Financial Regimes for Polymetallic Nodule Mining: A Comparison of Four Economic Models

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1 Background.

1. The International Seabed Authority is charged with regulating mining activities in the Area, being the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction. As part of that effort, and in realizing the financial and economic benefits from such activities, the ISA is seeking to define the financial terms for exploitation contracts, including the fees and royalties that would be collected from entities engaging in mining activities in locations under the ISA's jurisdiction. Several models have been developed to explore the economic consequences of potential ISA regimes both for the mining entity and upon the revenues collected by the ISA. This report compares four such regime evaluation models. The study of these models was specifically commissioned by the ISA Council in 2018.

2. The authors would like to establish at the outset that this comparison is intended to be strictly descriptive. It is not intended to critique or otherwise pass judgment on the validity of any specific model or assumption. Instead, we hope that the information presented in this report will focus discussions on the financial regime and facilitate future decision-making on regime design.

2 The Four Models

3. The four models being compared here are (1) the African Group Model (AG), (2) the China Southern University Model (CSU), (3) the German Federal Ministry for Economic Affairs and Energy Model (BMWi), and (4) the Massachusetts Institute of Technology model (MIT).

2.1 African Group Model (AG)

4. This model was used to generate the results reported in the document "Request for consideration by the Council of the African Group's proposal on the Economic Model/Payment Regime and Other Financial Matters in the Draft Exploitation Regulations under review" that was submitted to the ISA on September 7, 2018. The authors of this report did not have access to the model itself, but did have access to the aforementioned report. Additionally, representatives from the African Group filled out a data request template provided by the authors and answered all additional questions posed by the authors. Hereinafter, this model will be referred to as AG.

2.2 China Southern University Model (CSU)

5. This model was used to generate the results reported in the presentation "Financial model and economic evaluation of polymetallic nodules development in the Area" by Prof. Shaojun Liu from China Southern University that was submitted to the ISA on September 7, 2018. The authors again did not have access to the model itself, but did have access to the aforementioned presentation. Again, China Southern University representatives completed a data template provided by the authors and answered all additional questions posed by the authors. Hereinafter, this model will be referred to as CSU.

2.3 German Federal Ministry for Economic Affairs and Energy Model (BMWi)

6. This model was used to generate the results reported in the document "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" a report for the Federal Ministry for Economic Affairs and Energy (BMWi) issued on September 30, 2016. The authors did not have access to the model itself, but had access to the aforementioned report. Additionally,

representatives from BMWi filled in the data request template provided by the authors and answered all additional questions posed by the authors. Hereinafter, this model will be referred to as BMWi.

2.4 Massachusetts Institute of Technology Model (MIT)

7. The fourth model being compared was developed by the authors, members of the Materials Systems Laboratory at the Massachusetts Institute of Technology and was commissioned by the ISA secretariat for use by the Legal and Technical Commission (LTC) and the Council of the International Seabed Authority to help understand the economics of polymetallic nodule mining and advance discussion on the development of a payment mechanism and financial terms . Results from earlier versions of this model were reported at Council and LTC meetings in March and July of 2018. The results compared here may differ from those earlier reported results as data collection has continued in the intervening months. The assumptions and results referenced here represent the best knowledge of the authors as of December 2018. Hereinafter, this model will be referred to as MIT.

3 Differences in reported results

8. The primary motivation for undertaking this report is that, while the four models being compared are notionally similar, the results reported from these models vary significantly. For example, the AG report states that a mining entity operating under an ad-valorem royalty of 2% of net metal value for the first eight years of production and 4% thereafter would be expected to earn an internal rate of return (IRR) of 27%. In fact, the report concludes that even "a payment regime with a royalty of 20% … results in a high internal economic rate of return for a contractor undertaking nodule mining in the Area".

9. By contrast, the CSU report says that, given a constant ad-valorem rate of 2% for the life of the mining operation, a mining entity would only be expected to earn an IRR of 17%. In fact, the presentation notes "if the ad-valorem royalty mode is adopted, the royalty rate should not exceed 2%."

10. This report aims to identify the key differences across these models in the hopes of understanding what underlies this range of results.

