terrestrial cobalt resources[99] are estimated at 27 million tonnes. The corresponding cobalt reserves[100] are estimated at around 7.1 million tonnes. Given the current production volume of around 124,000 tonnes, this means a static lifetime[101] of terrestrial reserves of 57 years.

Recoverable reserves contain cobalt usually in a number of compounds together with other elements. It occurs in sulphide, arsenic, oxide and laterite ore forms and is therefore usually extracted as a by-element. Cobalt is extracted particularly often as a by-product or co-product of nickel (~50%) and copper (~35%), for example, together with nickel in nickel sulphide mines in Canada and Russia, in the production of nickel laterites in Australia and especially in the production of copper in the DR Congo. The cobalt mining and extraction processes are largely similar to those of nickel and copper mining due to the simultaneous occurrence of these minerals. The number of manufacturer and primary-mineral specific processes is hence very large. These processes additionally vary depending on the desired end product (pure metal, different cobalt compounds). (Bertau 2013, Gocht 1985, USGS 2016)

Table 2: Most important cobalt producing countries (2015 e)

Country	Production (tonnes)

[99] Resources: All reserves geologically proven, however, not necessarily commercially recoverable.
[100] Reserves: Reserves which are proven with a high level of geological certainty and which can be technically and commercially recovered – 'recoverable'. Reserves are therefore a dynamic parameter that can change depending on technical progress and price.
[101] Lifetime: Ratio of currently proven reserves and current production. "How long could the raw material be produced *ceteris paribus* before reserves are exhausted."

DR Congo	63.000
China	7.200
Russia	6.300
Canada	6.300
Australia	6.000
World	124.000

Source: USGS (2016)

Table 3: Largest terrestrial cobalt reserves[102] (2016):

Country	Reserves (1,000 tonnes)
DR Congo	3.400
Australia	1.100
Cuba	500
Zambia	270
Russia	250
World	7.100

Market and supply structure:

Uncertainty on the global cobalt market is relatively high. Market demand with a wide range of applications, including new technologies, can be considered to be relatively stable, but the demand side especially is still subject to a quite considerable risk of market disruptions. Although the cobalt market is relatively small in terms of volume, global production is geographically highly concentrated. The Democratic Republic (DR) of the Congo accounts for more than 50% of global production and therefore dominates the market. The DR Congo is a country that ranks in the lower fifth of the World Bank's rankings for political stability, rule of law and regulation efficiency. In extreme cases, this could mean government intervention in the form of protectionism (taxes, customs, export bans) and therefore endanger supply security. Furthermore, since cobalt is extracted as a by-product or co-product, there is a strong dependence on nickel and copper markets where the market situation could indirectly influence the cobalt market. The European Commission and DERA therefore classify cobalt as a critical raw material. (BGR 2015, USGS 2011, EUCOM 2014).

Cobalt in Germany:

The data situation regarding the cobalt market in Germany is incomplete and fragmented. However, Germany as a country without any relevant cobalt reserves is fully dependent on imports of cobalt and its precursors as well as recycling in order to cover the country's demand. According to the British GeoInformation Group, Germany's absolute import volumes in 2014 totalled around 4,697 tonnes of pure cobalt, 65 tonnes of cobalt

[102] Reserves: Reserves which are proven with a high level of geological certainty and which can be technically and commercially recovered – 'recoverable'. Reserves are therefore a dynamic parameter that can change depending on technical progress and price.

ore and 1,275 tonnes of cobalt oxides. This corresponds to around 7.3% of Europe's total imports of cobalt. (BGS 2016)

Annex 2: Raw material synopses

Annex 2.2: Copper

In brief:

Is copper important for the German economy?	Yes. Copper is irreplaceable for the German economy.
Is copper rare world-wide?	No. Statistics suggest that the proven reserves will last for another around 39 years.
Is copper a critical resource with threatened supply security for Germany?	No. The supply situation can be generally considered to be non-critical to moderately critical.
Global production concentration: *[0 (evenly distributed) to 1 (concentrated in a single country)]*	0.20 ≙ medium country concentration (see section 2.2.2)
Weighted governance indicators of the production countries [-2.5 (very poor) to +2.5 (very good)] *(Germany as a reference country: +0.93; +1.85; +1.69)*	Political stability: +0.06 (medium) Rule of law: +0.51 (quite good) Regulatory quality: +0.63 (quite good)

Copper is a reddish shiny metal that is used in almost all areas of the economy and everyday life, and it belongs to the economically most important metals world-wide. Modern society is hardly conceivable without secure and comprehensive copper supply.

Element symbol Cu; atomic number 29; reddish shiny; solid; non-magnetic; melting point at 1,083°C; tough but nevertheless easy to process; very corrosion-resistant; second-best electrical and thermal conductivity of all metals; anti-bacterial properties; seldom naturally occurring in its pure form.

Use and economic relevance:

Copper is the third most frequently used metal world-wide after iron and aluminium. Copper has many valuable properties that make it suitable for use in almost all industries. This technical versatility is especially due to its high ductility (formability) and its very high electrical conductivity so that copper has a dominant position as a conductor material in electrical engineering. The manufacture of computers, mobile phones, electricity grids, electronic circuit boards, transformers, generators, cables and countless everyday products would be inconceivable without this metal. Further important attributes are its good thermal conductivity – and hence its suitability as a material for heat exchangers – as well as its corrosion resistance so that copper is used for tanks and boilers, pipes, etc. Copper's omnipresence in industry and business means that the copper price responds to economic signals in a very sensitive manner, so that the copper price often reflects the state of the economy as well as expectations regarding future economic cycles. In addition to its use in its pure form, copper is an important part of many alloys, such as bronze, brass or copper nickel. The varied applications of these alloys, from musical instruments right through to special steels and superalloys, increase the importance of copper even further (Bertau 2013, ICSG 2015).

Table 4: Most important uses of copper

Use	Share in total consumption
Construction sector	36%
Electronics	37%
Machines	9%
Transport sector	8%
Other	7%

Source: (Bertau 2013)

Industries:
Construction sector,
power generation and transmission,
electrical and mechanical engineering, industrial plants, car industry, transport sector, consumer goods industry.

Products:
Batteries, superalloys, chemicals, permanent magnets, aircraft turbines, tools.

Substitutes:

Aluminium in power cables and electronic components; titanium and steel for heat exchangers, optical fibres in telecommunications; plastic materials as substitutes for tubes and pipes (USGS 2016).

Occurrence and production

The identified terrestrial copper resources[103] are estimated at 2.1 billion tonnes in terms of copper content (USGS 2014). The current terrestrial reserves[104] are estimated at 720 million tonnes of copper. Copper production in 2015 totalled around 18.7 million tonnes. In static terms, the range[105] totals around 39 years.
Deep sea deposits are not included in the resources. In the German licence territory[106] alone, copper resources from manganese nodules total 8.25 to 16.5 million tonnes. (USGS 2016, USGS 2014)

Table 5: Most important copper producing countries (2015 e)

Country	Production (1,000 tonnes)
Chile	5.700
China	1.750
Peru	1.600
US	1.250
DR Congo	990
World	18.700

Source: USGS (2016)

103 Resources: All reserves geologically proven, however, not necessarily commercially recoverable.
104 Reserves: Reserves which are proven with a high level of geological certainty and which can be technically and commercially recovered – 'recoverable'. Reserves are therefore a dynamic parameter that can change depending on technical progress and price.
105 Lifetime: Ratio of currently proven reserves and current production. "How long could the raw material be produced *ceteris paribus* before reserves are exhausted."
106 75,000 km^2 in the Clarion-Clipperton Zone; calculations with an average manganese nodule population density of 10 to 20 kg/m²; copper content of 1.17%.

Table 6: Largest terrestrial copper reserves (2016):

Country	Reserves (1,000 tonnes)
Chile	210.000
Australia	88.000
Peru	82.000
Mexico	46.000
US	33.000
World	720.000

Source: USGS (2016)

Copper is extracted either from underground (approx. 25%) or open-cast (around 75%) mines. Copper production has a long history and its processing and refining technology has undergone substantial further development. As a consequence, production costs have fallen and a continuously growing number of new reserves has been commercially recovered.

During the course of time, technical progress made the exploitation of large copper deposits near the surface and often with a low copper content competitive with underground mining. The mining of copper ores can in some cases be economically viable even at contents as low as 0.3%. Extractable copper ores occur in two mineral forms, i.e. as sulphide and oxide copper ores. Production from copper sulphide ores accounts for around 80% and hence for the predominant share of global copper production.

Details of the variants of today's copper production process differ depending on the type of mineral deposit, the mining region and the extraction company. Notwithstanding this, the production process of all variants is based primarily on three steps, i.e. extraction, concentration and further refining to higher levels of purity. The ore type (sulphide/oxide) is the most important difference when it comes to processing. After crushing and milling, sulphide ores are primarily treated by pyrometallic processes whilst hydrometallurgical treatment is the most common form for oxide ores. In the concentration process of the sulphide type, the milled ore first undergoes so-called flotation in order to separate the ore from the host rock and to achieve a copper content of 20% to 50%. During the further course of processing, the copper concentrate is smelted and unwanted elements, such as iron or sulphur, are removed. During this step, it is also possible to add copper scrap for recycling. The resultant raw copper has a purity of 90% to 97% which is still too low for certain applications, such as copper cables. The remaining components are therefore separated by electrolytic refining so that copper of a higher purity degree is obtained. In order to produce copper from oxide ores, the so-called SX-EW (*solvent extraction-electrowinning*) process is used where acid is first used to remove the copper from the ore, followed by electrowinning to obtain pure copper (Bertau 2013).

Market and supply structure

The earth's copper deposits are found on all continents and in many countries. High concentrations of deposits occur in regions on the west coast of the Pacific Ocean in South and North America and in some copper belts in East Europe and South Asia. The most important producing countries are Chile (market share of 31%), China (9%) and the US (7%) (see Table 11). Copper is one of the most-traded metals. According to the assessment of geopolitical risks and concentration of companies, the copper market can be considered to be non-critical to moderately critical (Dorner 2013).

