Think Tank: GLOBAL MINERAL SUPPLY AND MEETING THE CHALLENGE OF FUTURE DEMAND

22 October 2021

Moderated by Dr. Marijn Rabaut and Prof. Dr. Em. Johan Vande Lanotte

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Introduction

On October 22, 2022, Ghent University and Bluebridge-Ostend Science Park, in cooperation with Global Sea Mineral Resources NV (GSR), organized a conference ('Think Tank') on "global mineral supply and the challenges of future demand". The main aims of the event were to (1) provide a science-based overview of the global mineral supply chain and the associated challenges and (2) facilitate a discussion and provide an environment where all participants could express their views and opinions freely.

The debate was moderated by Dr. Marijn Rabaut, an independent marine/maritime expert, and Prof. Dr. Em. Johan Vande Lanotte of UGent. To ensure a broad range of perspectives, this Think Tank assembled both national and international academics, NGO representatives, industry researchers and managers and other stakeholders such as policy makers to stimulate and contribute to a debate on global mineral supply and demand from a holistic point of view and within the framework of the UN sustainable development goals (SDGs). The full list of attendees is provided in appendix 1. Due to COVID-19 restrictions the number of people allowed in attendance was limited. Participants were invited *intuitu personae*. Three reports were prepared and made available to the participants[1]. Additionally, a publicly available website has been established that includes a bibliographic repository organized into the themes of the workshop[2].

Covering four major themes, 13 international keynote speakers and specialists from academia and industry were invited to describe the current state-of-the-art knowledge with respect to their expertise and to share their opinions in a debate. Two speakers associated with Ghent University in Belgium were also invited to speak. This report contains a summary of the key points presented and the questions that were addressed.

SETTING THE SCENE

Prof. Dr. Em. Johan Vande Lanotte, Ghent University, Ghent, Belgium

Prof. Em. Dr. Vande Lanotte was Deputy Prime Minister and Minister of Economy and the North Sea between 2011 and 2014. He is professor emeritus of constitutional law at Ghent University and currently a senior legal counsel at a law firm. He laid the policy foundation of the offshore wind energy industry in Belgium. Since 2018 Prof. Em. Dr. Vande Lanotte, has been involved with the work of the International Seabed Authority through Ghent University.

<u>Summary of the talk:</u>

In his introductory remarks, Prof. Vande Lanotte stated that the objective of this conference was to stimulate the debate regarding the global mineral supply and the role of deep-seabed mining in

[1] https://thinktankminerals.eu/documents/

[2] https://thinktankminerals.eu/library/

helping to meet demand. He stressed that a key aim of the conference was an open discussion and he welcomed all evidence-based opinions stating: "Academia, policy makers, NGOs, every opinion is to be heard. We are here to learn. There will be no strict conclusions. Everyone is free to express their opinion."

Prof. Vande Lanotte concluded by providing an overview of the conference agenda[3] and explained that four themes/topics would be explored. Each theme would comprise an introduction by a keynote speaker, followed by two specialist talks and a discussion period involving all participants.

KEYNOTE

Mr. Michael W. Lodge, Secretary-General, International Seabed Authority, Kingston, Jamaica

Mr. Lodge received his LLB from the University of East Anglia and has an MSc in marine policy from the London School of Economics and Political Science. He is a barrister of Gray's Inn, London. Prior to his election as Secretary-General of the International Seabed Authority (ISA) in July 2016, he served as Deputy to the former Secretary-General and Legal Counsel. Mr. Lodge has extensive knowledge of the United Nations and other international organizations. Mr. Lodge has facilitated high-level multilateral and bilateral negotiations at international and regional levels. His significant achievements include his pivotal role in the ISA from its inception in 1996 and helping to create and implement the first international regulatory regime for seabed mining.

Summary of the presentation:

The demand for minerals is rising rapidly. Rising demand is the key factor accelerating the interest in seabed minerals. To accommodate net zero greenhouse gas (GHG) emission targets by 2050, the supply of critical minerals (whatever the origin) needs to increase by huge amounts. Land mining, coastal mining, oceanic/deep-seabed mining are all potential sources, and one is not necessarily better than the other. There are certain advantages and disadvantages related to each of them and we need to discuss these tradeoffs. It is important to note that deep seabed mining is not a new concept. Deep sea exploration began in the 1960s.

The work of the International Seabed Authority (ISA) aims to help in the following ways:

- by responding to the challenge of increasing interest in deep-seabed mining;
- through the development and maintenance of a comprehensive system of regulations regarding deep seabed mining, which is fundamentally based on two key elements: the precautionary principle and transparency (with decision-making based on scientific evidence)
- by encouraging investment in exploration in the Area Beyond National Jurisdiction, currently involving 22 countries.

[3] https://thinktankminerals.eu/full-programme/

Mr. Lodge states that it is the first time that an extractive industry has been regulated before the exploitation starts. The ISA hopes that the benefits of mineral extraction will be available equitably across all countries, including access to minerals and the profits they generate, and access to scientific knowledge. This is a completely new model for resource allocation. Mr. Lodge ended his talk by emphasizing that there should be no production without protection.

> *".. there should be no production without protection"*
> – Secretary General of the ISA, Mr. Michael Lodge

Theme 1 I Climate Change, Population Growth and Metal Demand

This part of the conference shed some light on the phenomenal infrastructure challenges that we face if we are to shift towards a carbon neutral economy. More specifically, it focused on the metal requirements for renewable energy and the electrification of transport, at a time when 140 million people are joining the middle classes annually and the world's population is expected to increase by two billion people in the next 30 years.

SETTING THE SCENE:

CLIMATE CHANGE AND THE URGENCY TO DECARBONIZE WHILE PURSUING THE SUSTAINABLE DEVELOPMENT GOALS (SDGs)

Prof. Dr. Jean-Pascal van Ypersele, UCLouvain, Louvain-la-Neuve, Belgium

Prof. Dr. van Ypersele is a professor in climate and environmental science at UCLouvain and is the former vice-chair of the Intergovernmental Panel on Climate Change. His talk addressed the current trends with respect to climate change, the world's greatest challenge.

Summary of the presentation:

Prof. van Ypersele stated that there is an urgent need to decarbonize, while pursuing the SDGs. Climate change is real and is caused by human activity, mainly through the use of fossil fuels. There is a scientific consensus on anthropogenic global warming. It is widely recognized that climate change adversely affects ecosystems and people. However, there is hope: we have the knowledge and technology to avoid the worst consequences.

Prof. van Ypersele continued his presentation by saying that we have used the atmosphere as a free dustbin for greenhouse gasses (GHGs), resulting in the thickening of the thermal insulation layer around our planet. This insulation layer will keep increasing and will eventually suffocate us, if we do not stop emitting GHGs into the atmosphere. Simply put, this is why we need to reduce net GHG emissions to zero as quickly as possible. If we consider the CO_2 concentration (in ppm) of the atmosphere over the past 10,000 years, it is only in the last 200 years that CO_2 concentrations have started to rise dramatically. This is a result of burning fossil fuels and deforestation on a large scale. Natural systems, including the oceans, can no longer capture all CO_2 emissions. We are adding twice as much CO_2 as can be absorbed by natural systems.

Prof. van Ypersele subsequently summarized the key messages of the sixth IPCC report (2021) as follows:

Human activity has warmed the climate at an unprecedented rate over the last 200 years and other variables have changed. The atmosphere today contains the highest CO_2 concentration than it ever has over the last 2 million years. The sea level is rising faster than at any time in the last 3000 years. Arctic sea ice is at its lowest level in the last 1000 years. Averages of climate parameters (e.g. extreme heat, increased rainfall) are changing as well. To establish what will happen in the future, we can attempt to make projections and not predictions. To make predictions, we have to know how CO_2 levels will evolve, but this is dependent on human activity so we cannot predict this. This is why we resort to developing scenarios and projections. Climate models are able to project global temperatures based on the different scenarios. Feeding these scenarios into climate models yields information. As such, we already know that the arctic and Antarctica are warming significantly more than the tropics. Projections show that if the global temperature were to increase1.5°C, extreme events that would normally occur every 50 years will increase in frequency by a factor of 9. The same is true for precipitation intensity – this is because warmer air can contain more water vapour. Sea level projections show a potential rise of up to 2 m by the end of this century, although the rise depends on the stability of the ice sheets in Antarctica.

Prof. van Ypersele stated that we need to stop thickening the global insulation layer. If we want to stay below a global temperature increase of 1.5°C, we have to reach net zero emissions by 2050. However, over the last 100 years, emissions have been increasing exponentially (by a factor of 1.65). He further discusses the importance of the global human population and the production of CO_2 per capita. To illustrate this point, Prof. van Ypersele shared that the richest 10% of the world's population is responsible for 50% of global emissions. He concludes that although population growth plays a role, control of the CO_2 output per capita is also an important factor.