4 Process

11. The review for this document was undertaken in three steps.

1) The authors reviewed publically available information about each of the review models. Based on this review, a data collection template and set of questions was developed for each team that either developed or were knowledgeable about each model to complete and return.
2) The information thus provided were discussed by follow-up phone and/or email.
3) Once this information was collected, the authors created models that used those data to replicate the results reported for each model. These proxy models were then used to explore the key drivers of the differences among the results previously reported.

5 Comparison

12. Overall, the four models reviewed here are, in fact, quite similar. All four carry out some kind of discounted cash flow (DCF) analysis for the cash flows associated with a mining operation of polymetallic nodule extraction from the deep ocean. This DCF is used to construct economic metrics of performance for evaluating that mining operation. The most common metric reported is the internal

rate of return (IRR), which presents the discount rate at which the net present value for the operation equals zero.

13. Based on our review of the available materials, we identified 21 significant characteristics that vary across the models. These model features, grouped into five categories, are:

Analytical framing

1) Reported evaluation metric
2) Operational scope
3) Analysis Period

Production characteristics

4) Scale
5) Ramp up period
6) Metallurgical processing
7) Metals recovered
8) Metals Content of Nodules
9) Metallic yield

Magnitude of estimated future prices

10) Cobalt
11) Copper
12) Manganese
13) Nickel
14) Gross Metal Value of Nodule (USD / tonne nodule)
15) Net Metal Value of Nodule (USD / tonne nodule)

Magnitude of estimated operations-related cost cash flows

16) CAPEX
17) OPEX
18) Salvage value
19) Site remediation

Magnitude of estimated financial regime-related cash flows

20) Sponsoring State Tax rate
21) Royalties
22) ISA Fees

14. In making these selections, we have leveraged our knowledge of the types of calculations that go into such models and attempted to be comprehensive, while keeping the list at a level of granularity to make it tractable.

15. Here we discuss a few of the less quantitative model features. Values for all features are listed in Table 1 to this report.

5.1 Analytical framing

5.1.1 Reported Evaluation Metric(s)

16. As DCF models, all four of the models could be used to generate a range of financial performance metrics, presumably both for the entities engaging in mining and metals processing and for the ISA. In the accessible reports, three groups (AG, CSU, and MIT) report internal rates of return (IRR) and three groups (BMWi, CSU, and MIT) report net present values (NPV). Various other metrics are included in individual reports (see Table 1). In our concluding comparative analysis, we focus on IRR as it is the most commonly cited in other reports about the economics of seabed mining.

5.1.2 Operational scope

17. A key difference of the MIT model compared to the other three is that the MIT model assumes that ISA revenue can only derive from activities at the collector (i.e., the project component under ISA jurisdiction). The other three models evaluate the problem using the revenues accrued by the metals processor (on land) and the costs incurred by both that processor and the at-sea collector. Implicitly the AG, BMWi, and CSU models assume that the collector and processor are vertically integrated. The MIT model assumes that, for taxation and royalty collection purposes, the two businesses are distinct.

18. For an ad-valorem based royalty scheme, this accounting difference is irrelevant as the royalty is to be calculated on a basket of metals and by reference to international market values. However, for profit-based schemes, if the collector is treated independently, then the ISA could only collect a portion of the profits realized, if any, at the collector level.

5.1.3 Analysis period

19. Each model computes the metrics of interest over differing time periods. Given the nature of the analyses, the framing of the start and duration of phases of the project is important. Each model establishes different time frames for the two key phases of the project: (1) exploration/preparation and (2) exploitation (including production system construction). All of the models compute metrics to evaluate the economic regime that consider the time-value of money – that is funds expended or received today are more valuable than an equal amount of fund expended or received in the future. In the context of the economics of seabed mining, cases that assume operations and, therefore, revenues occur earlier will generate more favorable metrics than cases where operations are deferred. In general, the longer the pre-exploitation phase, the less attractive the project's financial metrics will be. In this document, we assume that the exploitation period starts when construction of production systems (design and build phase (D&B)) begins.