Copper in Germany:

With a share of 5.1% in global consumption of refined copper, Germany ranks third after China and the US. However, Germany does not have any national copper mines and is therefore completely dependent on imports of copper and copper precursors. In 2014, around 400,000 tonnes of copper concentrate was imported as refinery feedstock, with Brazil, Chile, Argentina and Peru supplying almost 80% of this. In Germany, 57% of total copper volume is used in the cable and electrical engineering industry. Other consumers are the construction sector (15%), the car industry (9%) and mechanical engineering (8%). The import dependency risk for unrefined copper can be considered to be generally non-critical, for copper concentrates as moderately critical and for refined copper as harmless (Dorner 2013, BGR 2015).

Appendix 2: Raw material synopses

Appendix 2.3: Manganese

In brief:

Is manganese important for the German economy?	Yes. Manganese is an essential metal for the metal industry.
Is manganese rare world-wide?	No. Statistics suggest that the proven reserves will last for another around 35 years.
Is manganese a critical resource with threatened supply security for Germany?	No.
Global production concentration: *[0 (evenly distributed) to 1 (concentrated in a single country)]*	0.18 ≙ medium concentration (see section 2.2.2)
Weighted governance indicators of the production countries [-2.5 (very poor) to +2.5 (very good)] *(Germany as a reference country: +0.93; +1.85; +1.69)*	Political stability: -0.10 (medium) Rule of law: +0.16 (medium) Regulatory quality: +0.17 (medium)

Manganese is a silver-grey metal which is predominantly used in many applications as a steel stabiliser in the metal industry. Thanks to its important properties as an alloying component and due to its low degree of substitutability, manganese is economically important for industrialised nations.

Element symbol Mn; atomic number 25; silver-grey heavy metal; hard and very brittle; paramagnetic; low electricity and thermal conductivity; low corrosion resistance; twelfth most frequent element in the earth's crust; seldom naturally occurring in its pure form; the most frequent ore forms (20% to 48% Mn) are manganese(IV) oxides, manganese(II) carbonates and silicates.

Use and economic relevance:

Manganese is primarily an alloying metal. Around 90% of manganese production is used as an alloying component in the steel industry. Pure manganese is practically of no interest for applications and therefore seldom used in technical applications. With very few exceptions, manganese is only used as an alloying addition rather than as the main component of alloys. The key property of manganese is its metallurgical property as an iron and steel stabiliser. It increases the strength of steels without significantly impairing their tensile elongation behaviour. In certain concentrations, manganese also increases the tensile strength of steels. It also positively influences the forging and welding capability of iron alloys. However, manganese also adds advantageous properties to nonferrous alloys. Manganese nickel alloys feature higher tensile strength without impaired corrosion properties. Manganese increases, for instance, the high-temperature strength of copper.

Since manganese improves the material characteristics of many different alloys, the metal is relevant for a vast range of industries and products. Manganese is used in construction steel and is therefore relevant for all kinds of basic structures (buildings, industrial plants, bridges and roads). Due to its use in stainless steels, manganese is relevant for the entire field of mechanical engineering (manganese magnesium alloys for engine and transmission housings), the equipment industry (tools, machine tools, etc.) and the defence industry. The same applies to electrical engineering where iron manganese alloys are used for all kinds of applications (expansion controllers, relays, shielding). Manganese is also used in the chemical industry where nickel manganese alloys are used in equipment construction as well as copper manganese alloys for seawater pipes. Some countries maintain stocks of manganese as a strategic resource due to its importance. (Gocht 1985, Bertau 2013, USGS 2016)

Table 7: Most important uses of manganese

Use	Share in total consumption
Iron and steel	90%
Nonferrous alloys	3%
Other	7%

Source: Bertau (2013)

Industries:
Mechanical engineering, construction sector,
chemical industry, electrical engineering, defence industry.

Products:
Construction steel, stainless steel, tools, machines

Substitutes:

There are no satisfactory substitutes for manganese in its main uses.

Occurrence and production

Manganese is the twelfth most frequent element in the earth's crust. Its terrestrial resources[107] total around 2.1 billion tonnes. The existing global proven reserves[108] are estimated at around 620 million tonnes. This means a static lifetime[109] of around 32 years before the manganese reserves will be exhausted according to calculations (Gocht 1985, Bertau 2013, USGS 2016).

Table 8: Most important manganese production countries (2015 e)

Country	Production (1,000 tonnes)
South Africa	6.200
China	3.000
Australia	2.900
Gabon	1.800
Brazil	1.000
World	18.000

Source: USGS (2016)

[107] Resources: All reserves geologically proven, however, not necessarily commercially recoverable.
[108] Reserves: Reserves which are proven with a high level of geological certainty and which can be technically and commercially recovered – 'recoverable'. Reserves are therefore a dynamic parameter that can change depending on technical progress and price.
[109] Lifetime: Ratio of currently proven reserves and current production. "How long could the raw material be produced *ceteris paribus* before reserves are exhausted."

Table 9: Largest terrestrial manganese reserves (2016)

Country	Reserves (1,000 tonnes)
South Africa	200.000
Ukraine	140.000
Australia	91.000
India	52.000
Brazil	50.000
World	620.000

Source: USGS (2016)

Manganese ore occurs in more than 300 different mineral forms, most of them being oxides, carbonates and silicates. Manganese oxides are the most important ore minerals for manganese and ferromanganese production. Most manganese ore mining takes place in open-cast mines. The economic efficiency of further processing operations depends on the manganese percentage in the ore as well as the manganese mineral itself. In most processes, manganese ore is refined by processes such as crushing, screening and washing. Further processing steps depend on the desired final product, i.e. the question as to whether pure manganese metal or ferromanganese is to be produced. These further processes use both pyrometallic and hydrometallic refining methods. (Gocht 1985, Bertau 2013, USGS 2016)

Market and supply structure

The world market for manganese is divided into several sub-markets. Main trading forms are manganese ore, ferromanganese and manganese dioxide. Most of the manganese used in steelmaking is used in the form of ferromanganese. Just 3% of the manganese ore mined is processed to pure manganese metal. The market for ferromanganese is therefore dominant. (Bertau 2013)

Manganese in Germany:

In Germany, no manganese ore is mined. Only a few German companies refine steels, so that detailed data for Germany is difficult to obtain. Demand is covered by imports, mostly ferromanganese alloys, small percentages of pure manganese, manganese ore or oxides. In 2014, Germany imported around 21,000 tonnes of manganese and manganese precursors. Exporting countries are South Africa, Norway, Ukraine, France and India. Manganese accounts for around 3% of the net import values of all metals to Germany. (BGR 2015)

Appendix 2: Raw material synopses

Appendix 2.4: Nickel

In brief:

Is nickel important for the German economy?	Yes. Nickel is vitally important for the steel industry.
Is nickel rare world-wide?	No. Statistics suggest that the proven reserves will last for another around 32 years.
Is nickel a critical resource with threatened supply security for Germany?	No. Due to low country concentration and low political uncertainty, the supply situation is non-critical to moderately critical.
Global production concentration: *[0 (evenly distributed) to 1 (concentrated in a single country)]*	0.10 ≙ low country concentration (see section 2.2.2)
Weighted governance indicators of the production countries *[-2.5 (very poor) to +2.5 (very good)]* *(Germany as a reference country: +0.93; +1.85; +1.69)*	Political stability: -0.05 (medium) Rule of law: +0.20 (quite good) Regulatory quality: +0.33 (quite good)

Nickel is a silvery-white metal. Its main beneficial property is to increase the strength and resistance of stainless steel and other alloys at extreme temperatures and in corrosive environments.

Element symbol Ni; atomic number 28; silvery shining heavy metal; solid; ferromagnetic; in compact form at room temperature resistant to air, water, non-oxidising acids, such as hydrochloric acid, lyes and most organic substances; does not naturally occur in elemental form; most common deposits: nickel sulphide ores and laterite ores.

Use and economic relevance:

The most important features which make nickel valuable for the economy and industry are its hardness and corrosion resistance even at high temperatures, especially when used as an alloying metal. Just around 15% of nickel production is not used in alloys. Especially in its function as a steel stabiliser, nickel increases the hardness, toughness and ductility as well as the corrosion resistance of stainless steels with all kinds of material requirements. Applications range from common V2A steel right through to extremely special-purpose, customised steel grades for high-tech products. Steels containing nickel are found in many industrial everyday products, such as pots, tools, pipes, kitchen appliances and hospital equipment. Most steels for the car and chemical industries contain nickel due to improved corrosion resistance. Superalloys containing nickel are used in aircraft engines or other engines. Pure nickel is additionally used in electroplating processes to coat other metals in order to protect these against corrosion and due to its hardness as well as in catalytic processes. (Bertau 2013)

Table 10: Most important uses of nickel

Use	Share in total consumption
Stainless steel	65%
Nonferrous alloys	20%
Coatings	9%
Other (batteries, catalysts)	6%

Source: Bertau (2013)

Industries:
Metal processing, mechanical engineering, plant construction, medical devices, chemical industry, construction industry, electrical engineering, marine technology, aviation industry.

Products:
Stainless steel, batteries, superalloys, chemicals, tools.

Substitutes:

Ultrahigh-chromium stainless steels in the construction industry; titanium alloys instead of nickel alloys in chemical applications; lithium ion batteries instead of nickel metal hydride batteries for energy storage. (USGS 2016)

Occurrence and production

The terrestrial nickel resources[110] containing at least 1% nickel are estimated at more than 130 million tonnes. Current reserves[111] are estimated at 79 million tonnes of nickel (USGS 2016). This means a lifetime[112] of around 31 years. These can be broken down into nickel sulphide ores (~40%) and laterite ores (~60%). Deep sea deposits are not included in the resources. In the German licence territory[113] alone, nickel resources from manganese nodules total 9.75 to 19.5 million tonnes.

Table 11: Most important nickel production countries (2015 e)

Country	Production (tonnes)
Philippines	523.000
Russia	240.000
Canada	240.000
Australia	234.000
New Caledonia	190.000
World	2,530,000

Source: USGS (2016)

[110] Resources: All reserves geologically proven, however, not necessarily commercially recoverable.
[111] Reserves: Reserves which are proven with a high level of geological certainty and which can be technically and commercially recovered – 'recoverable'. Reserves are therefore a dynamic parameter that can change depending on technical progress and price.
[112] Lifetime: Ratio of currently proven reserves and current production. "How long could the raw material be produced *ceteris paribus* before reserves are exhausted."
[113] 75,000 km^2 in the Clarion-Clipperton Zone; calculations with an average manganese nodule population density of 10 to 20 kg/m²; nickel content of 1.3%.