We are still very far from being on track to reach net zero emissions by 2050. Humanity has a choice about which trajectory to follow. The best framework to look at to make these choices are the SDGs. Humankind should focus on SDG 13 (climate action) in the framework of the 16 other SDGs, including SDG 14 (life below water).

Prof. van Ypersele concludes as follows:

- The IPCC AR6 WGI report confirmed that the habitability of the Earth for its current occupants is threatened by climate change.
- It is important that we listen to climate and biodiversity scientists.
- The challenge is huge: we must consider the SDGs as a package (and not as separate goals).

> *".. we must consider the SDGs as a package and not as separate goals."* – Prof. Dr. van Ypersele

THE ROLE OF CRITICAL MINERALS IN CLEAN ENERGY TRANSITIONS

Mrs. Amrita Dasgupta, Energy Analyst, International Energy Agency (IEA), France

Mrs. Dasgupta is an energy analyst and modeler at the International Energy Agency (IEA), with an in-depth knowledge of - and research experience in - the renewables sector, working on the global clean energy transition. Mrs. Dasgupta is a physicist and engineer alumnus of EPFL, École Polytechnique (l'X) and KTH Royal Institute of Technology.

Summary of the presentation:

More than 40 countries and the EU, making up 70% of today's global Gross Domestic Product (GDP) and emissions, have committed to net zero emissions by 2050, implying a massive acceleration in clean energy deployment. Consequently, many more minerals and metals for clean energy solutions are required (e.g. lithium, nickel cobalt, manganese and graphite are needed for batteries, while copper and aluminium are required for electricity networks).

Clean energy technologies indeed require significantly more minerals than their fossil fuel-based counterparts (e.g. 6 times more for electric vehicles compared with vehicles running on internal combustion engines). The world has enough resources to make the shift to clean energy, but we cannot be certain these resources will be available when we need them at a reasonable price. There is currently no shortage of mineral resources, but recent (high) prices for cobalt, copper, lithium highlight how supply might struggle in the future.

> *".. net zero emissions by 2050 will require a sixfold increase in mineral demand."* – Mrs. Dasgupta (International Energy Agency)

Mineral demand is expected to quadruple by 2040 to reach a scenario consistent with the Paris agreement. An even faster transition is required for a net zero emissions scenario by 2050 and this will result in a sixfold increase in mineral demand. For some minerals, growth will be even faster (lithium) depending on the selected technologies and policies. E.g. for a scenario compatible with the Paris agreement, the demand for lithium will be 40 times higher by 2040 than it is today. It is concluded that the demand for critical minerals is set to soar over the next decades to reach climate change goals.

However, it should be realized that economies of scale are bringing down the costs of these applications. Batteries are considerably cheaper than they were 5 years ago. Still, each supply chain has its own complexities. Production and processing of the required minerals are geographically concentrated, with the top 3 producers accounting for more than 75% of supply. This fact increases the risk of disruption to supply. For example, the Democratic Republic of Congo produces more than 70% of cobalt. There is a looming mismatch between mineral supply and climate ambition. An accelerated energy transition could lead to a rapid depletion of stocks.

From her analysis, Mrs. Dasgupta concludes that there is a need for policy makers to clarify their goals and state how they are going to reach them. To help with this, the IEA has made 6 key recommendations:

1. Ensure adequate investment in diversified sources of supply.
2. Promote technology and innovation at all points along the value chain (e.g. decrease of silver requirements in solar panels).
3. Scale up recycling (to become a significant source of supply). Recycled materials could reduce combined primary supply of minerals by 10%.
4. Enhance supply chain resilience and market transparency.
5. Mainstream higher environmental, social and governance standards. Solutions of climate change cannot work with injustice.
6. Strengthen international collaboration between producers and consumers.

THE EU'S RESPONSE TO GROWING RESOURCE DEMAND

Prof. Dr. ir. Bernard Mazijn, Department of Conflict and Development Studies, Ghent University, Ghent, Belgium

Prof. ir. Mazijn has a rich experience of multidisciplinary research in the field of sustainable development and is one of the founders of the Centre for Sustainable Development at Ghent University. Furthermore, he has been involved in preparing and evaluating sustainable development policies at different levels (regional, federal, international) throughout his career. He is also one of the pioneers of the methodology for life cycle analysis based on social aspects. While still active in teaching and supervising master thesis research at Ghent University, in October 2020, Prof. ir. Mazijn became chief of staff of the cabinet of the Minister for Climate, Environment, Sustainable Development and Green Deal in the Belgian federal government.

<u>Summary of the presentation:</u>

Prof. Mazijn stated that the EU's response to growing resource demand must not be ever growing extractivism. Therefore, he considers the following three issues as critical:

1. Comparing the impact of extractive resource supplies through Life Cycle Assessment (LCA) by integrating the environmental, social and economic dimensions.
2. Recent evolutions: innovations, circular economy and deep-seabed mining.
3. Where and at what level do we set up a global economy?

These three themes require research and education.

Megaforces or megatrends occur in a focused way at a global level and are often defined as an evolution that one cannot grasp very well. Three examples of megaforces are: population growth, welfare and urbanisation. Urbanisation will increase 54% by 2050. For population growth, we expect an increase of 25% by 2050, while for welfare, we expect a rise of 130% by 2050. The latter is particularly related to the increase in purchasing power of the middle class in emerging economies. These megaforces require a growing demand for resources, currently occurring in parallel with a scarcity of water and resources, food security issues, and degradation of ecosystems. To understand the impact of these megaforces, we should look at global carbon inequality: the poorest 50 % of the world population are responsible for only 12% of global emissions, while the richest 1% are responsible for 17% of global emissions. The richest 10% are responsible for almost half of total lifestyle consumption emissions.

Rare earth metals and biomass are required to transfer to a low carbon society and by 2050, the demand for resources may have more than doubled. There are reasons to be concerned for a "war on resources" and several criteria have to be taken into account, not only geological resources, but also economic factors. The rapid growth cannot be sustained by the market as there are limits to market expansion. Some materials are being added to the list (e.g. sand). These raw materials are not in themselves scarce but play a crucial role in future development.

> *".. we need to move away from extractivism through the management of the demand side and through making the supply side more sustainable."*
> – Prof. Dr. Mazijn

What is the implication of scarcity of resources on reaching the SDGs? Prof. Mazijn concludes that we need to move away from extractivism through the management of the demand side and through making the supply side more sustainable.

Discussion with all participants

In the following section, questions from the audience are reported, as well as the responses of the panel members.

Question 1: *The reports of the IPCC, IPES and the international resource panel show that we won't be able to get out of the climate change problem and the biodiversity and resource problems by technology and innovation alone. Decoupling the impact of economic growth and climate change seems necessary. Shouldn't we aim for growth without economic growth? What about those 10% responsible for 50% of the emissions with economies based on overconsumption? Don't we need transformative change of our economies and our lifestyles as well? Why would we just switch all cars to electric when we have a GDP loss of 4% caused by traffic jams? What is your view on transformative economies and lifestyles?*

Responses:

- **Prof. dr. Ir. Bernard Mazijn:** We need a compass other than GDP to quantify growth. For example, our compass could be linked to an index for sustainable development, to orient our policies and our economic activities. This compass should comprise all SDGs
- **Prof. dr. Jean-Pascal Van Ypersele:** Indeed, the IPCC has said that technology is crucial, but we also need behavioural changes and changes in the way society is organised. For these changes to happen, investment is needed. You cannot make such decisions as an individual. It is not a question of growth or no growth. This depends on the sector (e.g. thermal insulation of buildings needs to grow, but companies who continue their investment in fossil fuels will need to de-grow). The societal debate has to decide which sectors need to grow and which have to de-grow.
- **Mrs. Amrita Dasgupta:** Growth and de-growth areas need to be selected. There cannot be growth in all regions in the world and in every sector. We expect growth in developed countries to stagnate, but we cannot expect this for developing countries. Behavioural changes are definitely part of the solution.

Question 2: *We always think of measures to reduce the emissions of those 10% causing 50% of the emissions, but also demographics are mentioned to justify increasing demands. It is not in developed countries that demographics will play a central role as some of these countries have decreasing population. No one ever talks about Africa, where demographics will play an important role. We do not have any measures or policies for those developing countries where demographics will play an important role, as is the case for Africa. What about policies and collaborations with Africa?*

Response:

> **Prof. dr. Jean-Pascal Van Ypersele:** It is in Africa that approximately one billion people do not have access to clean water, electricity or education, so it is difficult to think about ways to decrease their emissions before thinking about these basic needs. All of this relates to SDGs. So indeed, we have to think one step ahead (i.e. to develop Africa in a better and cleaner way) but we have to understand that they want to meet their basic needs first and that it is not our place to tell them what to do as we did in the past. The best way to stabilize the problem in Africa is education.

Remark 1: A view was expressed by a participants that we must be very careful that we do not turn this into an African problem. It is not so much about demographics but rather about politics and we have to make sure that the EU is stepping up in this regard.