20. The AG model assumes a 7-year exploration phase and a 28 year exploitation phase (including three years of D&B). The BMWi model only considers a 16-year exploitation phase (including four years of D&B), arguing in their report that future uncertainty motivates the use of a shorter analysis period. The CSU model similarly treats a 28-year exploitation period (three years of D&B).The MIT model assumes a 7- year exploration/preparation phase and a 30 year exploitation period (three years of D&B)

5.2 Production characteristics

5.2.1 Scale

21. All four models assume a steady state production level of three million dry tonnes of nodules collected per year.

5.2.2 Ramp up duration

22. An influential assumption is whether production (a) begins at full steady state levels or (b) takes time to reach full capacity. A ramp up reduces income in the early years, with strong adverse impacts on financial metrics. Both the AG and CSU models assume no ramp up. The BMWi and MIT models assume a three year ramp up period (i.e., two years below full production levels). Specifically, the BMWi model assumes a production level of 50% in year 1 and 75% in year 2. The MIT model assumes 33% in year 1 and 66% in year 2. For both the BMWi and MIT models, the production ramp up leads to less production during the ramp years and this is not compensated for by additional production in later years. As such, overall the production over the life of the production period is modeled as less than the nominal capacity (e.g., 3 million tonnes per year) times the production period (e.g., 25 years).

5.2.3 Metallurgical Processing & 5.2.4 Metals Recovered

23. Revenues for seabed mining ultimately derive from the sale of the metals extracted from the recovered nodules. No consensus has been reached about which process(es) will be most economically attractive for extracting metals from nodules. The selected process will influence two key financial aspects: (a) the capital and operating costs for the processing and (b) the types and forms of metals that are recovered and sold.

24. All four of the reviewed models assume that cobalt, copper, and nickel will be recovered. Two models (AG and CSU) do not specify the process that is being modelled. The CSU model notes that the manganese will be recovered and sold into the electrolytic manganese metal (EMM) market. The AG model notes that its assumptions regarding costs are consistent with all manganese being processed to EMM grade and assumes a manganese price of $2,040 per tonne. The BMWi report assumes the use of a high-pressure/high-temperature leaching process using sulphuric acid. This process would not recover manganese. The MIT model assumes a four-metal process that would recover EMM. However, the MIT model assumes that this volume of EMM production would suppress prices in that market, which is reflected in the metals prices assumed.

6 Comparison of Drivers of the Results

25. The previous section describes the various differences in the framing and inputs across the four models. The natural question that arises is: *Which of these differences drives the differences in results that have been reported*. To attempt to address this question, the research team assembled all of the information provided about the AG, BMWi, and CSU models and created a discounted cash flow model that replicated the reported results. These calibrated proxy models can be used to explore how changes in assumptions will change the results. A proxy-MIT model was not required, because, as its developers, we have access to that model. Also, because the BMWi documentation did not report out IRR values, we did not attempt to create a proxy-BMWi model. Although we cannot guarantee that the proxy models replicate every feature of the original AG and CSU models, we were able to evaluate both models against at least two publically reported results. As a consequence, we believe that the proxies are sufficiently accurate to provide useful insights.

26. Finally, the easiest way to understand which parameters are most influential is to reset these parameters to a consistent reference value, and then assess the influence of this change on the resulting project metric. For this analysis, we used values in the MIT model as this reference, not because we claim that those values are definitive, but rather out of convenience. For instance, in exploring impacts to the AG model, we look at a case with 11% lower nodule metal value. This is the difference between the reported nodule value assumption in the AG model report (net value = $974/dry tonne) and the average value assumed in the MIT model (average net nodule value = $869/ dry tonne).

6.1 Influential Assumptions in the AG model

27. Figure 1 shows the impact of seven assumption changes on the baseline result from the AG proxy-model. Here we define baseline as the first case analysis described in the AG report: an ad-valorem system of 2% of net nodule value for the first eight years, followed by 4% thereafter. For that case, the AG report states an IRR of 27%. The discussions and plot explore changes to that case to understand which assumptions drive the difference in result from the reference model result.

28. The changes are grouped into four categories: 1) changes in timing including assuming a three year production ramp and spreading D&B costs uniformly over that period; 2) changes in costs including assuming less CAPEX and OPEX; 3) change in revenue from 11% less net nodule value; and 4) changes in the fees and royalty system including the inclusion of ISA fees in the cash flow analysis and the assessment of royalty on gross nodule value (not net).