Table 12: Largest terrestrial nickel reserves (2016)

Country	Reserves (1,000 tonnes)
Australia	19.000
Brazil	10.000
New Caledonia	8.400
Russia	7.900
Cuba	5.500
World	79.000

Source: USGS (2016)

Elemental nickel does not occur in nature and must be produced from ores. Production varies in terms of both the time of deposit (sulphide(/laterite) and manufacturer-specific process variants. Production from nickel sulphide ores and from laterite deposits is commercially relevant. The preferred form of production is from easy-to-process sulphide ores which are, however, becoming increasingly scarce. Nickel is therefore increasingly extracted from laterite ores.

Extraction from sulphide ores: Nickel ores are first mechanically processed and concentrated. The ore concentrates are then smelted in electric furnaces. The product is nickel matte which, for its part, undergoes pyrometallurgical or hydrometallurgical further treatment and electrolytic refining. Alternative: Carbonyl process (Mond process). Nickel oxide is reduced with a water gas mixture of carbon monoxide and hydrogen.

Extraction from laterite ores: After drying (water content of the ore of up to 45%), the ore directly undergoes pyrometallurgical or hydrometallurgical treatment. So-called ferronickel rather than pure nickel is often produced from laterite ores. Ferronickel is an iron nickel alloy containing 20% to 60% nickel. Since a particularly high degree of purity is normally not required in steelmaking, lower-grade ferronickel is often sufficient.

Market and supply structure:

The structure of the nickel market has changed substantially over the past decades. In the 1960s, Canadian manufacturer INCO (International Nickel Co. of Canada) was still the largest producer (at times with 75% of global production) with a market-dominating position before structural change set in at the end of the 1960s (Gocht 1985). The market structure changed from a monopoly to an oligopoly. This change was accompanied by increasing exhaustion of the Canadian reserves and declining nickel demand, facilitating the development and exploitation of laterite nickel deposits. Since 1979, nickel has been traded on the London Metal Exchange (LME). Since then, producer prices and 'free-market prices' have become increasingly less relevant and have been replaced by stock market prices as price indicators.

Nickel in Germany

Germany does not have any nickel deposits and is completely dependent on imports. Imports in 2014 totalled around 72,000 tonnes of nickel metal (primary nickel and alloys) and around 20,000 tonnes of ferronickel. Consumption of refined nickel in 2014 totalled around 68,100 tonnes, making Germany the fifth largest nickel consumer world-wide.

Appendix 2: Raw material synopses

Appendix 2.5: Rare earths

In brief:

Are rare earths important for the German economy?	Yes. Although absolute volumes are small, rare earths are very important for many (German) key industries.
Are rare earths rare world-wide?	No. Statistics suggest that the proven reserves will last for more than 1,000 years.
Are rare earths a critical resource with threatened supply security for Germany?	Yes. Due to high country concentration and political uncertainty in the producing countries, the supply situation must be considered to be very risk-prone.
Global production concentration: *[0 (evenly distributed) to 1 (concentrated in a single country)]*	0.81 ≙ extremely high concentration (see section 2.2.2)
Weighted governance indicators of the production countries [-2.5 (very poor) to +2.5 (very good)] *(Germany as a reference country: +0.93; +1.85; +1.69)*	Political stability: -0.37 (quite poor) Rule of law: -0.18 (quite poor) Regulatory quality: -0.13 (quite poor)

Rare earths, also called rare earth elements or rare earth oxides, is the collective term for a total of 17 metals of the periodic table. Due to the use of rare earth elements in high-tech and environmental technologies, their importance has increased strongly in recent decades. In view of their varied and at the same time highly specific applications and the absence or insufficient availability of substitutes, rare earth elements have become extremely important despite the small volumes in which they are used. Especially since the dramatic price increase at the end of the 2000s as a result of trade restrictions in China, this group of raw materials has been receiving strong public and political attention. Due to the dominant market position of the People's Republic of China and the continuously growing economic interest in high technology, rare earth elements are considered to be critical resources. (Bertau 2013, Haxel et al. 2002)

Rare earth elements are the elements of the 3rd subgroup of the periodic table (with the exception of actinium) as well as the elements of the lanthanide series. Rare earth elements are: scandium (Sc), yttrium (Y), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu).

Physical characteristics are metallic gloss, relatively low melting point and low hardness. Rare earth elements are relatively stable in atmospheric gases, but very susceptible to acid and caustic attack. Most elements show strong paramagnetism. Due to their special electron arrangement, rare earth elements feature similar chemical behaviour. Due, amongst other things, to their special spectroscopic properties, rare earth elements are attractive for many high-technology applications. (Gocht 1985, Marscheider-Weidemann et al. 2016)

Use and economic relevance:

The fields of application of rare earth elements are very diverse and varied. The use of the in total 17 different metals is marked by high specificity and a high unit value of the good produced. Thanks to a large number of metallurgical, chemical, catalytic, electrical, nuclear, magnetic and optical properties, the technological applications of rare earth elements have multiplied dramatically in recent decades. Uses range from everyday items (flints, glass polish) to high technology (lasers, magnets, batteries) right through to futurist applications (high-temperature superconductors).

Alloys containing Nd, Sm, Gd, Dy or Pr have a key role to play for permanent magnets which are especially used in the manufacture of miniaturised small electric parts in audio and video devices, in communications equipment, for electric motors and generators or for medical devices, such as magnetic resonance imaging devices. Many innovations in electrical engineering and in the information technology sector in recent years would not have been possible without rare earth elements. Rare earth elements are also vital for industries in the field of renewable energy because many essential magnet and battery applications (for instance, for wind turbines) depend on alloys containing rare earth elements. Furthermore, rare earth elements are used in the chemical industry as catalysts in oil refining as well as in motor vehicle catalysts, as diesel fuel additives and in water treatment processes. Rare earth elements are also vital in the optical industry. Almost all glass polishing processes – for both normal mirrors and precision contact lenses – require certain rare earth oxides in the manufacturing process. Rare earth elements are also indispensable in the production of illuminants, such as lasers, LEDs, fluorescent light or flat screens. (Haxel et al. 2002, Marsceider-Weidemann et al. 2016, Van Gosen et al. 2014, Goonan 2011)

Table 13: Most important uses of rare earth elements

Use	Share in total consumption
Permanent magnets	20%
Metallurgy	20%
Catalysts	19%
Polish	13%
Glassware	8%
Ceramic	7%
Other	13%

Industries:
Chemical industry, mechanical engineering,
oil processing industry,
optical industry, car industry, renewable-energy industries.

Products:
Small electric parts, communications equipment, information technology, magnets, batteries.

Source: (Bertau 2013)

Substitutes:

Not all rare earth elements can be substituted in the same manner and to the same extent in view of their diverse applications. Although certain substitutes are available in some applications, rare earth elements are strongly preferred in most applications where substitutes feature less or weaker properties. Moreover, no substitutes at all are known in many specific applications. (USGS 2016)

Occurrence and production
Total global reserves[114] are estimated at 130 million tonnes. In relation to current production, the lifetime[115] totals more than 1,000 years with a purely static approach.

[114] Reserves: Reserves proven with a high level of geological certainty and which can be technically and commercially recovered – 'recoverable'. Reserves are therefore a dynamic parameter that can change depending on technical progress and price.

The name 'rare earths' in the proper sense is misleading because they are not 'rare' in the meaning of the word. The term historically meant 'strange' rather than 'rare'. In reality, rare earth elements – with the exception of (unstable) promethium – are not rare, with cerium, for instance, accounting for a higher share in weight of the earth's crust than copper or lead. Although rare earth elements usually occur together in ores, there are only a few large, concentrated and recoverable deposits. Rare earth elements tend to be found in widespread areas and at a very low concentration. As a largely coherent group, rare earth elements often occur together in minerals. More than a hundred host minerals of rare earth elements are known. However, of these, only a few ore forms are recoverable, with the most common ore forms being bastnaesite, monazite and laporite. Just a handful of deposits account for the largest share of global supply. (USGS 2016, Klinger 2015, Bertau 2013, Long 2010)

Table 14: Most important REE production countries (2015 e)

Country	Production (tonnes)
China	105.000
Australia	10.000
US	4.100
Russia	2.500
Thailand	2.000
World	124.000

Source: USGS (2016)

Table 15: Largest terrestrial REE reserves (2016)

Country	Reserves (1,000 tonnes)
China	55.000
Brazil	22.000
Australia	3.200
India	3.100
US	1.800
World	130.000

Source: USGS (2016)

Deposits of rare earth elements vary considerably in terms of their geology, mineralogy and concentration. Many specific and often expensive production and processing processes are therefore necessary in order to extract rare earth elements in a commercially viable manner. The mined ore is milled, concentrated, separated, purified and refined to industrial purity grades. All kinds of chemical and physical processes are used for this purpose, such as flotation, gravitational separation, electrostatic processes, magnetic separation as well as acid and alkaline methods. A description of the diversity of the different forms in which rare earth elements are traded (pure elements, mixed forms, oxides, chlorides, etc.) and of the respective complex processing steps would go beyond

[115] Lifetime: Ratio of currently proven reserves and current production. "How long could the raw material be produced *ceteris paribus* before reserves are exhausted."

the level of detail of this overview. (Gocht 1985, Bertau 2013, USGS 2016, Dutta et al. 2016)

Market and supply structure:

Since the end of the 1990s, the People's Republic of China has accounted for more than 85% of global supply of rare earths. This world market share even rose to around 95% in recent years. In 2010, China announced plans to reduce its rare earth element exports and to limit supply through taxes, export quotas and licences. Fears of supply bottlenecks and, as a result, sharply rising prices triggered deep concerns especially among those nations that are dependent on high technology. At that time of supply fears, rare earth elements attracted greater public attention whilst they had been previously only known to geologists, chemists or material scientists. Since then, politics has increasingly focused on the existence of potential supply interruptions and questions as to how access to rare elements can be secured. At the same time, exploration activities have increased world-wide in order to identify recoverable deposits of rare earth elements. Rare earths have always ranked among the first positions in criticality rankings for raw materials. In 2015, China abandoned its export quota and export duties regime, replacing it with ad-valorem resource taxes. In 2015, China increased its rare earth element exports by 20%, so that prices are now far from the highs of recent years. (Macheri 2015, USGS 2016, Goonan 2011, Dutta et al. 2016)

Rare earths in Germany:

German industry is completely dependent on imports of rare earth elements. Although the data situation regarding rare earth elements has improved in recent years, data is usually only available in aggregated form for all rare earth elements together. However, production, consumption and trading data is sometimes incomplete, available at a country level only and often inhomogeneous. In 2014, Germany imported around 7,500 tonnes of rare earth compounds, corresponding to around 29% of total European imports. For Germany, supply security of rare earth elements is essential, especially due to the economic importance for the renewable energy industry, electric mobility, the optical industry and the many high-technology sectors in Germany (BGR 2014, Marscheider-Weidemann 2016, BGS 2016).