Question 3: *What are the contributions of the different sectors to the scenarios of climate change?*

Responses:

- **Prof. dr. Jean-Pascal Van Ypersele:** The IPCC is preparing a new report to look in detail at the different scenarios. However, for climate models per se, only the total amount of CO_2 matters, independent of the sector it comes from.
- **Mrs. Amrita Dasgupta:** The largest growth is currently seen in batteries (lithium, nickel, cobalt) and transport. Industry and developed economies need to tackle those first.

Theme 2 I Europe and The Search for Metal Supply

In this part of the ThinkTank, the conference aimed at providing an overview of how China, the USA and Europe are securing access to future mineral supplies. In the intervention, the challenges the EU currently faces in securing access to metals and minerals in the context of the EU Green Deal were highlighted.

SETTING THE SCENE

Prof. Dr. Jonathan Holslag, VUB, Brussels, Belgium

Prof. Dr. Holslag lectures on international politics at the Free University Brussels (VUB) as well as at various universities. He specializes in Asian affairs, geopolitics, and economic power politics. His last book is titled "Silk Road Trap". Prof. Dr. Holslag worked as a special advisor to the First Vice-President of the European Commission and as an advisor to various other governmental organizations.

<u>Summary of the presentation:</u>

The Chinese government has prioritized resource security and increased control over the minerals sector and aims to achieve this as a mining country, an investor in minerals abroad, and as a key processor. Except for a few specific minerals, however, China has limited control and has not yet come to dominate supply chains. A detailed examination of cobalt, manganese, and nickel, three minerals vital for various strategic industries, illustrate that Chinese mines still deliver less than 35 % of the Chinese demand. Much of Chinese processing capacity is dependent on foreign industries such as electric vehicles. While the ambition of resource security and control has been affirmed, it has not yet been achieved.

Prof. Dr. Holslag stressed that the threat of a clash between different regions (Europe, China) regarding the global supply market is real. China, driven by economic nationalism, mainly prioritizes its sovereignty and economic security. China seeks to achieve this with its strategy in the mining industry. China seeks control over the mining industry (governmental, not the companies themselves) and wants to control the global supply chain. The government has a tight grip on companies and society regarding this topic. China does not consider its basic industries as backward (i.e. industries that we, in Europe, would rather get rid of and outsource to developing countries). China considers basic industries as very important industries for innovation. They are very polluting at the start but they pose huge opportunities for, less polluting, advancements. This approach is in stark contrast to that of European industry. The EU wanted to let these "basic" industries go as the EU is not very eager to try to make them less polluting and more innovative.

China is only about halfway towards what it wants to achieve. China's vision for mining is very ambitious in terms of quality and quantity and aims to make mining highly efficient both onshore and offshore (South-China Sea). If necessary, they will find new resources abroad. As such, onshore China remains the biggest investor in the minerals industry. China believes that the last 20 years were "adventurous years" (i.e. polluting etc.), now the emphasis shifts towards more advanced set-ups (e.g. Belt and Road initiative, the new Silk Road). China has a blueprint of the entire continent for potential exploitation sites. It is trying to make sure that when it invests, it is worth it. Not all investments are profitable, but capital is available and China is learning.

Prof. Holslag further explained that, in terms of mining, China's role is still modest, but we must remember that China is only at the start of its aspirations. China also does not currently dominate downstream activities in the mining industry. In absolute terms, it is a very big player with respect to mining volumes, but in relation to its consumption, it is a rather humble player. Hence, China remains a rather modest miner overall.

Considering the EU, Prof. Holslag noted that for the last 16 years, the EU has had policies on mining and the mineral supply chain in place. In terms of production, the volumes in Europe have decreased and mining in the EU is currently almost absent. Also, in terms of processing and supply chains, numbers are going down. Moreover, EU investments in mining outside of the EU are decreasing. For the US, such investments are also stagnant. China, on the contrary, is investing heavily and still considers this to be insufficient.

> *".. in terms of production, the volumes in Europe have decreased and mining in the EU is currently almost absent."*
> – Prof. Dr. Holslag

Prof. Holslag concluded his talk by posing these questions: "why is the proposed supply chain in terms of deep seabed mining any different? Why should we expect to be it different in Europe? We want to have our own supply chain, but what certainty do we have that the capital will be allocated? Resilience along the supply chain is aspired to, but will it be achieved? Looking at the past, why would this time be any different?"

ASSESSING CHINA'S MINING DOMINANCE

Mr. Peter Handley, EU DG GROW, Brussels, Belgium

Mr. Handley is Head of the Energy-Intensive Industries and Raw Materials Unit in the European Commission's Directorate-General for Growth. He was previously Head of the Resource Efficiency Unit at the Secretariat-General, where he was responsible for coordination of the Energy Union, 2030 climate and energy package, low emission mobility strategy and the circular economy programme.

<u>Summary of the presentation:</u>

In response to the presentation of Prof. Holslag, Mr. Handley stated that two elements should be added to the analysis of China's strategic vision on mining. China is amassing patents and knowledge in, among other areas, metallurgy and material science and it is more advanced than the rest of the world in these areas. Moreover, China is rolling out standardisation strategies and is becoming significant in ISO standardisation committees. Mr. Handley points out two main challenges:

- The access to critical raw materials is a geopolitical challenge, specifically with regard to resource security and competition. History teaches us that those who have (geopolitical) control over such resources, also drive innovation and hold the power and wealth. However, control over resources has also led to environmental damage, human cost and conflict.

- Planetary boundaries are potentially being exceeded. Sustainable resource management and efficiency have to be attained. The climate debate focuses too much on trying to eliminate GHGs, while we also have to look at the economy to see how pressures will shift. Mitigating climate change shifts pressure to raw material use, because technologies that deliver climate change mitigation require mineral resources.

> *"Mitigating climate change shifts pressure to the sourcing of raw materials, because technologies that deliver climate change mitigation require mineral resources."* – Mr. Handley, EU DG GROW

The EU has been focusing on identifying its strategic dependencies and exploring ways to mitigate supply risks. In September 2020, the EU presented an action plan with four major topics: building resilient value chains, how to organize resource efficiency and circularity, how to do better domestically and how to diversify internationally. Progress has also been made on the investment side. There will be funds for the best projects coming out of the European Raw Material Alliance and the European Battery Alliance.

Mr. Handley emphasized that domestic EU mining needs to be addressed. It would be irresponsible to outsource mining completely to other economies which do it in a less responsible manner than the EU would. He further stated that on the international front, the EU has been cooperating and building strategic partnerships with, among others, Canada, a reliable partner with experience in mining and a country that shares our values, and with our neighbours Ukraine and Serbia. The EU also aims to invite African countries to engage in developing raw material value chains and to help them develop their industries in a cleaner way. This global gateway approach is a new way of doing business, where the EU can help with soft and hard infrastructure.

Mr Handley presented a case study using the magnesium supply chain. The EU is 100% import dependent and almost 95% of its imports come from China. But China recently stopped producing magnesium due to high energy prices, meaning the global and EU supply chain is impacted (as magnesium is used for alloys and steel desulphurization). The effects on the supply chain quickly escalate given we are dependent on decisions of other countries/parties. This illustrates the need for the EU to get downstream sectors to commit to build a European supply chain that adheres to our values concerning the environment, even if the products cost more. Mr. Handley stated that the cost of investing in resilience is less than the cost of disrupted supply chains.

Mr. Handley concluded that he is concerned about possible conflict, and about overstepping planetary boundaries. Moreover, he underlined that global governance is currently lacking and asked whether it is possible to rein in the ambitions of countries like China.

GLOBAL MINERAL RESOURCES: CASE FOR CAUTIOUS OPTIMISM?

Prof. Dr. Gavin M. Mudd, Environmental Engineering, School of Engineering, RMIT University, Melbourne, Australia

Associate Prof. Gavin Mudd is a member of the Environmental Engineering department at RMIT University, Melbourne, Australia. His research interests include environmental impacts, management of mine wastes, acid mine drainage, sustainability frameworks, life cycle assessment, groundwater and mine rehabilitation - and is a renowned expert on the sustainability of mining.

Summary of the presentation:

The global mining supply chain produces a vast array of metals, minerals and energy. Prof. Mudd explained that there are two schools of thought regarding global mineral sources:

- There is a fixed stock, meaning Earth's resources are finite and mining is, in itself, not sustainable;
- There is an opportunity cost associated with mining. Resources will always be supplied as market prices set the costs of supply.

Since the 2002 Johannesburg Earth Summit, global mining has committed to improving its sustainability performance. Yet, modern mining is facing many problems (e.g. declining ore grades, increasing mine wastes, regulatory compliance). Important questions that require answers in the near future include: How does mining connect to climate change? How do we bring more sustainability into the mining sector while facing difficulties like degrading ores? These key questions revolve around finding new deposits, the way in which they are mined and the environmental standards of mining operations. To date, all these issues remain poorly studied and documented.