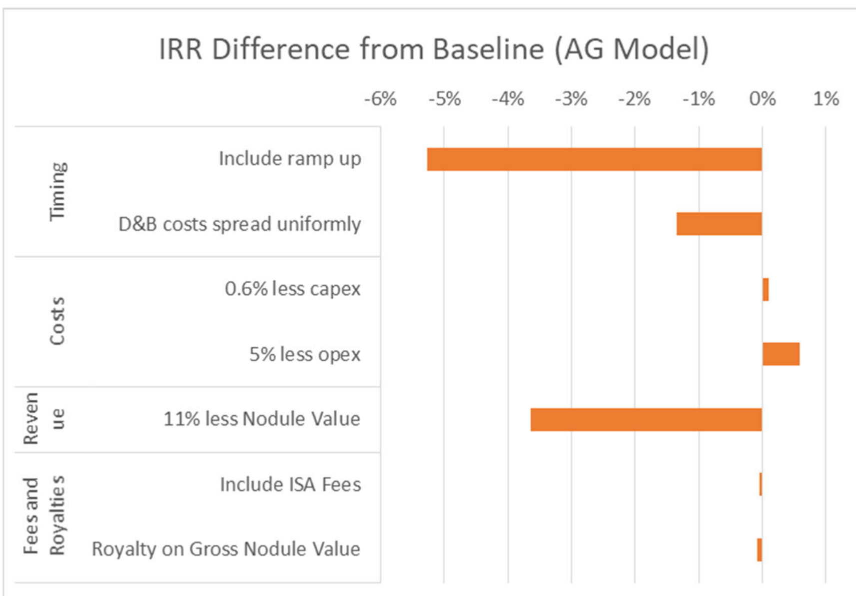

Figure 1. Difference from baseline IRR for the AG model for selected parameters. Baseline is defined as the first case analysis in the AG report for an ad-valorem system of 2% of net nodule value for the first eight years, followed by 4% thereafter. Accept for the row "Royalty on Gross Nodule Value" all rows represent a results for an ad-valorem royalty system of 2% of net value of the nodules for the first eight years then 4% thereafter.

29. Interestingly, the most impactful changes would be including a three year ramp (like the BMWi and MIT models) and assuming the future net value of nodules is 11% less (i.e., at the net value assumed in the MIT model). Note that net nodule value derives from three factors: the composition of the nodules, the metal yield of the processor, and the prevailing price of metals.

30. Interestingly, making only the two most influential changes (including ramp up and 11% lower nodule value), drops the IRR reported in the AG-proxy model from 27% to 18.7%.

6.2 Influential Assumptions in the CSU Model

31. Despite several significant differences in assumptions, the CSU model generates results similar to those reported from the MIT model. (For example, the CSU report lists an IRR of 17.1% for a 2% ad-valorem. The MIT model reports an IRR of 18.1% for that same system.) Figure 2 shows that when compared to MIT model assumptions, the CSU model makes assumptions that would tend to both raise and lower the IRR result.

32. Of the specific changes that were explored, the most influential aspects of the CSU modeling were 1) comparatively low investments, operating costs, and net nodule value, 2) the inclusion of an additional VAT tax, and 3) the exclusion of production ramp up.