Expert group

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Tabelle 3-13

Table 3-13-1: Investment costs Assignment of economic activities

Item	Description	WZ 2008 Code	Economic activity
1	**Mining vessel**		
1.1	Hull	30.11	Building of ships and floating structures (100%)
1.2	Vessel-specific equipment	28 27 33.2	Manufacture of machinery and equipment n.e.c. (50%) Manufacture of electrical equipment (35%) Installation of industrial machinery and equipment (15%)
1.3	Mining-specific equipment	28.22 28.29 27 26.51 33.2 71.12.2	Manufacture of lifting and handling equipment (30%) Manufacture of other general-purpose machinery n.e.c. (25%) Manufacture of electrical equipment (20%) Manufacture of instruments and appliances for measuring, testing and navigation (10%) Installation of industrial machinery and equipment (10%) Engineering activities and related technical consultancy (5%)
1.4	Shipyard costs	30.11	Building of ships and floating structures (100%)
2	**Conveying line**		
2.1	Riser sections with flexible or rigid couplings, with/without buoyancy elements, with additional air supply systems for airlift systems	24.20 25.50 22.19 71.12.2	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel (70%) Forging, pressing, stamping and roll-forming of metal; powder metallurgy (15%) Manufacture of other rubber products (10%) Engineering activities and related technical consultancy (5%)
2.2	Pump or airlift system	28.13 27 33.2 71.12.2	Installation of industrial machinery and equipment (75%) Manufacture of electrical equipment (15%) Installation of industrial machinery and equipment (5%) Engineering activities and related technical consultancy (5%)
2.3	Buffer	28 27 33.2 71.12.2	Manufacture of machinery and equipment n.e.c. (60%) Manufacture of electrical equipment (20%) Installation of industrial machinery and equipment (10%) Engineering activities and related technical consultancy (10%)
2.4	Flexible hose system between buffer and collectors	22.19 24.20 71.12.2	Manufacture of other rubber products (80%) Manufacture of tubes, pipes, hollow profiles and related fittings, of steel (10%) Engineering activities and related technical consultancy (10%)
2.5	Power and data cables integrated into the riser sections and flexible hoses	27.3 27.9 26.51 26.20 33.2 71.12.2	Manufacture of wiring and wiring devices (60%) Manufacture of other electrical equipment (35%) Manufacture of instruments and appliances for measuring, testing and Manufacture of computers and peripheral equipment (10%) Installation of industrial machinery and equipment (5%) Engineering activities and related technical consultancy (5%)

Table 3-13-2: Investment costs Assignment of economic activities

Item	Description	WZ 2008 Code	Economic activity
3	**Collector**		
3.1	Chassis with drive and collector enclosure	28.15 25.11 27 33.2 71.12.2	Manufacture of bearings, gears, gearing and driving elements (40%) Manufacture of metal structures and parts of structures (25%) Installation of industrial machinery and equipment (10%) Engineering activities and related technical consultancy (5%)
3.2	Nodule collection system, crusher and pumps	25.11 28.13 28.29 27 33.2 71.12.2	Manufacture of metal structures and parts of structures (30%) Installation of industrial machinery and equipment (30%) Manufacture of other general-purpose machinery n.e.c.(10%) Manufacture of electrical equipment (15%) Installation of industrial machinery and equipment (10%) Engineering activities and related technical consultancy (5%)
3.3	Sensors and navigation, control and instrumentation systems	26.51 26.20 27 33.2 71.12.2	Manufacture of instruments and appliances for measuring, testing and Manufacture of computers and peripheral equipment (30%) Manufacture of electrical equipment (10%) Installation of industrial machinery and equipment (10%) Engineering activities and related technical consultancy (10%)
4	**Process water separation system**		
4.1	Riser sections with flexible/rigid couplings	24.20 25.50 22.19 71.12.2	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel Forging, pressing, stamping and roll-forming of metal; powder metallurgy (15%) Manufacture of other rubber products (10%) Engineering activities and related technical consultancy (5%)
4.2	Pump system	28.13 27 33.2 71.12.2	Manufacture of other pumps and compressors (75%) Manufacture of electrical equipment (15%) Installation of industrial machinery and equipment (5%) Engineering activities and related technical consultancy (5%)
4.3	Sensors, control and instrumentation systems	27.3 26.51 26.20 27.9 33.2 71.12.2	Manufacture of wiring and wiring devices (25%) Manufacture of instruments and appliances for measuring, testing and navigation (30%) Manufacture of computers and peripheral equipment (25%) Manufacture of other electrical equipment (35%) Installation of industrial machinery and equipment (5%) Engineering activities and related technical consultancy (5%)

Table 3-13-3: Investment costs Assignment of economic activities

Item	Description	WZ 2008 Code	Economic activity
5-A	**Bulk carrier (new)**		
5.1-A	New Supramax bulk carrier	30.11	Building of ships and floating structures (100%)
5.2-A	Equipment for offshore loading of bulk carrier (transshipment)	28.22 22.1 27 26.51 33.2 71.12.2	Manufacture of lifting and handling equipment (30%) Manufacture of rubber products (30%) Manufacture of electrical equipment (15%) Manufacture of instruments and appliances for measuring, testing and navigation (10%) Installation of industrial machinery and equipment (10%) Engineering activities and related technical consultancy (5%)
5-B	**Bulk carrier (used)**		
5.1-B	Acquisition of used Supramax bulk carrier	46.14.2	Agents involved in the sale of machinery, industrial equipment, ships and aircraft (100%)
5.2-B	Modification for offshore loading of bulk carrier (transshipment)	30.11 28.22 22.1 27 26.51 33.2 71.12.2	Building of ships and floating structures (12.5%) Manufacture of lifting and handling equipment (27.5%) Manufacture of rubber products (27.5%) Manufacture of electrical equipment (12.5%) Manufacture of instruments and appliances for measuring, testing and Installation of industrial machinery and equipment (7.5%) Engineering activities and related technical consultancy (5%)
6	**Harbour facilities**		
6.1	Transshipment and warehouse systems, buildings	28.22 25.11 27 F 33.2 71.12.2	Manufacture of lifting and handling equipment (55%) Manufacture of metal structures and parts of structures (15%) Manufacture of electrical equipment (10%) Construction industry (10%) Installation of industrial machinery and equipment (5%) Engineering activities and related technical consultancy (5%)
6.2	Open spaces and infrastructure	F 71.12.2	Construction industry (95%) Engineering activities and related technical consultancy (5%)
7	**Processing and smelting plants (HP-HT-AL)**		
7.1	Technical equipment and buildings	28.91 27 F 33.2 71.12.2	Manufacture of machinery for metallurgy (70%) Manufacture of electrical equipment (10%) Construction industry (10%) Installation of industrial machinery and equipment (5%) Engineering activities and related technical consultancy (5%)
7.2	Open spaces and infrastructure	F 71.12.2	Construction industry (95%) Engineering activities and related technical consultancy (5%)

Table 3-13-4: Investment costs Assignment of economic activities

Item	Description	WZ 2008 Code	Economic activity
8	**Research vessel for environmental**		
8.1	Construction of a new research vessel specifically designed for environmental monitoring in deep sea mining	30.11	Building of ships and floating structures (100%)
8.2	Modification for environmental monitoring	26.51 26.20 27 33.2 71.12.2	Manufacture of instruments and appliances for measuring, testing and navigation (40%) Manufacture of computers and peripheral equipment (25%) Manufacture of electrical equipment (15%) Machinery (10%) Installation of industrial machinery and equipment (5%) Engineering activities and related technical consultancy (5%)
9	**Disciplines on behalf of owner**		
9.1	Engineering, supervision	71.12.2 71.12.9	Engineering activities and related technical consultancy (75%) Other engineering firms (25%)
9.2	Certifications/class	71.12.9	Other engineering firms (100%)
9.3	Management	70.10	Activities of head offices (100%)

Abbildung 4-10:

<table>
<tr><td colspan="2">Ad valorem (value-based)</td><td></td></tr>
<tr><td>Based on the realised or market value of the raw material</td><td>Simple administration
Inefficient
Fluctuates with raw material prices</td><td></td></tr>
<tr><td colspan="2">Profit-based</td><td></td></tr>
<tr><td>Royalty rate based on a measure for net income or profit</td><td>Higher administrative costs
More efficient
Unstable revenues</td><td rowspan="3">Administrative requirements increase
Stability of revenue decreases
Efficiency increases
Requirements for transparency increase</td></tr>
<tr><td colspan="2">Hybrid forms</td></tr>
<tr><td>Combination of ad-valorem and profit/return basis</td><td>Depending on design, certain revenue potential
Otherwise as above</td></tr>
<tr><td colspan="2">Return-based</td><td></td></tr>
<tr><td>Based on the calculated economic return</td><td>Significantly higher administration costs
Theoretically efficient
Unstable revenues, increase possible</td><td></td></tr>
</table>

Beschriftungen der Abbildungen in der Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie,
Referat U C 4
Projekt-Nr. 59/15