There is a long term decline in mineral resources (as exemplified by nickel and copper). Along with the previous concerns and questions, Prof. Mudd stated that we must think about what we mine, where we mine and how we mine. Although these questions seem obvious, there are only a few limited studies addressing these questions at a global level.

Looking at global copper resources, current mining is located in enriched zones. Global copper trends confirm Skinner's distribution from the 1970s, proposing a bimodal distribution for minerals. Skinner's distribution illustrates that these enriched zones are different and unique compared to the average crustal rock zones. The switch from these enriched mineral deposits to average crustal rock is the mineralogical barrier. Concerning manganese nodules, their grade is decent and the deposit size is certainly large. Nonetheless, like any mining project, there are other aspects related to mining them that must be considered, such as biodiversity issues and energy costs. Prof. Mudd then discussed the long-term trends in copper. The availability of this metal is declining based on long-term datasets from different countries throughout the world. This decline results in higher energy requirements to extract the metal and more waste left behind by mining activities.

Looking at global nickel mining, we see that there is a rise and fall of mining in different countries. To understand the bigger picture of these trends we need to examine what types of ores are being mined. Since the mid-20th century, there has been a shift towards nickel laterites. Laterites are more abundant but are much more energy intensive than other ores/sources. Laterites are typically higher in nickel grades, but the value, when compared with nickel sulphide deposits, evens out if one also factors in the by-products. Ore grades of both laterites and sulphides are declining. For laterites this decline is consistent and steep. Nickel demand is expected to grow exponentially with the transition to renewable energy and electric vehicles that require batteries.

Prof. Mudd underlined that LCAs should be framed in terms of mining. As ore grades go down, energy costs and carbon costs go up. The important question is how we tackle these degrading ores. Mechanisation would increase energy costs, while innovation and new technologies could lower energy costs. At the moment there is no active deep-seabed mining, so, LCAs for such activities cannot be validated using operating data as is the case for terrestrial mining.

> *"Decreasing ore grades and, arguably, increasing mine wastes, are leading to higher energy costs, putting pressure on carbon costs."* – Prof. Dr. Mudd

Prof. Mudd concluded that of all the metals/minerals studied, there is no evidence of resource depletion. On the contrary, new deposits and expanding resources have always been found to meet global demands (e.g. Cu/Ni). The great challenge of modern mining remains the increasing environmental (and social) footprints and mine wastes. Decreasing ore grades and, arguably, increasing mine wastes are leading to higher energy costs, putting pressure on carbon costs. There are a variety of solutions or approaches, but we have a long way to go to find these and to transition mining to the 21st century needs and demands

Discussion with all participants

Question 4: *How significant is the amount of metal available from deep seabed mining? It is worth recognizing that the amount of nickel needed to double the amount we have available today would require opening 60 mines on the deep seabed? About 500,000 km^2 of seabed would have to be mined to produce 50 million tonnes of nickel. Scientists say that the actual footprint of that operation would be up to three times that of the mining itself, given the plume flows of the seabed and other knock-on effects. With that footprint, do we really need to keep building batteries with that much nickel? Could the EU invest in different types of batteries (iron sulfate, for example) and other technologies that do not require such metals causing effects on land and in the deep sea? Is the ocean the next playground of geopolitical access for resources?*

Responses:

- **Prof. Dr. Jonathan Holslag:** For China, it has always been a contest. When China talks about the sea and its resources, they use the word "battleground". China's push is going to be decisive. India and South-Korea have the innovative push, but China has the investment capital that it is willing to use in this context. If China decides to go with deep-seabed mining, it will be big and hard to resist.
- **Mr. Peter Handley:** It has already started, this conflict. We are internationally collaborating in the context of the G7. Also other types of batteries are being looked at.
- **Prof. Dr. Gavin M. Mudd:** There are indeed lots of technologies. Although, battery technologies might change, we still need the metals and China will still be involved. One of

the basic questions we have not answered concerns biodiversity and environmental issues related to deep-seabed mining. Often the data being used to address these issues is not representative and we simply do not have the data needed to answer these questions. We need to think about what we mine and where we mine.

Question 5: China already has a circular economy policy, are they equally focussing on their secondary metal production? Same question for the EU.

Responses:

- **Mr. Peter Handley:** In terms of glass, wood, and base metals recycling has always been quite good in the EU. For certain critical raw materials on the other hand, this has been less than 1%. We must do more to create these economies required for circular economy.
- **Prof. Dr. Gavin M. Mudd:** We cannot wait for circular economy to be put into place later. We have to think about this now, while we are making the transition.
- **Kurt Vandeputte (Umicore):** China is rolling out this technology. The global battery alliance has been launched and discussing what information should go into a passport. One of the key reasons to have such passport is to increase the possibility of recycling. We need global regulation to increase recycling rates.

Question 6: *Demand management seems to be lacking in ambition. Adopting a binding EU reduction target might be useful, as suggested by NGOs. What is your view on binding material footprint targets in the EU?*

Responses:

- **Mr. Peter Handley:** You can only set a target for what you can measure. We thus need to improve understanding of how the different kinds of materials are used. Only on the basis of good evidence, can such strict standards be set. You also have to keep in mind that there is a rest of the world out there, so you have to address this on a global scale. There is insufficient understanding of the relationship between GHG reduction and what this means in terms of resources.

Theme 3 I Recent evolutions: Innovation, Circular Economy and Deep-Seabed Resources

In this part of the Think Tank, the conference aimed to address when and to what extent innovation is likely to affect demand and to what degree recycling can impact/reduce demand. Additionally, the conference aimed to explore different options and trade-offs to meet future metal demand and if a more circular economy can be achieved. It also tried to elaborate on the level of 'circularity' of today's economy.

SETTING THE SCENE:

METALS, TECHNOLOGIES AND INNOVATIONS

Prof. Dr. Eric Pirard, ULiège, Liège, Belgium

Prof. Dr. Pirard is a full professor of Mineral Resources at the Department of Urban and Environmental Engineering of the University of Liège. He is the academic coordinator of the European Master in Resources Engineering (EMerald) program and Prof. Dr. Pirard is an expert in resource characterization and the circular economy of minerals and metals. His research group is active in developing artificial intelligence and low energy technologies for extracting metals from complex ores and end-of-life products.

<u>Summary of the presentation:</u>

In his introduction, Prof. Pirard reported that "green growth" requires the use of more metals: there has been an exponential growth in their use since the 1960-80s, which is a result of technologies increasingly relying on metals. Raw material consumption is concurrently decreasing according to Eurostat 2020. However, the apparent raw material consumption and statistics do not reflect all metals imported within finished products. There is a need to monitor the flows of metal and promote/evolve to circular use. It will take a long time to establish a circular economy, for now: new metal inputs will still be needed and waste generation will still occur. Currently, four challenges have been identified:

1. **Feeding the loop:** recycling alone will not be enough to meet growing resource demands. For example, Nickel stocks today represent only 30% of the anticipated needs. Without mining, we cannot cover the current needs. Hence, responsible sourcing is required and polymetallic nodules could be one of these sources.
2. **Designing the loop:** we need to think further about how we use resources after extraction. The full picture, from cradle to cradle, should be taken into account rather than solely the use phase. Moreover, it is important that functionality is not lost at the expense of recyclability. For example, aluminium batteries are completely recyclable, but are far too heavy for use in electrical cars. Li/Ni batteries, on the other hand, are too complex (in internal structure) to de-manufacture.
3. **Slowing down the loop**: In this regard, single use products should be banned and the lifetime of all goods extended.

4. **Closing the loop**: The whole chain should be reindustrialised to make sure that the loop is closed at the regional level (sorting). To aid in sorting, we can develop robots with smart sorting capabilities (e.g. identification based on composition of alloys/stainless steel).

Finally, one should keep in mind that even with a highly efficient process recovering 95% of the metal content of a product, half of the material will have dissipated after only 14 cycles. Hence, these cycles must be extended for as long as possible. This recommendation is best summarized by the concept of "slowing down the loop".

BATTERY MATERIALS IN CLEAN MOBILITY

Dr. Kurt Vandeputte, SVP Government Affairs Umicore, Antwerp, Belgium

Dr. Vandeputte joined Umicore in 1997. In 2003, he moved to a technical marketing role for cobalt containing products used in the Li-ion battery supply chain. After several leadership assignments in marketing, research, sales and production he was appointed Senior Vice President (SVP) of Umicore Rechargeable Battery Materials Business Unit in 2017. In October 2020, he was appointed SVP global Government Affairs of Umicore.

Summary of the presentation:

Umicore is the world's leading recycler of complex waste streams. Umicore holds an exceptional position in recycling, recovering over 20 metals using unique technologies treating production scrap, by-products and complex residues. Regarding the circular model, Umicore is part of the upgrading of raw materials (purifying) and making it part of the product (e.g., through conversions, chemical activation). Umicore is also involved in the end-of-life of these products.