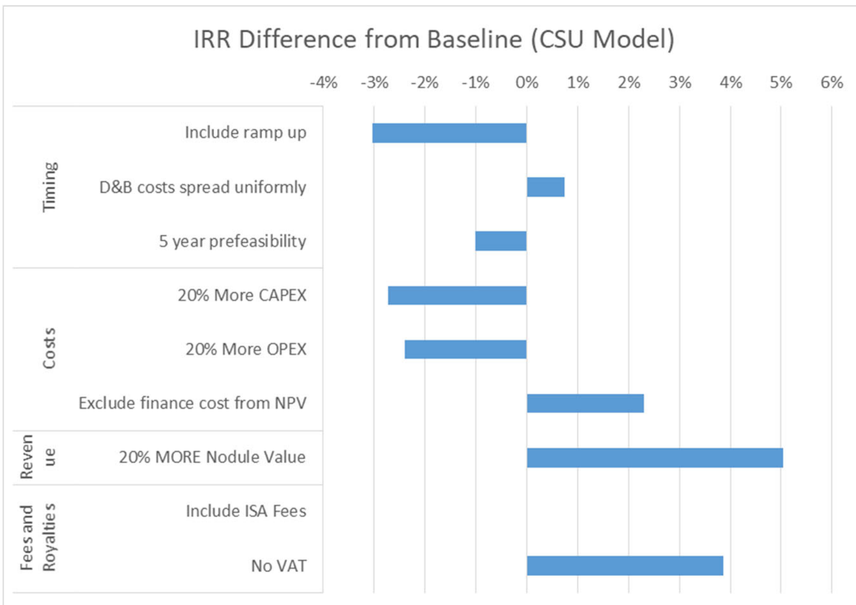

Figure 2. Difference from baseline IRR for the CSU model for selected parameters. All rows represent a results for an ad-valorem royalty system of 3% of gross value of the nodules

6.3 Impact of assumptions on the MIT model

33. Having seen the influential parameters in the AG and CSU models, we now explore the impact of changing these variables on the MIT model directly. Here we analyze the ad-valorem royalty system 2% on the gross metal value for five years and 4% thereafter. Specifically, we select ranges for five key parameters. The ranges are intended to be sufficiently large to capture the range of values suggested by the AG and CSU models. The parameters chosen are: 1) the value of the nodules; 2) the magnitude of OPEX costs; 3) the magnitude of CAPEX costs; 4) the duration of the production ramp up and 5) the timing of capital expenditures. In the analysis of the CSU model, we noted that the inclusion of a VAT was very influential. We do not explore that here because it is a very location specific issue.

34. Figure 3 plots the results of these sensitivity analyses on the MIT model result. From this we see that, while all four parameters can be impactful (particularly in increasing the IRR), the largest influence on IRR is associated with the nodule value. As noted earlier, nodule values derive from nodule composition, process metal yields, and the prevailing metal prices. For simplicity's sake, we did this

analysis simply by varying the metals prices 20% above and below the baseline values used in the MIT model. This range leads to an increase or decrease of IRR by a little more than 4% from the baseline.

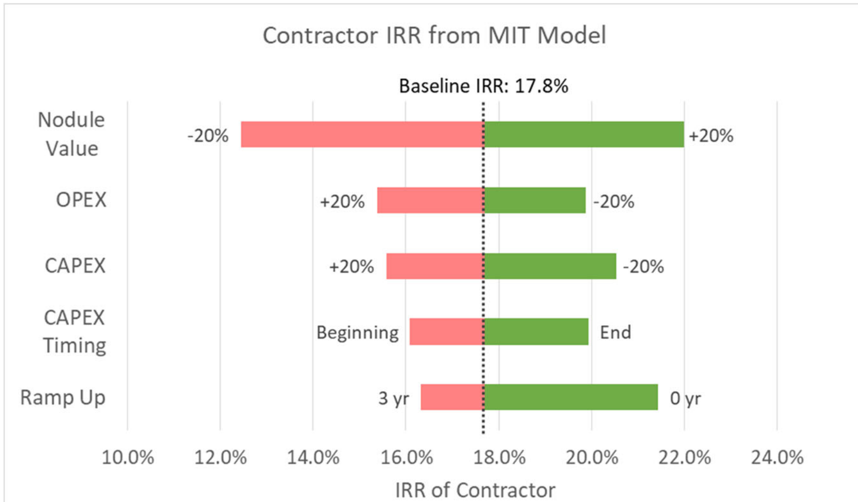

Figure 3. Sensitivity of baseline model results to changes in key parameters. Baseline case represents an ad-valorem royalty on gross metal value for five years followed by a 4% ad-valorem royalty.

7 Conclusion

35. In the end, the four models reviewed here are structurally very similar. Based on the analyses carried out and reported here, the authors believe that the wide range of reported results derives from differences in the input parameters that describe the mining operation being modeled.