Abb. 3-1	Fig. 3-1
Nickel	Nickel
Kobalt	Cobalt
Kupfer	Copper
Quellen:	Sources:
Abb. 3-2	Fig. 3-2
Preis Kobalt	Cobalt price
1979: 2. Ölkrise	1979: 2nd oil crisis
1994: Lieferverzögerungen afrikanischer Produzenten	1994: Delays in deliveries of African producers
2002: Angebotsverknappung	2002: Supply shortage
2007: Boom China + Spekulation	2007: Boom in China + speculation
2008: Allgemeine Rezession	2008: General recession
Quellen:	Sources:
Preis Nickel	Nickel price
1987: Boom Edelstahl + Exportabgabe Dom. Republik	1987: Stainless steel boom+ export duty, Dom. Republic
2000, 2003: Streiks bei INCO	2000, 2003: Strikes at INCO
2007: Boom China + Spekulation	2007: Boom in China + speculation
2008: Allgemeine Rezession	2008: General recession
Quellen:	Sources:
Preis Kupfer	Copper price
1973: 1. Ölkrise	1973: 1st oil crisis
1988: Streiks in Peru und Kanada	1988: Strikes in Peru and Canada
2007: Boom China + Spekulation	2007: Boom in China + speculation
2008: Allgemeine Rezession	2008: General recession
Abb. 3-3	Fig. 3-3
Periode t-1	Period t-1
Gewünschte Bestandsveränderung	Desired change in inventory
Zinssatz	Interest rate
Stückkosten	Unit costs
Produktionsniveau Industrie	Industrial production level
Preise Substitute/ Komplemente	Prices of substitutes/complements
Angebot	Offer
Preis	Price
Bestand	Inventory
Nachfrage	Demand
Periode t	Period t
Regression 1	Regression 1
Regression 2	Regression 2
Regression 3	Regression 3
Regression 4	Regression 4
Identität	Identity
Abb. 3-4	Fig. 3-4
Projektionen: Nominaler Nickelpreis	Projections: Nominal nickel price
Projektionen: Nominaler Kupferpreis	Projections: Nominal copper price
2 % Wachstum BIP	2% GDP growth
3 % Wachstum BIP	3% GDP growth
4 % Wachstum BIP	4% GDP growth

Abb. 3-5	Fig. 3-5
Bulk-Carrier	Bulk carriers
Basisschiff	Mining vessel
Hawser	Hawser
Handhabungssysteme	Handling systems
Kran	Crane
Aussetzen/ Einholen Kollektor	Lower/raise collector
Rack für Risersektionen	Rack for riser sections
Stillwasserlinie	Still-water line
Schwimmendes Schlauchsystem (Transsshipment)	Floating hose system (transshipment)
Laderaum, Systeme für Entwässerung	Hold, dewatering systems
Moonpool	Moonpool
Wassertiefe 500 m	Water depth: 500m
Förderstrang	Conveying line
Risersektionen	Riser sections
Pumpensystem bzw. Airlift-System	Pump or airlift system
Flexibles Schlauchsystem	Flexible hose system
Kollektor	Collector
Meeresboden	Seabed
Buffer	Buffer
Rückführung Prozesswasser	Process water return
Tabelle 3-6-1	Table 3-6-1
Schätzung der Investitionskosten [Mio. USD]	Investment cost estimate [million USD]
Pos.	Item
Beschreibung	Description
Anzahl	Quantity
Beschaffung bevorzugt in Deutschland	Primary German supply
Beschaffung bevorzugt in Europa	Primary European supply
Beschaffung international	International supply
Einsatz	In use
Reserve	Standby
unterer Ansatz	Lower approach
oberer Ansatz	Upper approach
Basisschiff (Förderplattform)	Mining vessel
Schiffskörper	Hull
Schiffsspezifische Ausrüstung	Vessel-specific equipment
Abbauspezifische Ausrüstung	Mining-specific equipment
Werftkosten	Shipyard costs
Förderstrang	Conveying line
Risersektionen mit flexiblen oder starren Kopplungen, mit/ ohne Auftriebselemente, bei Airlift-System zusätzlich Leitungen zur Luftversorgung	Riser sections with flexible or rigid couplings, with/without buoyancy elements, additional air supply pipes for airlift systems
Pumpensystem bzw. Airlift-System	Pump or airlift system
Buffer (Zwischenspeicher)	Buffer
Flexibles Schlauchsystem zwischen Buffer und Kollektoren	Flexible hose system between buffer and collectors
Kabel zur Energie- und Datenübertragung, integriert in Risersektionen und flexiblem Schlauchsystem, Sensorik, Mess- und Kontroll-Systeme	Power and data cable, integrated into riser sections and flexible hose systems, sensors, control and instrumentation systems
Kollektor	Collector
Fahrwerk mit Antrieb und Einhausung des Kollektors	Chassis with drive and collector enclosure

Knollenaufnahmesystem, Brechwerk und Pumpen	Nodule collection system, crusher and pumps
Sensorik und Navigation, Mess- und Kontroll-Systeme	Sensors and navigation, control and instrumentation systems
Austragungssystem für Prozesswasser	Process water separation system
Risersektionen mit flexiblen/ starren Kopplungen	Riser sections with flexible/rigid couplings
Pumpen-System	Pump system
Sensorik, Mess- und Kontroll-Systeme	Sensors, control and instrumentation systems
Tabelle 3-6-2	Table 3-6-2
Schätzung der Investitionskosten [Mio. USD]	Investment cost estimate [million USD]
Pos.	Item
Beschreibung	Description
Anzahl	Quantity
Beschaffung bevorzugt in Deutschland	Primary German supply
Beschaffung bevorzugt in Europa	Primary European supply
Beschaffung international	International supply
Einsatz	In use
Reserve	Standby
unterer Ansatz	Lower approach
oberer Ansatz	Upper approach
Bulk-Carrier (Neubau)	Bulk carrier (new)
Neubau Supramax Bulkcarrier	New Supramax bulk carrier
Ausrüstung für die Offshore-Beladung des Bulkcarriers (Transshipment)	Equipment for offshore loading of bulk carrier (transshipment)
Bulk-Carrier (Secondhand)	Bulk carrier (used)
Beschaffung Secondhand Supramax Bulkcarrier	Acquisition of used Supramax bulk carrier
Umrüstung für die Offshore-Beladung des Bulk-Carriers (Transshipment)	Modification for offshore loading of bulk carrier (transshipment)
Hafenanlagen	Harbour facilities
Umschlag- und Lagertechnik, Gebäude	Transshipment and warehouse systems, buildings
Flächen und Infrastruktur	Open spaces and infrastructure
Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	Processing and smelting plants (HP-HT-AL)
Anlagentechnik und Gebäude	Technical equipment and buildings
Flächen und Infrastruktur	Open spaces and infrastructure
Forschungsschiff zur Umweltüberwachung	Research vessel for environmental monitoring
Neubau eines speziell für das Umweltmonitoring beim Tiefseebergbau ausgelegten Forschungsschiffes	Construction of a new research vessel specifically designed for environmental monitoring in deep sea mining
Ausrüstung für das Umweltmonitoring	Modification for environmental monitoring
Leistungen des Bauherrn	Disciplines on behalf of owner
Ingenieurleistungen, Überwachung	Engineering, supervision
Zertifizierungen / Klasse	Certifications/class
Management	Management
Tabelle 3-7	Table 3-7
Schätzung der Investitionskosten [Mio. USD]	Investment cost estimate [million USD]
Pos.	Item
Beschreibung	Description
Anzahl	Quantity
Beschaffung bevorzugt in Deutschland	Primary German supply
Beschaffung bevorzugt in Europa	Primary European supply
Beschaffung international	International supply
Einsatz	In use
Reserve	Standby

unterer Ansatz	Lower approach
oberer Ansatz	Upper approach
Basisschiff (Förderplattform)	Mining vessel
Förderstrang	Conveying line
Kollektor	Collector
Austragungssystem für Prozesswasser	Process water separation system
Bulk-Carrier (Neubau)	Bulk carrier (new)
Bulk-Carrier (Secondhand)	Bulk carrier (used)
Hafenanlagen	Harbour facilities
Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	Processing and smelting plants (HP-HT-AL)
Forschungsschiff zur Umweltüberwachung	Research vessel for environmental monitoring
Leistungen des Bauherrn	Disciplines on behalf of owner
Gesamtinvestitionskosten mit Neubau der Bulk-Carrier	Total investment costs with new bulk carriers
Gesamtinvestitionskosten mit Beschaffung der Bulk-Carrier auf dem Zweiten Markt	Total investment costs with bulk carriers purchased on the second market
Abb. 3-6	Fig. 3-6
Anteile der Investitionskosten Fördersystem in [Mio. USD]	Shares of investment costs for conveyor system [million USD]
Beschaffung bevorzugt in Deutschland	Primary German supply
oberer Ansatz: gesamt = 626 Mio. USD	Upper approach: total = 626 million USD
Basisschiff	Mining vessel
Förderstrang	Conveying line
Kollektor	Collector
Austragungssystem für Prozesswasser	Process water separation system
Anteile der Investitionskosten Fördersystem in [%]	Shares of investment costs for conveyor system [%]
Beschaffung bevorzugt in Deutschland	Primary German supply
oberer Ansatz: gesamt = 626 Mio. USD	Upper approach: total = 626 million USD
Basisschiff	Mining vessel
Förderstrang	Conveying line
Kollektor	Collector
Austragungssystem für Prozesswasser	Process water separation system
Abb. 3-7	Fig. 3-7
Anteile der gesamten Investitionskosten in [Mio. USD]	Shares of total investment costs in [million USD]
Beschaffung bevorzugt in Deutschland	Primary German supply
oberer Ansatz: gesamt = 1667 Mio. USD	Upper approach: total = 1667 million USD
Fördersystem	Conveyor system
Bulk-Carrier (Secondhand) und Hafenanlagen	Bulk carrier (used) and harbour facilities
Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	Processing and smelting plants (HP-HT-AL)
Forschungsschiff zur Umweltüberwachung	Research vessel for environmental monitoring
Leistungen des Bauherrn	Disciplines on behalf of owner
Anteile der gesamten Investitionskosten in [%]	Shares of total investment costs in [%]
Tabelle 3-8, 3-9, 3-10	Tables 3-8, 3-9, 3-10
Pos.	Item
Beschreibung	Description
Anzahl	Quantity
Schätzung der Investitionskosten	Investment cost estimate
Beschaffung bevorzugt in Deutschland	Primary German supply
[Mio. USD]	[million USD]
Anteil an Gesamtinvestitionskosten	Share in total investment costs