Dr. Vandeputte discussed that electrification (of a.o. transport and industry) encompasses the transition from single use fossil-fuels to multiple-use and high efficiency metals (Electrification forecast, McKinsey, 2021). According to the McKinsey forecast, it is hard to predict at which speed this electrification will occur. However, as electrification increases, the physical supply chain needs will necessarily follow. If one link is missing, the whole supply chain will be impacted. For example, currently, there is a shortage of (computer) chips for vehicles. As a result, almost-complete cars are sitting in parking lots of the manufacturers, waiting for these final missing parts. Car companies realize that they are facing the end of a linear model. Hence, they are all starting to become involved in mobility services in the future.

Dr. Vandeputte continued his presentation by illustrating the importance of the cathode for battery performance. He underlined that a faster charging rate, longer battery power, the cost of the battery and the embedded CO_2-impact are all dependent on which metals are used in the cathode (e.g. lithium cobaltite or new generation metals). Umicore is currently producing new/alternative cathodes based on innovative extraction processes that reduce energy and intrinsic CO_2emissions and costs.

Dr. Vandeputte further explained that thermodynamics and historical habitats in industry and trade determine the current state of battery production (also in terms of embedded CO_2 costs in metals) and how this could be improved in the future. The metal resource is oxidized and distributed in a low energetic level around the globe. Historically, we purify the resource into the metal state, this is the solidification phase. As this involves a chemical reduction, it is energy consuming. After this step, the cathode material is produced (chemical reduction). This last step produces hydrogen that currently is not captured. In an innovative extraction processes will skip the solidification phase. This is the big improvement.

What is the impact of recycling on current metal needs (for energy applications)? Dr. Vandeputte stated that recycling everything available on the current market would only provide, based on a very optimistic scenario, 10% of the future needs (related to green energy shift).

> *"Recycling everything available on the current market would only provide, based on a very optimistic scenario, 10% of the future needs."* – Dr. Vandeputte, Umicore

WASTE AND MATERIALS MANAGEMENT IN A CIRCULAR ECONOMY

Mr. Dirk Van Nelen, R&D researcher sustainable material, VITO – Flemish Institute for Technological Research, Mol, Belgium

Mr. Van Nelen is a senior researcher on sustainable resources management, contributing to the development and implementation of strategies for waste and materials management in a circular economy. His current research topics focus on urban mining, recycling, life cycle and value chain sustainability assessment, industrial ecology and industrial symbiosis. Mr. Van Nelen is involved in a number of initiatives driven by European wide partnerships.

<u>Summary of the presentation:</u>

Materials acquire value from their function and relevance for satisfying fundamental human "needs". These needs are constant through cultures and over time. Human "wants" on the other hand, as proposed by Neef (1986), are strategies to satisfy these few, finite fundamental needs. These can never be satisfied (infinite and insatiable), differ between cultures, and are not constant through time. This is why it is possible to change habits, policies and material needs.

Mr. Van Nelen then discussed aspects of linear versus circular economies. The linear model was dominant until recently and was focused on waste management. We used a waste hierarchy. In a circular economy (CE), the focus is more on stock management. CE is about what we already have, and what comes before the waste step. The aim is to maintain the value of materials over time, as such time is a very relevant factor.

Different key elements define performance of a linear and a CE. There are various indicators to measure performance for both economies. We cannot establish the success rate in CE, using the parameters used in linear

> *"The circular economy contains a waste-resource paradox: transforming waste into value, increases demand for that waste."* – Mr. Van Nelen, VITO

economy: CE is not about materials, it is about products. We are moving from a material-centred linear economy to a product-centred CE. The CE contains a waste-resource paradox: Transforming waste into a value proposition, increases the risk creating a demand for the waste stream. Hence, the CE is a balancing act.

The objective of establishing a CE is not circularity but sustainability. Material scarcity is the driver. The historic answer to resource scarcity has always been system expansion, not decreased resource consumption (e.g. carbon-based energy). The only metric that matter for measuring CE progress is the absolute primary resource consumption per unit of time. Secondary raw materials are only relevant when they can in fact substitute primary resources: avoid rebound and increased material throughput.

THE EUROPEAN POTENTIAL OF POLYMETALLIC NODULES IN THE CCZ REGION

Dr. Carsten Rühleman, Chief Scientist of the Federal Institute for Geosciences and Natural Resources (BGR)

Dr. Rühleman is a marine geologist at the German Institute for Geosciences and Natural Resources (BGR) and is the project manager for the exploration of manganese nodules in the German ISA contract area. He has participated in more than 20 ocean-going expeditions.

Summary of the presentation:

Dr. Rühleman provided an overview of the European potential of polymetallic nodules in the Clarion Clipperton Zone (CCZ) as a metal source for the future production of batteries in Europe.

Several European countries have an exploration contract for polymetallic nodules in the CCZ (GSR - Belgium; BGR - Germany; IFREMER – France; 2x UKSRL – UK; IOM – consortium of Eastern European countries). In total, there are 17 contract areas in the CCZ. The CCZ is known for its dense coverage of polymetallic nodules, with high contents of manganese, nickel, copper and cobalt, which are all important raw materials. Dr. Rühleman reports that these materials are urgently needed for the transition from the hydrocarbon era to a renewable energy era, especially for electro-mobility.

The total size of the 6 exploration areas is 433,000 km^2. BGR is currently the only European contractor that has published detailed data of the resources present in the area (i.e. 600 Mt of dry nodules in an 75,000 km^2 area). It is currently uncertain how many of these nodules are present in the other six areas. However, based on the available data, Dr. Rühleman presents the following estimates. The eastern part of the BGR exploration area contains about 540 ± 140 Mt of dry weight nodules which were found on a total area of 60,000 km^2. Hence, conservative estimates indicate the presence of 600 million tonnes of dry weight nodules in the entire BGR contract area of 75,000 km^2. Based on this estimate, at least 500 Mt dry weight nodules would be present in the GSR (Belgium), IFREMER and IOM exploration areas and 3,000 million tonnes in total (in the six areas). These are conservative estimates. Not all polymetallic nodules can be collected as some of regions will need to stay untouched for environmental reasons. On the other hand, it is uneconomical to mine a seabed for only a few nodules.

> *"European contract holders have access to battery metals for at least 280 million 60kWh batteries."* – Dr. Rühleman, BGR

Dr. Rühleman suggests a theoretical potential of 2,000 Mt of nodule resources, and based on the average metal content, this could provide 26 Mt of Ni, 4 Mt of Cb, 24 Mt of Cu and 540 Mt of Mn. As such, European contract holders have access to battery metals for at least 280 million 60kWh batteries, representing 17,000 GWh, which could supply a large part of the 36 planned European gigafactories (430-770 Gwh/Year; 25 years; Total required: 10,750-19,250 GWh). The mining of 145,000 km² would take about 100 years, according to the current technical plans and capacity of the nodule collectors.

Discussion with all participants

Question 7: *Circular economy (CE) is basically already some kind of stock management? Could you elaborate on what you mean with 'stock management'?*

Response:

- **Dr. Kurt Vandeputte:** The overarching principle of CE is still "in definition", but everyone agrees that CE should preserve the functionality of products over time. This functionality is moving from waste management to stock management. Recycling means that the product/waste has to be taken apart in its several originating compounds. Using the entropy analysis, we look at the effectiveness of the recycling metabolism.

Question 8: *To clarify, did I understand correctly that we would need 6 times the extraction rate than that what is physically possible? In all of the areas held by Europe?*

Response:

- **Dr. Carsten Rühleman:** If we want to produce enough nodules to keep pace with the battery production, we would need to be 6 times faster than we are now with the current technology of nodule collectors. We would have to mine 4 times as fast (current speed 200-300 km²/year). This could potentially be solved by deploying more collectors at once.

Question 9: *The calculation you made excludes import from other countries? Europe extracts nodules for production in Europe?*

Response:

- **Dr. Carsten Rühleman:** Indeed, it's just a calculation to demonstrate the potential of the nodules.

Question 10: Could you clarify the value chain development of manganese in Europe? Who would be the miners/the consumers? Do we have processing companies in Europe?

Responses:

- **Dr. Kurt Vandeputte:** The industry in Europe is equipped to convert these metals e.g. cobalt refining industry and such techniques are interchangeable between metals. Typically concentrates are upgraded in such factories. Subsequently, there is a chemical conversion and lithium is added in a third step (dry powder mixing and cooking at high temperature). Umicore was the first to develop it in Europe, but more players are coming on the playing field of metal transformation. Hence, this value chain will appear in Europe. Production of concentrates themselves is usually done at the mining site itself so we do not have this type of industry in Europe yet.
- **Mr. Dirk Nelen:** It seems obvious if we conclude that CE is mainly about stock management that the CE would not be appealing for the seabed mining industry. However, we have always tackled resource scarcity by pushing system boundaries. Seabed mining is also a form of system expansion. Asteroid mining is another example.
- **Prof. Dr. Eric Pirard:** There is nothing special in asteroids according to geologists. I do not see why we are talking about asteroid mining before more exploration on this planet. We do not know what exists 500 m below our feet. We need techniques to explore in depth, but such techniques do not exist yet. For stock management (with the CE), we first need enough nickel in the CE so we have to think about these techniques as well. I am not worried about the amount of resources, we will just have to go deeper.