36. Some of those differences are methodological in nature. For instance, the CSU model elects to account for financing cost in computing the IRR. Some differences are attributable to the case that was being analyzed. The best example of this is the inclusion of a VAT for an operation in China. Most differences however are assumptions about an uncertain future mining operation.

37. As was noted previously, probably the most influential of these assumption differences are

1) the value of the nodules;
2) the magnitude of OPEX costs;
3) the magnitude of CAPEX costs;
4) the duration of the production ramp up; and
5) the timing of capital expenditures

38. This comparative analysis leads to a shared understanding that these are the key variables that will affect different perceptions of the economics of polymetallic nodule mining. Further discussion of these parameters will be productive to enable the Council to reach consensus on an appropriate payment mechanism for seabed mining.

8 Summary of Key Characteristics of the Models Reviewed

Table 1. Summary of Key Values for the Four Models

	AG	BMWi	CSU	MIT
Analytical framing				
Reported evaluation metric				
IRR	✓	✗	✓	✓
NPV	✗	✓	✓	✓
Revenues to ISA	✓	✗	✗	✓
Revenues to Sponsoring State	✓	✗	✗	✗
ISA share of profit	✓	✗	✗	✗
Sponsoring state share of profit	✓	✗	✗	✗
Other			Break-even time and grade, payback period	
Operational scope				
Collector	✗	✗	✗	✓
Metals Processor	✗	✗	✗	✓
Integrated	✓	✓	✓	✓
Analysis Period	35 years	16	28	37
Exploitation period analyzed	28 years incl. 3 years D&B	16 years incl. 4 years D&B	28 years incl. 3 years D&B	30 years incl. 3 years D&B
Production characteristics				
Scale	3 million dry tons/year	3	3	3
Ramp up period (years not at full production)	0 years	2	0	2
Metallurgical processing	Mn recovered to EMM	High-pressure/high-temperature leaching using sulphuric acid	Mn recovered to EMM	Mn recovered to EMM
Metals recovered (✓ = included)				
Cobalt	✓	✓	✓	✓
Copper	✓	✓	✓	✓
Manganese	✓	✗	✓	✓
Nickel	✓	✓	✓	✓
Metals Content				
Cobalt	0.25%	0.18%	0.22%	0.21%
Copper	1.2%	1.18%	1.02%	1.07%
Manganese	27%	31.5%	27.15%	28.4%
Nickel	1.3%	1.4%	1.27%	1.3%
Metallic yield				
Cobalt	85%	85%	83%	85%
Copper	90%	95%	88%	90%
Manganese	95%	n/a	90%	90%
Nickel	95%	95%	87%	95%

	AG	BMWi	CSU	MIT
Magnitude of estimated future prices				
Notes	Current (2017) spot prices; constant over analysis period	Several scenarios -- projections & recent year averages (e.g., 5yr avg listed below)	Expert-based forecast; constant over analysis period	Expert-based forecast; values listed below represent averages over the production period
Cobalt (USD / tonne)	91,000	28,946	64,855	55,535
Copper (USD / tonne)	6,886	6,745	6,500	6,965
Manganese (USD / tonne)	2,040	980	1,685	1,640
Nickel (USD / tonne)	14,840	14,920	12,862	22,962
Gross Metal Value of Nodule (USD / tonne nodule)	1054	341	830	956
Net Metal Value of Nodule (USD / tonne nodule) Includes metal yield of process	974	318	731	869
Magnitude of estimated operations-related cost cash flows				
Capex				
Prior to exploitation	360	---	210	313
Exploitation – collector	1,276	789	1,100	1,643
Metallurgical Processor	2,415	754	2,000	2,072
Total	4,051 million USD	1,543	3,310	4,028
Opex				
Exploitation – collector	450	91.5	300	413
Metallurgical Processor	670	321	600	654
Total	1,120 M USD / year	412	900	1,067
Salvage value	0 M USD	0	0	500
Site remediation	0 M USD	0	0	50
Magnitude of estimated financial regime-related cash flows				
Sponsoring State Tax rate	25%	n/a	25% + 17% VAT	25%
Royalties	Included	Not included	Included	Included
ISA Fees	0	n/a	0	Licensing fees and environmental levies totaling ~505 M USD