Einsatz	In use
Reserve	Standby
Unterer Ansatz	Lower approach
Oberer Ansatz	Upper approach
Fördersystem	Conveyor system
Bulk-Carrier (Secondhand) und Hafenanlagen	Bulk carrier (used) and harbour facilities
Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	Processing and smelting plants (HP-HT-AL)
Forschungsschiff zur Umweltüberwachung	Research vessel for environmental monitoring
Leistungen des Bauherrn	Disciplines on behalf of owner
Gesamtinvestitionskosten mit Beschaffung der Bulk-Carrier auf dem zweiten Markt	Total investment costs with bulk carriers purchased on the second market
Abb. 3-8	Fig. 3-8
Anteile der gesamten Investitionskosten in [Mio. USD]	Shares of total investment costs in [million USD]
Beschaffung bevorzugt in Europa	Primary European supply
oberer Ansatz: gesamt = 1657 Mio. USD	Upper approach: total = 1657 million USD
Fördersystem	Conveyor system
Bulk-Carrier (Secondhand) und Hafenanlagen	Bulk carrier (used) and harbour facilities
Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	Processing and smelting plants (HP-HT-AL)
Forschungsschiff zur Umweltüberwachung	Research vessel for environmental monitoring
Leistungen des Bauherrn	Disciplines on behalf of owner
Anteile der gesamten Investitionskosten in [%]	Shares of total investment costs in [%]
Abb. 3-9	Fig. 3-9
Anteile der gesamten Investitionskosten in [Mio. USD]	Shares of total investment costs in [million USD]
Beschaffung international	International supply
oberer Ansatz: gesamt = 1618 Mio. USD	Upper approach: total = 1618 million USD
Fördersystem	Conveyor system
Bulk-Carrier (Secondhand) und Hafenanlagen	Bulk carrier (used) and harbour facilities
Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	Processing and smelting plants (HP-HT-AL)
Forschungsschiff zur Umweltüberwachung	Research vessel for environmental monitoring
Leistungen des Bauherrn	Disciplines on behalf of owner
Anteile der gesamten Investitionskosten in [%]	Shares of total investment costs in [%]
Tabelle 3-11-1:	Table 3-11-1:
Beschaffung international	International supply
Schätzung der Investitionskosten [Mio. USD]	Investment cost estimate [million USD]
Erreichbarer deutscher Lieferanteil	Achievable German delivery share
Pos.	Item
Beschreibung	Description
Anzahl	Quantity
Einsatz	In use
Reserve	Standby
unterer Ansatz	Lower approach
oberer Ansatz	Upper approach
Basisschiff (Förderplattform)	Mining vessel
Schiffskörper	Hull
Schiffsspezifische Ausrüstung	Vessel-specific equipment
Abbauspezifische Ausrüstung	Mining-specific equipment
Werftkosten	Shipyard costs
Förderstrang	Conveying line
Risersektionen mit flexiblen oder starren	Riser sections with flexible or rigid couplings,

Kopplungen, mit/ ohne Auftriebselemente, bei Airlift-System zusätzlich Leitungen zur Luftversorgung	with/without buoyancy elements, additional air supply pipes for airlift systems
Pumpensystem bzw. Airlift-System	Pump or airlift system
Buffer (Zwischenspeicher)	Buffer
Flexibles Schlauchsystem zwischen Buffer und Kollektoren	Flexible hose system between buffer and collectors
Kabel zur Energie- und Datenübertragung, integriert in Risersektionen und flexiblem Schlauchsystem, Sensorik, Mess- und Kontroll-Systeme	Power and data cable, integrated into riser sections and flexible hose systems, sensors, control and instrumentation systems
Kollektor	Collector
Fahrwerk mit Antrieb und Einhausung des Kollektors	Chassis with drive and collector enclosure
Knollenaufnahmesystem, Brechwerk und Pumpen	Nodule collection system, crusher and pumps
Sensorik und Navigation, Mess- und Kontroll-Systeme	Sensors and navigation, control and instrumentation systems
Austragungssystem für Prozesswasser	Process water separation system
Risersektionen mit flexiblen/ starren Kopplungen	Riser sections with flexible/rigid couplings
Pumpen-System	Pump system
Sensorik, Mess- und Kontroll-Systeme	Sensors, control and instrumentation systems
Tabelle 3-11-2:	Table 3-11-2:
Schätzung der Investitionskosten [Mio. USD]	Investment cost estimate [million USD]
Erreichbarer deutscher Lieferanteil	Achievable German delivery share
Pos.	Item
Beschreibung	Description
Anzahl	Quantity
Beschaffung bevorzugt in Deutschland	Primary German supply
Beschaffung bevorzugt in Europa	Primary European supply
Beschaffung international	International supply
Einsatz	In use
Reserve	Standby
unterer Ansatz	Lower approach
oberer Ansatz	Upper approach
Bulk-Carrier (Neubau)	Bulk carrier (new)
Neubau Supramax Bulkcarrier	New Supramax bulk carrier
Ausrüstung für die Offshore-Beladung des Bulkcarriers (Transshipment)	Equipment for offshore loading of bulk carrier (transshipment)
Bulk-Carrier (Secondhand)	Bulk carrier (used)
Beschaffung Secondhand Supramax Bulkcarrier	Acquisition of used Supramax bulk carrier
Umrüstung für die Offshore-Beladung des Bulk-Carriers (Transshipment)	Modification for offshore loading of bulk carrier (transshipment)
Hafenanlagen	Harbour facilities
Umschlag- und Lagertechnik, Gebäude	Transshipment and warehouse systems, buildings
Flächen und Infrastruktur	Open spaces and infrastructure
Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	Processing and smelting plants (HP-HT-AL)
Anlagentechnik und Gebäude	Technical equipment and buildings
Flächen und Infrastruktur	Open spaces and infrastructure
Forschungsschiff zur Umweltüberwachung	Research vessel for environmental monitoring
Neubau eines speziell für das Umweltmonitoring beim Tiefseebergbau ausgelegten Forschungsschiffes	Construction of a new research vessel specifically designed for environmental monitoring in deep sea mining
Ausrüstung für das Umweltmonitoring	Modification for environmental monitoring

Leistungen des Bauherrn	Disciplines on behalf of owner
Ingenieurleistungen, Überwachung	Engineering, supervision
Zertifizierungen / Klasse	Certifications/class
Management	Management
Tabelle 3-12	Table 3-12
Beschaffung international	International supply
Pos.	Item
Beschreibung	Description
Schätzung der Investitionskosten	Investment cost estimate
Erreichbarer deutscher Lieferanteil	Achievable German delivery share
[Mio.USD]	[million USD]
Beschaffung international	International supply
unterer Ansatz	Lower approach
oberer Ansatz	Upper approach
Basisschiff (Förderplattform)	Mining vessel
Förderstrang	Conveying line
Kollektor	Collector
Austragungssystem für Prozesswasser	Process water separation system
Bulk-Carrier (Neubau)	Bulk carrier (new)
Bulk-Carrier (Secondhand)	Bulk carrier (used)
Hafenanlagen	Harbour facilities
Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	Processing and smelting plants (HP-HT-AL)
Forschungsschiff zur Umweltüberwachung	Research vessel for environmental monitoring
Leistungen des Bauherrn	Disciplines on behalf of owner
Gesamt (Bulk-Carrier Neubau):	Total (new bulk carrier):
Gesamt (Bulk-Carrier Secondhand):	Total (used bulk carrier):
Abb. 3-10	Fig. 3-10
Gesamt-Investitionskosten – Beschaffung international	Total investment costs – International supply
Erreichbarer deutscher Lieferanteil in [Mio. USD]	Achievable German delivery share in [million USD]
Unterer Ansatz: gesamt = 327 Mio. USD = 26.8 %	Lower approach: total = 327 million USD = 26.8%
Fördersystem	Conveyor system
Bulk-Carrier (Secondhand)	Bulk carrier (used)
Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	Processing and smelting plants (HP-HT-AL)
Forschungsschiff zur Umweltüberwachung	Research vessel for environmental monitoring
Leistungen des Bauherrn	Disciplines on behalf of owner
Abb. 3-11	Fig. 3-11
Gesamt-Investitionskosten – Beschaffung international	Total investment costs – International supply
Erreichbarer deutscher Lieferanteil in [Mio. USD]	Achievable German delivery share in [million USD]
Unterer Ansatz: gesamt = 968 Mio. USD = 59.8 %	Lower approach: total = 968 million USD = 59.8%
Fördersystem	Conveyor system
Bulk-Carrier (Secondhand)	Bulk carrier (used)
Anlagen zur Aufbereitung und Metallurgie (HP-HT-AL)	Processing and smelting plants (HP-HT-AL)
Forschungsschiff zur Umweltüberwachung	Research vessel for environmental monitoring
Leistungen des Bauherrn	Disciplines on behalf of owner

Tabelle 3-13-1, 2, 3, 4: siehe gesonderte Datei	Tabelle 3-13-1, 2, 3, 4: siehe gesonderte Datei
Tabelle 3-14-1	Table 3-14-1
Schätzung der jährlichen Betriebskosten [Mio. USD/a]	Estimated annual operating costs [million USD/a]
Pos.	Item
Beschreibung	Description
unterer Ansatz	Lower approach
oberer Ansatz	Upper approach
Energieverbrauch beim Abbau der Knollen	Energy consumption for mining the nodules
Energiebedarf [kW]	Energy demand [kW]
Betriebsstunden [h/ a]	Operating hours [h/a]
Basisschiff: 1.01 bis 1.09	Mining vessel: 1.01 to 1.09
Propulsion und Positionierung	Propulsion and positioning
Aktive Kompensation der Tauchbewegungen	Active compensation of vessel movements
Kransysteme	Crane systems
Handhabungssysteme	Handling systems
Separatoren und Kreiselpumpen	Separators and centrifugal pumps
Schiffseitige Transport- und Fördersysteme	On-board transport and conveyor systems
Umschlagsystem (Transshipment)	Transshipment system
Hotel-Last (58 Personen)	Hotel usage (58 persons)
Förderstrang: Pumpen bzw. Airlift System	Conveying line: Pumps or airlift system
Buffer	Buffer
2 Kollektoren	2 collectors
Austragungssystem für Prozesswasser	Process water separation system
Remotely Operated Vehicles (ROV), Seafloor Working Units (SWU)	Remotely operated vehicles (ROV), seafloor working units (SWU)
Instandhaltung Basisschiff und Fördersystem	Maintenance of mining vessel and mining system
Basisschiff	Mining vessel
Fördersystem: - Förderstrang - Kollektoren - Austragungssystem für Prozesswasser	Conveyor system: - Conveying line - Collectors - Process water separation system
Tabelle 3-14-2	Table 3-14-2
Schätzung der jährlichen Betriebskosten [Mio. USD/a]	Estimated annual operating costs [million USD/a]
Pos.	Item
Beschreibung	Description
unterer Ansatz	Lower approach
oberer Ansatz	Upper approach
Schiffsmanagement Basisschiff	Ship management, mining vessel
Kommerzielles und technisches Management	Commercial and technical management
Klasse einschl. Dockung	Class including docking
Versicherung (Haftpflicht + Hull & Machinery)	Insurance (third-party liability + hull & machinery)
Besatzung Basisschiff	Mining vessel crew
Schiffsbesatzung	Crew
Besatzung für Betrieb Fördersystem	Crews for operation of the mining system
Unterbringung und Verpflegung	Accommodation and catering
Besatzungs-Wechsel	Crew change
Bulk-Carrier Supramax – 2 Einheiten (Transport nach Mexico, Lazaro Cardenas)	Bulk carrier Supramax – 2 units (transport to Mexico, Lazaro Cardenas)
Treibstoff, 2 x 34 Fahrten 2 x 1000 nm plus Transshipment und Entladung	Fuel, 2 x 34 trips 2 x 1,000 nm plus transshipment and offloading