Question 11: We have been saying all day long that we have enough resources, so do you see deep-seabed mining as something useful or should we just mine deeper as you have explained?

Response:

- **Prof. Dr. Eric Pirard:** Personally, I see deep-seabed mining as a quick win. We have the technology today to make this possible, so it is a quick win to mitigate the resource supply disruption we are facing. On land, after a deposit has been identified, it requires another ten years at least to develop a new terrestrial mining project.

Question 12: Do we have in Europe the possibilities to manage stocks. How long would it take to develop such stock?

Response:

- **Mr. Dirk Nelen:** The discussion concerns the definition of stock management. Recycling can be part of such management but recycling alone will not be enough to respond to the enormous increase in demand. However, we have the knowledge and capacity to perform stock management in Europe. Stock management has a cost. For example, for recycling collection and separation, costs could be significant. The investment must make sense, which is why a CE is a balancing act including yields and costs.

Question 13. A large amount of waste produced in Europe ends up in Africa. What can we do to tackle this?

Response:

- **Mr. Dirk Nelen:** That is not entirely true and needs some nuancing. There has been an effort of the (EU) Commission to determine the destination of waste through an Interpol report. It was found that most was going to Eastern Europe. Nonetheless there is a flow of - among other things - vehicles to Africa. Here in Europe, we can take parts out. African mobility on the other hand, is based on second hand vehicles. They still can be used over there, and it is too expensive to dismantle them here. Problems related to managing our vehicles are not related to these vehicles themselves, but rather to the general work conditions that are apparent in most sectors in Africa. It is thus a poverty problem and this is where Europe can play a role rather than halting these waste streams.

Question 14: It was mentioned earlier that *harvesting deep-sea nodules can be seen as a quick win. Nonetheless, considering the surface areas that are required, would this not just be a temporary solution? Moreover, what about the environmental damage related to the harvesting of these exhaustible nodules? Wouldn't moving into the deep-sea halt the innovation that is necessary now to transfer to a low carbon society? Are we creating a new addiction to metals, like our current addiction to fossil fuels?*

Responses:

- **Prof. Dr. Eric Pirard:** Polymetallic nodules are indeed exhaustible. Concerning environmental impacts, for example on biodiversity, it is difficult to make statements, although current other sources of nickel are likely worse. Moreover, we are also performing other activities on the seafloor that are not even discussed. Battery technology is evolving, but this will take years so we need an intermediate solution until stable as mature technologies are developed.
- **Dr. Carsten Rühleman:** We need to put this in perspective. I do not think we need continuous production of metals from seabed nodules, maybe only for a few decades.

Question 15: There is still the issue of the unknown impact on biodiversity. You also mentioned deep-seabed mining is a quick win because there is often a lot of social resistance against terrestrial mining projects. However, there is already quite some resistance against deep-seabed mining as well and it is growing.

Response:

- **Prof. Dr. Eric Pirard:** I would like to put into balance the significant environmental and social impact of the current nickel sources. Also the targeted area in the pacific (CCZ) is only a small part of the entire Pacific Ocean.

Theme 4 l Comparing Impact through Life Cycle Assessments

In this theme, the conference aimed to address the impact deep-seabed (nodule) mining could have on the sustainability of metal production and consumption. The set of decision-support tools available (in this context) will be discussed. The conference also aimed to focus on the impact on society of collecting polymetallic seafloor nodule ores versus terrestrial ores from a carbon emission and sequestration perspective.

SETTING THE SCENE:

MINING: IMPACT AND CHOICES

Prof. Dr. Jo Dewulf, UGent, Ghent, Belgium

Prof. Dr. Dewulf is a principle investigator at the Department of Green Chemistry and Technology, UGent, Belgium. His research focuses on clean production with emphasis on resources, relying mainly on thermodynamic principles and life cycle thinking. Prof. Dr. Dewulf and his team have recently worked on a life cycle assessment comparing land-based ores with polymetallic nodule ores as metal sources.

Summary of the presentation:

Prof. Dewulf stated: No poverty, no hunger, … My take on the SDGs is everything is for everyone. For how many people do we want to make SDGs happen? Population growth is the elephant in the room. Nobody talks about it, but there are some constraints. The planetary boundaries (based on the paper from Rockström et al., 2009) have already been exceeded for nutrient balance, climate change and biodiversity loss.

We have to mitigate climate change, Prof. Dewulf continued. We need a sustainable energy transition to harvest and to store energy. This requires specific material needs. Using a balance as a metaphor, Prof. Dewulf stated that we need to lift climate impacts, but this requires specific material needs to make this happen (a cost), to build the required infrastructure". For these material needs, there are several scenarios available from, among others, OECD and the European Commission. Projected needs according to the European Commission are, for example: a quadrupling metal demand by 2060 and, respectively, a three and tenfold growth in nickel and cobalt demand by 2050. Prof. Dewulf noted that, in the 1990s, when we already faced some environmental limitations/issues, there was a school of thought that clearly advocated the need to dematerialize. Prof. Dewulf contrasts this with what we say now: "we need more metals".

Is setting up a new value chain sustainable in the context of dematerialization? Prof. Dewulf presented some tools that are available that he referred to as the lifecycle sustainability assessment toolbox, which are applied for identifying the footprint of an activity. Prof. Dewulf stated that we do not only have to consider carbon footprint, but also environmental footprint, social impacts and so on. The key set of tools are a Life Cycle Assessment (LCA) which considers the environmental pillar, a Social Life Cycle Assessment (sLCA) and a Life Cycle Costing (LCC), representing the economic dimension. Methods addressing environmental impacts such as LCA are the most advanced.

Prof. Dewulf underlined that we are focusing on the burden of production and consumption. To a lesser extent, however, do we focus on the benefits which are important as well. When it comes to metal supply, we aim to add primary metals to the functional stock. This is the reason for mining. Yet, metals are not added to the functional stock at all, based on his study looking at cobalt in the European Union in 2016. We added about 11,000 tonnes (10,821 t) to the functional stock. To make this happen, we needed an extraction of nearly 36,000 tonnes (35,954t). This means that 70 % got lost in tailings, landfilling, downcycling & hoarding. With 70% loss, we can't claim circularity.

Prof. Dewulf then introduced the two key strengths of environmental sustainability assessments using LCAs. First, it is a life cycle approach, taking into account the different life cycle stages (extraction, manufacturing, transport, …). Second, multiple environmental impacts are accounted for (more than just climate change). Typically, we identify 10 to 20 environmental impact categories (e.g. acidification). It is thus an umbrella methodology and depends on the state-of-the-art of the understanding of the respective impact categories and the developed methodologies to study those categories. Regarding the carbon footprint recommendation from the European Commission, we are quite confident that we can model this impact category, applying the current scientific knowledge (e.g. data from IPCC, …), to assess the footprint of a certain production and consumption system. However, it should be recognized that there are also some impacts that are not included in the environmental footprint methodology: biodiversity is a very difficult impact category and biodiversity methods are not mature enough to be integrated in LCAs.

Prof. Dewulf and his team recently applied the sustainability assessment toolbox to deep seabed mining and examined the three pillars of impact: economic, social and environmental. Their major conclusions were:

- **The macro-economic impact:** Deep-seabed mining can indeed affect supply to the EU. The extent (how big/small), however, is uncertain at this time.
- **The social impact:** deep-seabed mining will likely have a social impact as well, although currently there are only some semi-quantitative indicators that are used. Based on an EC-JRC Technical report (2020) on the responsible and sustainable sourcing of battery materials, indicators of the social impact of cobalt mining in Congo DR, negative impacts related to child labour, global peace index, etc. were identified. If deep seabed mining is carried out, the social impacts will change on a global level. How it will evolve is not yet clear.
- **Environmental sustainability assessment** (of deep-seabed mining activities) by LCA poses some challenges. (1) A classical LCA is not possible, as there are currently no operating data available. Only a prospective LCA is feasible, but this comes with uncertainty. (2) Some impact categories are mature (e.g. climate change) in terms of their potential applications, and our understanding of the cause-effect chain. Yet, no quantitative impact assessment is possible for the biotic system. Prof. Dewulf concludes with citations from a review paper on deep-seabed mining: "the effects of mining activities on deep-sea ecosystems are poorly known but are likely to be long-term."

Ghent University performed a quantitative prospective impact assessment on 3 specific impact categories: climate change, acidification and photochemical oxidant formation in terms of deep-seabed mining. The authors studied the value chain, starting offshore with nodule harvesting in the

CCZ, followed by transport to the shore and processing of the full nodule into commodities (the functional unit) in two different countries.

> *"Regarding climate change, the study found a potential reduction in CO_2 emissions of about 30-40%..."* – Prof. Dr. Dewulf

Regarding climate change, the study found a potential reduction in CO_2 emissions (compared with land-based mining) of about 30-40%, depending on the scenario. The authors did not find a clear difference for photochemical oxidant formation, but for acidification there is a significant reduction potential associated with deep-seabed mining compared to land-based mining.

Prof. Dewulf concludes:

- There are more environmental categories than just climate change.
- Only limited categories were used in this prospective assessment.
- Prospective analysis takes into account the footprint per tonne ore mined, but the global impact is dependent on how many tonnes are going to be produced. This is dependent on many factors (management of extracted metals, i.e. inaccessibility, population growth).

ENVIRONMENTAL IMPACTS OF (FUTURE) METAL SUPPLY

Prof. Dr. Ester Van der Voet, Institute of Environmental Sciences, Leiden University, The Netherlands

Prof. Dr. Van der Voet is an Associate Professor at Leiden University at the Department Industrial Ecology of the Institute of Environmental Sciences, CML. Within the field of Industrial Ecology, she specializes in methodology development: life-cycle assessment, material flow analysis, substance flow analysis, natural resource accounting, and indicator development. Prof. Dr. Van der Voet was the lead-author on a paper on the environmental implications of future demand scenarios for seven major metals. Prof. Dr. Van der Voet is a member of UNEP's International Resource Panel. Her present activities mainly focus on circular economy and urban mining, specifically scenario development at different scale levels and building information systems to support local, national, and international polices on sustainable resource use.

<u>Summary of the presentation:</u>

Prof. Van der Voet reported that compared with deep-seabed mining, we know a lot about the environmental impacts of land-based mining. Different studies have assessed different types of environmental impacts related to metals extraction and production. Regarding supply constraints, criticality assessments exist, but this is an economic/political problem. Geological scarcity is hardly ever a problem. There still may be supply constraints, especially in cases of rapidly growing demand.

Prof. Van der Voet explained that there are three types of environmental impacts of mining. (1) Directly related to mining where the mine is situated; (2) Metal cycles and emissions; (3) Energy use related to mining. This last impact is more important as metals are energy intensive compared to other materials or biomass. At the global level for example, 7 to 8% of total global energy use and 5% of total GHG emissions can be attributed to mining related activities.

The Global Resource Outlook (2019) report shows that resource extraction in general (=biomass, metals, non-metal minerals, fossils) has tripled in the last 50 years, however, the extraction of metals followed a similar trend. Moreover, in terms of climate change impact, the share created by metal production specifically, is much larger compared to other resources, due to high energy use for the production of metals. An increase in demand by a factor 2 to 5 is expected by mid-century (2050). This is mainly a result of population growth and development (as a result of the SDGs) and to some extent the energy transition (impact related to energy use). A second trend Prof. Van der Voet observed is that energy efficiency of metal production has improved over the last 50 years and this type of progress will continue. A third observation is that the ore grades are declining, requiring more energy to extract metals. Finally, in terms of energy transition, as the energy background system transforms, impacts related to energy use are reduced as well. Hence, the overall expectations are that the GHG emissions per kg will stabilize or decline, depending on the progression of the energy transition. Yet, the overall GHG-emissions of metal production will increase with a factor of 2 to 3, mainly as a result of the increase in demand, as mentioned above.

Regarding the use of LCA for assessing new routes of metal production, land-based mining can be compared with other types of mining or current mining practices. Prof. Van der Voet stated that from an environmental point of view, every type of mining is preferable to land-based mining . There is only one published study (Paulikas et al., 2020) using LCAs comparing land-based mining and seafloor mining. In terms of energy extraction, there is no real difference, but in terms of CO_2 emissions, sea based mining scores better compared with land based mining in this LCA; the same is observed for acidifying emissions. In terms of area use, seabed-based mining scores much worse. These findings give a first useful insight comparing these sources. Yet, LCAs suffer from several limitations:

- The use phase is ignored (in cradle-to-gate assessment)
- Life cycle inventory data for novel technologies is missing, incomplete or scarce
- Life cycle assessment for biodiversity is quite abstract and difficult to relate to actual impacts
- We miss a whole impact category in terms of marine life. The LCA for marine data is missing.

> *"The energy transition is essential, but so is preservation of the last undisturbed ecosystem on Earth."* – Prof. Dr. Van der Voet

Prof. Van der Voet concludes: LCA s are usually a good tool to assess midpoints (climate change, land use) and micro-level functional units, but are less straightforward for endpoints (biodiversity) or for translating to the global level. Assessing seafloor mining implies developing new impact categories for LCA. Energy transition is essential but so is preservation of the last undisturbed ecosystems on Earth. This is an ethical choice that cannot be captured by an LCA. Assessing sea floor mining implies developing new impact categories for LCA. Finally, LCA can be used to explore alternatives – e.g. engineering out critical materials.

LIFE CYCLE APPROACHES TO COMPARING DEEP SEABED AND TERRESTRIAL MINING

Prof. Dr. Saleem Ali, Minerals, Materials and Society Program, University of Delaware, Newark, DE, United States

Prof. Dr. Ali is a Blue and Gold Distinguished Professor of Energy and the Environment at the University of Delaware. Prof. Ali's research interests are in the causes and consequences of environmental conflicts in the mineral sector. He teaches environmental planning, conflict resolution and industrial ecology. Prof. Dr. Ali recently co-authored a paper on the life cycle climate change impacts of producing battery metals from land ores versus deep-seabed polymetallic nodules. Prof. Dr. Ali is a member of UNEP's International Resource Panel.

Summary of the presentation:

Prof. Ali introduced his topic by explaining that there are essentially 5 sources of metals: (1) terrestrial mining in regions with competing human use, (2) terrestrial mining with potentially compromised biodiversity, (3) coastal mining within national waters, (4) oceanic mining in the deep sea in international waters, and (5) recycling sources of metals from stocks.

Prof. Ali then posed the following question: How do we get enough recycled stocks of metals to achieve a circular economy? He stated that we do not have enough metal stocks, meaning we have to invest in extraction. A lot of exploratory mining projects are taking place in high biodiversity ecosystems on land. A lot of these terrestrial mining projects are in sensitive ecosystems compared with the deep seabed.

> *"A lot of of these terrestrial mining projects are in sensitive ecosystems compared with the deep seabed."*
> – Prof. Dr. Ali

Comparing the known resources of the deep seabed and the economically viable resources on land, Prof. Ali reported that one needs to extract less deep seabed material compared with land based sources. This is because the concentration of metals in the nodules is orders of magnitude higher than that in terrestrial reserves. This observation can be explained by the way that nodules are formed.

Prof. Ali continues by addressing the blue carbon question and reports that most of the blue carbon footprint impacts are in coastal areas, rather than in deep seabed areas. This is confirmed in published, peer reviewed research. There is also a considerable difference in the waste streams of the two approaches (land versus deep-seabed). Biodiversity concerns, especially with respect to hydrothermal vents ecosystems, require the most vigilance, though these ecosystems have an unusual restoration potential. In the CCZ, there is detailed evidence on biodiversity, important observations are: there is no phytodiversity, and the megafauna diversity is largely mobile. Microbial diversity is what matters most, and the reference zones are a key mitigation mechanism in this regard.

Prof. Ali further discusses the precautionary principle and states that it is a risk-based decision making tool and is not science. In fact, it can often impede science. This is why an LCA approach is more important, while still considering the precautionary principle and alternatives.

The ultimate goal is a circular economy. Deep seabed mining companies are considering a complete transition to a circular economy. The goal is to increase the stock of these metals to be able to obtain a circular economy trajectory. So, we would stop mining once there are enough metals to support a circular supply chain. Seafloor minerals can contribute to several SDGs, especially to SDG 12 by focusing on high-grade resources and minimizing waste.

Finally, the Smart Mineral Enterprise Development (SMED) model with public-private partnerships, the private sector and government(s) cooperating, is introduced. The government (agencies and national laboratories) ensures there is enough research done to allow appropriate green technology materials and that there is good communication with the suppliers. It provides a better coupling with supply.

Discussion with all participants

Question 16: *Please do not underestimate the biodiversity crisis on our planet. What is the purpose of this comparison (land based mining vs. deep-seabed mining)? Such a comparison only makes sense if one will replace the other? Will the social problems in the DR Congo disappear once the mines closed? Deep-seabed mining might even put land-based mining under pressure and worsen working conditions?*

Responses:

- **Prof. dr. Saleem Ali:** If you look at any metal market, there will be some reduction in mining activities if deep-seabed mining is commercialized. This will not be mentioned out loud. What will probably happen is that countries like the DRC diversify their economy. Exploration on land will still continue alongside deep-seabed mining, but the rush for new exploration activities will hopefully decrease. An international mining agency is required that coordinates aspects to lead to a system approach.
- **Prof. dr. Esther Van der Voet:** Maybe just the pressure on land ecosystems can be alleviated. LCAs are equipped to compare apples (i.e. land based mining) with pears (or oranges, i.e. deep-sea mining) as it translates supply chains to environmental impact categories that can be compared. It would be a good idea to develop a biodiversity impact category for LCA.
- **Prof. dr. Jo Dewulf:** Since 2003, the European commission has been making use of LCAs. It is more advanced than you might think, especially in some sectors.