Besatzung	Crew
Kommerzielles und technisches Management	Commercial and technical management
Klasse einschl. Dockung	Class including docking
Versicherung (Haftpflicht + Hull & Machinery)	Insurance (third-party liability + hull & machinery)
Schmieröle und Unterhaltung	Lube oils and maintenance
Basishafen (Mexiko, Lazaro Cardenas)	Base harbour (Mexico, Lazaro Cardenas)
Energiekosten (Treibstoffe und elektrische Energie)	Energy costs (fuels and electrical energy)
Lohnkosten (12 Mitarbeiter)	Wage costs (staff of 12)
Feste Kosten (Verwaltung, Instandhaltung, Versicherung etc.)	Fixed costs (administration, maintenance, insurance, etc.)
Tabelle 3-14-3	Table 3-14-3
Schätzung der jährlichen Betriebskosten [Mio. USD/a]	Estimated annual operating costs [million USD/a]
Pos.	Item
Beschreibung	Description
unterer Ansatz	Lower approach
oberer Ansatz	Upper approach
Energieverbrauch bei der Verhüttung (Metallurgie HP-HT-AL)	Smelting energy consumption (metallurgy HP-HT-AL)
Brennstoffe	Fuels
Elektrische Energie	Electrical energy
Weitere Betriebskosten Verhüttung (Metallurgie HP-HT-AL)	Other operating costs of smelting operations (metallurgy HP-HT-AL)
Hilfsstoffe für den metallurgischen Prozess	Auxiliary materials for the metallurgical process
Lohnkosten	Wage costs
Entsorgung Reststoffe	Disposal of residual material
Feste Kosten (Verwaltung, Instandhaltung, Versicherung etc.)	Fixed costs (administration, maintenance, insurance, etc.)
Tabelle 3-15	Table 3-15
Schätzung der jährlichen Betriebskosten [Mio. USD/ a]	Estimated annual operating costs [million USD/a]
Pos.	Item
Beschreibung	Description
unterer Ansatz	Lower approach
oberer Ansatz	Upper approach
[Mio. USD/a]	[million USD/a]
Anteil an Gesamtkosten	Share in total costs
Energieverbrauch beim Abbau der Knollen	Energy consumption for mining the nodules
Instandhaltung Basisschiff und Fördersystem	Maintenance of mining vessel and mining system
Schiffsmanagement Basisschiff	Ship management, mining vessel
Besatzung Basisschiff	Mining vessel crew
Abbau der polymetallischen Knollen	Mining of polymetallic nodules
Bulk-Carrier Supramax – 2 Einheiten (Transport nach Mexico, Lazaro Cardenas)	Bulk carrier Supramax – 2 units (transport to Mexico, Lazaro Cardenas)
Basishafen (Mexiko, Lazaro Cardenas)	Base harbour (Mexico, Lazaro Cardenas)
Seetransporte und Basishafen	Sea transport and base harbour
Energieverbrauch bei der Verhüttung (Metallurgie)	Smelting energy consumption (metallurgy)
Weitere Betriebskosten Verhüttung (Metallurgie)	Other operating costs of smelting operations (metallurgy)
Verhüttung (Metallurgie HP-HT-AL)	Smelting (metallurgy HP-HT-AL)
Jährliche Gesamtkosten Betrieb	Total annual operating costs

Abb. 3-12	Fig. 3-12
Anteile der gesamten jährlichen Betriebskosten in [Mio. USD]	Shares of total annual operating costs in [million USD]
unterer Ansatz: gesamt = 390 Mio. USD	Lower approach: total = 390 million USD
Abbau der polymetallischen Knollen	Mining of polymetallic nodules
Seetransporte und Basishafen	Sea transport and base harbour
Verhüttung (Metallurgie)	Smelting (metallurgy)
Anteile der gesamten jährlichen Betriebskosten in [%]	Shares of total annual operating costs in [%]
Abb. 3-13	Fig. 3-13
Anteile der gesamten jährlichen Betriebskosten in [Mio. USD]	Shares of total annual operating costs in [million USD]
oberer Ansatz: gesamt = 435 Mio. USD	Upper approach: total = 435 million USD
Abbau der polymetallischen Knollen	Mining of polymetallic nodules
Seetransporte und Basishafen	Sea transport and base harbour
Verhüttung (Metallurgie)	Smelting (metallurgy)
Anteile der gesamten jährlichen Betriebskosten in [%]	Shares of total annual operating costs in [%]
Tabelle 3-16	Table 3-16
Schätzung der jährlichen Betriebskosten [Mio.USD/a]	Estimated annual operating costs [million USD/a]
Pos.	Item
Beschreibung	Description
Unterer Ansatz	Lower approach
Oberer Ansatz	Upper approach
[Mio. USD/a]	[million USD/a]
Anteil an Gesamtkosten	Share in total costs
Jährliche Gesamtkosten Betrieb	Total annual operating costs
Davon	of which:
Energiekosten gesamt	Total energy costs
Hilfsstoffe gesamt	Total auxiliary materials
Verwaltung, Instandhaltung, Versicherungen gesamt	Total administration, maintenance, insurance costs
Lohnkosten und weitere Personalkosten gesamt	Total wage and other personnel costs
Sonstige Kosten gesamt	Total other costs
Abb. 3-14	Fig. 3-14
Anteile der gesamten jährlichen Betriebskosten in [Mio. USD]	Shares of total annual operating costs in [million USD]
Unterer Ansatz: gesamt = 390 Mio. USD	Lower approach: total = 390 million USD
Energiekosten gesamt	Total energy costs
Hilfsstoffe gesamt	Total auxiliary materials
Verwaltung, Instandhaltung, Versicherungen gesamt	Total administration, maintenance, insurance costs
Lohnkosten und weitere Personalkosten gesamt	Total wage and other personnel costs
Sonstige Kosten gesamt	Total other costs
Anteile der gesamten jährlichen Betriebskosten in [%]	Shares of total annual operating costs in [%]
Unterer Ansatz: gesamt = 390 Mio. USD	Lower approach: total = 390 million USD
Abb. 3-15	Fig. 3-15
Anteile der gesamten jährlichen Betriebskosten in [Mio. USD]	Shares of total annual operating costs in [million USD]
Oberer Ansatz: gesamt = 435 Mio. USD	Upper approach: total = 435 million USD

Energiekosten gesamt	Total energy costs
Hilfsstoffe gesamt	Total auxiliary materials
Verwaltung, Instandhaltung, Versicherungen gesamt	Total administration, maintenance, insurance costs
Lohnkosten und weitere Personalkosten gesamt	Total wage and other personnel costs
Sonstige Kosten gesamt	Total other costs
Anteile der gesamten jährlichen Betriebskosten in [%]	Shares of total annual operating costs in [%]
Unterer Ansatz: gesamt = 390 Mio. USD	Lower approach: total = 390 million USD
Tabelle 3-17	Table 3-17
Schätzung der Betriebskosten pro Tonne Trockenmaterial	Estimated operating costs per tonne of dry material
Pos.	Item
Beschreibung	Description
Unterer Ansatz	Lower approach
Oberer Ansatz	Upper approach
[USD/t]	[USD/tonne]
Anteil an Gesamtkosten	Share in total costs
Energieverbrauch beim Abbau der Knollen	Energy consumption for mining the nodules
Instandhaltung Basisschiff und Fördersystem	Maintenance of mining vessel and mining system
Schiffsmanagement Basisschiff	Ship management, mining vessel
Besatzung Basisschiff	Mining vessel crew
Abbau der polymetallischen Knollen	Mining of polymetallic nodules
Bulk-Carrier Supramax – 2 Einheiten (Transport nach Mexico, Lazaro Cardenas)	Bulk carrier Supramax – 2 units (transport to Mexico, Lazaro Cardenas)
Basishafen (Mexiko, Lazaro Cardenas)	Base harbour (Mexico, Lazaro Cardenas)
Seetransporte und Basishafen	Sea transport and base harbour
Energieverbrauch bei der Verhüttung (Metallurgie)	Smelting energy consumption (metallurgy)
Weitere Betriebskosten Verhüttung (Metallurgie)	Other operating costs of smelting operations (metallurgy)
Verhüttung (Metallurgie HP-HT-AL)	Smelting (metallurgy HP-HT-AL)
Gesamte Betriebskosten pro Tonne Trockenmaterial	Total operating costs per tonne of dry material
Abb. 3-16	Fig. 3-16
Anfangsinvestitionen	Initial investments
Discounted Cash Flow Modell zur Evaluierung der betriebswirtschaftlichen Rentabilität eines Tiefseebergbauprojekts	Discounted cash flow model for evaluating the commercial profitability of a deep sea mining project
Perioden (Jahre)	Periods (years)
Anfangsinvestitionen	Initial investments
Höhe Investitionskosten: Projektgröße (Fördermenge etc.), technisches Fördersystem; Lizenzen/Auflagen	Amount of investment costs: project volume (production volume, etc.), technical mining equipment; licences/requirements
Zeitpunkt der Investitionskosten	Time of investment costs
Operative Cash Flows (Einnahmen – operative Kosten)	Operative cash flows (revenues – operating costs)
Höhe und Zeitpunkt der operativen Kosten: Fördermenge, Transport, Verhüttung, Wartung etc. (Kostendegression?), regulatorische Kosten, fiskalische Kosten	Amount and time of operating costs: production volume, transport, melting, maintenance, etc. (cost degression?), regulatory costs, fiscal costs
Höhe und Zeitpunkt der Einnahmen: Fördermenge, Förderdauer, Förderbeginn, Extraktionsprozess (Metallauswahl,	Amount and time of revenues: production volume, duration of production, commencement of production, extraction process (metal

Gewinnungseffizienz), Metallpreise, Diskontierung (Zins, Risikoaufschlag)	selection, winning efficiency), metal prices, discounting (interest, risk premium)
Abb. 3-17	Fig. 3-17
Märkte	Markets
Technologie	Technology
Förderung	Mining
Verhüttung	Smelting
Metallpreise	Metal prices
Zinsen	Interest
Steuern, Abgaben	Taxes, duties
Genehmigung	Licence
Rechtliche Regulierung	Legal regulation
Abb. 3-18	Fig. 3-18
Häufigkeit	Frequency
Mio. USD	million USD
Dichte	Density
Szenario Primary German Supply	'Primary German Supply' scenario
Szenario Primary International Supply	'Primary International Supply' scenario
Abb. 3-19	Fig. 3-19
Mrd. USD	billion USD
Abb. 3-20	Fig. 3-20
Primary International Supply (Preise 1-Jahres-∅)	Primary International Supply (prices for 1-year ∅)
Primary German Supply (Preise 1-Jahres-∅)	Primary German Supply (prices for 1-year ∅)
Mrd. USD	billion USD
Primary International Supply (Preise 5-Jahres-∅)	Primary International Supply (prices for 5-year ∅)
Primary German Supply (Preise 5-Jahres-∅)	Primary German Supply (prices for 5-year ∅)
Mrd. USD	billion USD
Primary International Supply (Preise 10-Jahres-∅)	Primary International Supply (prices for 10-year ∅)
Primary German Supply (Preise 10-Jahres-∅)	Primary German Supply (prices for 10-year ∅)
Mrd. USD	billion USD
Abb. 3-21	Fig. 3-21
Mrd. USD	billion USD
Oberszenario 2: 1-Jahresdurchschnitt	Upper scenario 2: 1-year average
Oberszenario 2: 5-Jahresdurchschnitt	Upper scenario 2: 5-year average
Oberszenario 2: 10-Jahresdurchschnitt	Upper scenario 2: 10-year average
Abb. 3-22	Fig. 3-22
Mrd. USD	billion USD
Projektion	Projection
1 Jahr ∅	1-year ∅
5 Jahre ∅	5-year ∅
10 Jahre ∅	10-year ∅
Abb. 4-1	Fig. 4-1
Erkundung und Bewertung	Exploration and evaluation
Abbau und Förderung	Mining and production
Offshore & Onshore Logistik	Offshore & onshore logistics
Verarbeitung	Processing

Vertrieb und Verkauf	Distribution and sale
Forschungsschiffe und –ausrüstung	Research vessels and equipment
Kollektoren	Collectors
Produktionsschiff	Mining vessel
Transportschiffe	Transport vessels
Hafeninfrastruktur	Harbour infrastructure
Anlagen zur Verhüttung	Smelting plants
Engineering, Zertifizierung, Management	Engineering, certification, management
Abb. 4-2	Fig. 4-2
Gütergruppen	Product groups
Ges. Vorleistungen bzw. Endnachfrage	Total inputs and/or final demand
Komponenten der Wertschöpfung	Value chain components
Importe	Imports
Gesamtes Aufkommen	Total output
Input der Produktionsbereiche	Input of productive area
Vorleistungsmatrix	Input matrix
Letzte Verwendung	Last use
Konsum	Consumption
Investitionen	Investments
Exporte	Exports
Matrix des Primärinputs	Primary input matrix
Gesamtes Aufkommen = gesamte Verwendung	Total output = total use
Gesamte Verwendung	Total use
Abkürzungen	Abbreviations
PB = Primärer Bereich = Land- und Forstwirtschaft, Fischerei	PB = primary area = agriculture and forestry, fisheries
SB = Sekundärer Bereich = Produzierendes Gewerbe	SB = secondary area = production industry
TB = Tertiärer Bereich = Private und öffentliche Dienstleistungen	TB = tertiary area = private and public services
Abb. 4-3	Fig. 4-3
Förderkosten	Extraction costs
Nicht wirtschaftlich	Not economically viable
Technischer Fortschritt, Preise	Technical progress, prices
Reserven	Reserves
Abbau	Mining
Ressourcen	Resources
Exploration	Exploration
Nicht identifiziert	Not identified
Quelle	Source
Unbestimmtheit	Uncertainty
Abb. 4-4	Fig. 4-4
Anzahl Metalle (Förderanteil > 1 %)	Number of metals (production share of > 1 %)
Förderung 2013	2013 production
Quelle	Source
Abb. 4-5	Fig. 4-5
Herfindahl-Index	Herfindahl index
Bauxit	Bauxite
Blei	Lead
Chrom	Chromium
Eisen	Iron
Gold	Gold

Kobalt	Cobalt
Kupfer	Copper
Mangan	Manganese
Nickel	Nickel
Seltene Erden	Rare earths
Silber	Silver
Titan (Ilmenit)	Titanium (ilmenite)
Zink	Zinc
Zinn	Tin
Quelle	Source
Abb. 4-6	Fig. 4-6
Förderung global	Global production
Verbrauch global	Global consumption
Raffinade global	Global refinery output
Abb. 4-7	Fig. 4-7
Kupfer	Copper
Nickel	Nickel
Abb. 4-8	Fig. 4-8
Konzentration Förderung 2013 (Herfindahl-Index)	Production concentration in 2013 (Herfindahl index)
Anteil deutscher Importe an europäischen Importen	Share of German imports in European imports
Kobalt	Cobalt
Blei	Lead
Eisen	Iron
Chrom	Chromium
Zinn	Tin
Zink	Zinc
Mangan	Manganese
Bauxit	Bauxite
Nickel	Nickel
Silber	Silver
Kupfer	Copper
Gold	Gold
Titan	Titanium
Abb. 4-9	Fig. 4-9
In situ	In situ
Minen-Kopf	Mine head
Minen-Tor	Mine gate
Konzentrat	Concentrate
Exporthafen	Export harbour
Schmelzofen	Melting furnace
Metall	Metal
Exploration	Exploration
Abbau	Mining
Zerkleinern & Sichten	Crushing & classifying
Anreicherung	Concentration
Inländischer Transport	Domestic transport
Fracht & Versicherung	Freight & insurance
Raffinierung	Refining
Abb. 4-10 – siehe separate Datei	Abb. 4-10 – siehe separate Datei

Abb. 5-6	Fig. 5-6
Tauchboot-Mutterschiff	Diving-boat mother ship
Kollektor-Mutterschiff	Collector mother ship
Tauchboot Nautilus	Nautilus diving boat
Visuelle Testüberwachung	Visual test monitoring
LWL-Umbilical	Optical umbilical cable
Daten- und Energieübertragung	Data and power transmission
Operationsleitsystem auf FS Sonne	Operations control system on 'Sonne' research vessel
Navigation	Navigation
Fahrzeugsteuerung	Vehicle control
Auswertung	Evaluation
Trafo	Transformer
Telemetrie	Telemetrics
Windensystem	Winch system
Schleifring	Slipring
Selbstfahrendes Testfahrzeug mit Kollektor	Self-propelled vehicle with collector
Knollenaufnahme ohne Förderung	Nodule collection without transport
Prinzipieller Aufbau der (technischen) Tiefsee-Kollektortests zur Erprobung des Manganknollen-Sammelsystems	Configuration scheme of the (technical) deep sea collector trial to test the manganese nodule collection system
Abb. 5-10	Fig. 5-10
Transportschiff	Transport vessel
Förderplattform	Production platform
Förderstrang mit Pumpe	Conveyor pipe with pump
Trübewolke	Turbidity cloud
Mn-Knollen-Kollektor	Mn nodule collector
Manganknollen	Manganese nodules
Meeresboden	Seabed
Abb. 5-11	Fig. 5-11
Planung und Koordination – Überwachung und Dokumentation	Planning and co-ordination – monitoring and documentation
Design –Engineering – Systemintegration – Spezifikation	Design – engineering – system integration – specification
Fertigung – Beschaffung – Umbauten – Funktionstests	Manufacture – purchase – modifications – function testing
Umweltmonitoring: vorlaufend – begleitend – nachlaufend	Environmental monitoring: before – during – after
Durchführung des Pilot Mining Tests	Performance of the pilot mining test
Auswertung und abschließende Dokumentation	Evaluation and final documentation
Abb. 5-12	Fig. 5-12
Jahr …	Year ...
Planung und Koordination	Planning and co-ordination
Überwachung, Dokumentation und Auswertung	Monitoring, documentation and evaluation
Design und Engineering	Design and engineering
Systemintegration	System integration
Beschaffung und Fertigung	Procurement and manufacture
Umrüstung und Funktionstests	Modification and function testing
Durchführung Test	Testing
Umweltmonitoring vorlaufend – begleitend – nachlaufend	Environmental monitoring: before – during – after
Abb. 5-13	Fig. 5-13

Disziplin	Discipline
Mio. EUR	million EUR
Planung und Koordination, Überwachung, Dokumentation und Auswertung	Planning and co-ordination, monitoring, documentation and evaluation
Umrüstung Bohrschiff zum Förderschiff	Modification of drilling vessel to mining vessel
Förderstrang	Conveying line
Kollektor	Collector
System zur Rückführung der Tailings	Tailing return system
Durchführung Pilot Mining Test (90 Tage)	Performance of the pilot mining test (90 days)
Umweltmonitoring vorlaufend – begleitend – nachlaufend	Environmental monitoring: before – during – after
Summe	Total
Davon Leistungen für Design, Engineering und Systemintegration	of which design, engineering and system integration services
Tabelle 6-1	Table 6-1
Vertrag	Contract
Vertragsende	Expiry of contract
Staatliche Einrichtungen	Government institutions
Unternehmen	Companies
Russland, Polen, weitere Staaten	Russia, Poland, other states
Frankreich	France
Deutschland	Germany
Belgien	Belgium
Vereinigtes Königreich	United Kingdom
Singapur	Singapore
Cook Inseln	Cook Islands