Question 17: *It is not easy to compare land-based mining with seabed mining. LCAs do not take into account the level of control you have in the mining activity, i.e. monitoring impacts on the seafloor, implications of depth. Acting on an undesired impact seems much more difficult.*

Responses:

- **Prof. dr. Saleem Ali:** Deep-seabed mining involves the International Seabed Authority comprised of 167 Member States and the EU, which allows a much more robust policy-making while terrestrial mining depends on local jurisdiction. Deep-seabed mining has fewer safety issues (human) compared to terrestrial mining. It is, however, hard to compare human life and biodiversity, but then this becomes a philosophical question about values.
- **Prof. dr. Esther Van der Voet:** Such questions should be addressed in a risk assessment rather than in an LCA.

Question 18. The effects on biodiversity are essentially unknown. Wouldn't we have to call upon the precautionary principle?

Responses:

- **Participant:** The biodiversity discussion is an important discussion. A big effort is being done to characterize this biodiversity, also by these companies who want to perform these extractions. Maybe deep-seabed mining is putting in more effort (in these assessments/studies) than terrestrial mining has ever done or is doing.
- **Prof. dr. Jo Dewulf:** In LCAs for terrestrial mining, biodiversity impact categories are also not perfectly defined yet.
- **Prof. dr. Saleem Ali:** We put human wellbeing before biodiversity. Ocean mining allows for fewer safety implications and there are existential differences in social implications. We need to keep the big picture in perspective.

Concluding remarks

Prof. Dr. Em. Johan Vande Lanotte

It is impossible to make a conclusion after today, there is still a lot that needs to be discussed. It is also difficult to summarize everything that has been said today. Prof. Vande Lanotte shared some of his personal impressions of the day's proceedings.

Michael Lodge said that this is the first time we try to regulate something before exploitation activities even started. Prof. Vande Lanotte stated that he never considered the topic from this point of view, even though it is true. This has some consequences. It leads us to a circular reasoning: we want to regulate something that we do not know fully yet, so we don't start it. We do not start it, so we do not understand it. How can we get out of this cycle? Usually, we learn from our actions before we regulate it, after some damage is done. If we want to do something constructive, we have to get out of this circular reasoning. There was a similar discussion when placing wind turbines in the North Sea. People said: you cannot do this as it will impact biodiversity; so we received negative advice (from regulating agencies). The solution was a trial/pilot project with 6 wind turbines, which cost a lot of money. After three years of monitoring and a positive biodiversity result, the decision to start building wind turbines in the North Sea was made, and this decision did not cause a lot of discussion. Of course, building a wind turbine in the North Sea is far less complex than deep seabed mining. Yet, maybe if a pilot project with sufficient and transparent monitoring is tried out, we can get out of the circular reasoning and create regulations based on these findings. This is a suggestion, food for thought.

Secondly, professor Mudd said: we have enough resources, but we need to know what, where and how. We need to take into account all elements, based on what we know. Based on the presented graphs, I noticed from the carbon emission side, there is a big difference between land and sea based mining. Land based mining has a bigger impact on carbon emissions, negatively impacting climate change, based on what professor Dewulf said. From the biodiversity point of view, there is no strict comparison possible. If this is the case, and I agree with the conclusion of prof. Van der Voet, that the LCA will not help us make a choice. We humans have to make choices. Perhaps, hard choices, as prof. Saleem said. If we need more material, where will we mine? These are tough decisions that will have to be made.

Prof. Vande Lanotte's third reflection comes from his interactions with prof. Van Ypersele: the necessity to reduce GHG emissions is clear. During breakfast, Prof. Vande Lanotte learned (from Prof. van Ypersele) that during the COVID-19 crisis, when the world economy was shut down, we had a reduction of 6 % in emissions. If I understood correctly, we need an 8 % reduction in GHGs each year. Bluntly speaking, we need a cumulative corona crisis each year to reach these goals. That is enormous. But, there is hope. Coupling these facts with what Mrs. Dasgupta said: "the need for lithium is 41 times the actual production" this need will not be achieved in 16 years. Otherwise we will need de-growth in renewable energy or a new technology has to appear within these 16 years, which is unlikely . Recycling on its own will not be sufficient either, it was argued. You could conclude that we will need a combination of all of these factors to reach and respect all the UN goals, the SDGs. That is my personal opinion. It is not the conclusion of today.

If these figures are right, the choices we need to make will need to be made quickly. At a certain moment, there may be a problem that causes a deviation from reaching the goals of the Green Deal, as put forward by the EU. Choices will then have to be made. Up to now, we did not have a problem with scarcity of material , but in the future this will likely be the case, if the figures are correct. We should be prepared, because under those circumstances, we will need to have a practical, rather than a theoretical, discussion, and in such situations, mistakes often are made.

Prof. Vande Lanotte concluded by saying that he learnt a lot at the Thinktank conference, and he thanked the speakers of the day for their presentations.

Appendix

Appendix 1: Attendance list

First name	Last name	Organization
Jurgen	Adriaen	BlueBridge, Belgium
Rodrigo	Alvarenga	Ghent University, Belgium
Stefano	Arciprete	EIT Raw materials
Alain	Bernard	DEME, GSR, Belgium
Gian Andrea	Blengini	EU Comission
Marie	Bourrel-McKinnon	International Seabed Authority
Ariana	Broggiato	EU Comission
Jan	Callebaut	Callebaut Collective, Belgium
Pauline	Caumont	EU Comission
Jo	Dewulf	Ghent University, Belgium
Carl	Devos	Ghent University, Belgium
Ann	Dom	Seas at Risk
Margriet	Drouillon	Ghent University, Belgium
Guy	Franceschi	GF Consult, Belgium
Mario	Gaitan	Ghent University, Belgium
Matthew	Gianni	Deep Sea Conservation Coalition
Patrick	Govaert	DIPLOBEL, Belgium
Peter	Handley	EU Comission
Sheila	Heymans	European Marine Board
Jonathan	Holslag	VUB, Belgium
Marie	Houdart	EU Comission
Colin	Janssen	Ghent University, Belgium
Edward	Knapp	Flanders Marine Institute, Belgium
An	Lambrechts	Greenpeace
Brigitte	Lauwaert	Royal Belgian Institute of Natural Sciences, Belgium
Olivia	Lazard	CEIP
Michael	Lodge	International Seabed Authority
Lieven	Machiels	KU Leuven, Belgium
Aurore	Maillet	EU Comission
Chantal	Martens	Flanders Marine Institute, Belgium
Kamila	Mascart	Ghent University, Belgium
Jan	Mees	Flanders Marine Institute, Belgium
Kim	Meeus	Fed. Government, Belgium
Nicolas	Menou	EIT Raw materials
Dirk	Nelen	VITO, Belgium
Geert	Noels	Econopolis, Belgium
Ellen	Pape	Ghent University, Belgium
Evelyn	Paredes Coral	Ghent University, Belgium
Francesca	Pasotti	Ghent University, Belgium
Arnout	Pieters	Fed. Government, Belgium
Eric	Pirard	University of Liège, Belgium

Hans	Pirlet	Flanders Marine Institute, Belgium
Nils	Préat	Ghent University, Belgium
Marijn	Rabaut	Independent expert Marine & Renewables
Ana	Rodriguez	European Marine Board
Marleen	Roelofs	Ghent University, Belgium
Ulrich	Schampers	International Seabed Authority
Patrik	Schotte	Fed. Government, Belgium
Jean	Scoyer	Umicore, Belgium
Ilias	Semmouri	Ghent University, Belgium
Griet	Van Avermaet	Ghent University, Belgium
Sarah	Van den Eede	WWF, Belgium
Sabine	Van Belle	Cabinet Minister Khattabi, Belgium
Dries	van Den Eynde	Royal Belgian Institute of Natural Sciences, Belgium
Esther	Van der Voet	Leiden University, The Netherlands
Tycho	Van Hauwaert	Bond Beter Leefmilieu, Belgium
Kris	Van Nijen	GSR, Belgium
Jean-Pascal	Van Ypersele	UCLouvain, Belgium
Johan	Vande Lanotte	Ghent University, Belgium
Steven	Vandenborre	Fed. Government, Belgium
Kurt	Vandeputte	Umicore, Belgium
Jeroen	Vangindertaal	Ackermans & van Haaren, Belgium
Ann	Vanreusel	Ghent University, Belgium
Arno	Verhasselt	Fed. Government, Belgium
Gert	Verreet	Departement EWI, Belgium
Klaas	Willaert	Ghent University, Belgium
Noemie	Wouters	BlueBridge, Belgium