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The set-up of an international agreement on the conservation and sustainable use of geologically scarce mineral resources

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ABSTRACT

For more than a century, the use of mineral resources has increased exponentially with annual growth percentages of between 4% and 6%. While for most mineral resources, depletion is not an issue, for some mineral resources the current level of extraction is likely to pose a problem for future generations. Depletion of a mineral resource means that its enriched deposits will have been extracted, and consequently it will become much more expensive for future generations to continue to use these minerals. While technology may reduce some of the adverse effects of depletion, future generations may be deprived of potential innovations for which these specific materials would be essential. The question arises as to how the currently unsustainable extraction of mineral resources can be decreased to safeguard them for future generations. It is submitted that it is unlikely that market forces alone will sufficiently impact the prices of minerals to resolve the unsustainable use of certain minerals timely enough. In this article, it is posited that an international agreement on the conversation and sustainable use of geologically scarce minerals is necessary. The agreement will recognize that the geological scarcity of mineral resources differs between different minerals. It will therefore make a selection of priority minerals, determine how far the extraction rate of these substances must be reduced and decide on a fixed time period within which the extraction must decrease from the current rate to a sustainable rate. The design of such an agreement will be based on two basic principles contained in existing international environmental agreements: (1) the inter-generational equity principle and (2) the principle of conservation of natural resources. Furthermore, the obligatory reduction of the extraction of mineral resources will affect the sovereign rights of resource countries to exploit their own resources. Therefore, any international agreement should make arrangements to ensure resource countries are adequately compensated for their loss of income.

1. Introduction

For more than a century, the use of mineral resources has increased exponentially with annual growth percentages of between 4% and 6%. A mineral resource is a concentration of naturally occurring solid, liquid or gaseous material in or on the Earth's crust, in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible (Craig et al., 1988, p 20). Table 1 provides the annual increase of the extraction of a number of minerals. The growth is caused by a combination of population growth and economic growth per capita (see Fig. 1).

The population data until 1950 is from United Nations (1999), the population data since 1950 is from United Nations (2015), the GDP data until 1969 is from Maddison (2010) and the GDP data from 1970 is from the United Nations Statistics Division (2014). The GDP data is based on 2005 US$.

The question arises whether current levels of extraction of certain mineral resources will result in a problem for future generations and what measures, if any, humanity should take to reduce current levels of extraction of the scarcest mineral resources to safeguard them for future generations.

The goal of the present paper is to discuss the necessity of an international agreement on the conversation and sustainable use of geologically scarce mineral resources and the possible design of such an agreement.

Discussions on the geological scarcity of mineral resources and the consequences of unsustainable use are nothing new. Section 2

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Table 1
Historical growth rates of the extraction of several important mineral resources (United States Geological Survey, 2015).

	Molybdenum (%)	Chromium (%)	Nickel (%)	Copper (%)	Zinc (%)	Lead (%)	Tin (%)	Grand average (%)
Average growth of the world extraction 1900–2013	16.5	7.6	7.3	3.9	3.5	2.8	1.9	6.2
Average growth of the world extraction 1950–2013	6.0	4.9	4.5	3.5	3.4	2.3	1.2	3.7
Average growth of the world extraction 2000–2013	5.4	5.3	3.3	2.6	3.9	4.4	1.8	3.8

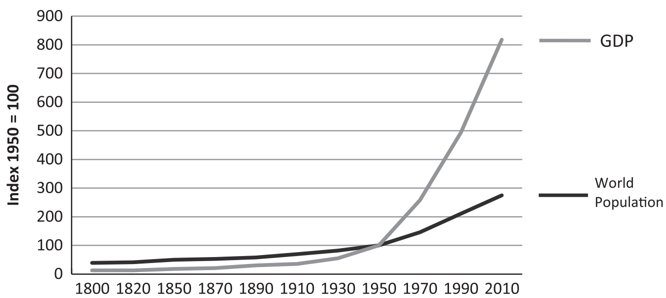

Fig. 1. Development of world population and global GDP between 1800 and 2010.

will provide a brief overview of the debate between the so-called resource pessimists and the resource optimists, and it will provide an operational starting point of what could be a *"sustainable extraction rate"* of mineral resources. Section 3 will examine the role that an international agreement on the conservation and sustainable use of geologically scarce mineral resources could serve, identifying key objectives. Section 4 outlines which policy instruments are adequate to implement these objectives. Section 5 will look at the set-up and principles in an international agreement. Section 6 will look at the financial mechanisms that can support the realization of objectives. Section 7 will provide an overview of the core elements of an international agreement on the conservation and sustainable use of geologically scarce mineral resources. Section 8 will provide recommendations on further research. Finally, the Supplementary data include a draft framework agreement on the conservation and sustainable use of geologically scarce mineral resources.

2. Geological scarcity of mineral resources and sustainable extraction

Malthus (1798) predicted that continuous population growth could outpace the production capacity of fertile land, which would then lead to massive starvation by hunger, epidemic diseases and wars for resources. The only solution, as he saw it, was to limit the number of children in poor families. Later, Malthus' pessimistic view on the limited resources for an increasing world population was followed by influential essays from Ricardo (1817) and Mill (1848). Ricardo includes minerals scarcity in his publication as a limiting factor for population growth. Mill, however, recognizes the possibilities of new technology for increasing the productivity of exploiting land and other resources and thus sustaining a growing world population.

By the end of the 19th century there was a broad concern about resource availability, especially in the USA. This was reflected by the so-called Conservation Movement that was active between 1890 and 1920 (Tilton, 2001). The origin of the concern about scarce resources was especially connected to the fast industrialization and the development of vast wild lands. This Conservation Movement, of which President Theodore Roosevelt was one of the prominent members and supporters, promoted the wise use of resources. This entailed using renewable resources instead of nonrenewable resources, more abundant nonrenewable resources instead of less abundant nonrenewable resources and recycled products instead of primary resources (Tilton, 2001).

After World War II, new concerns on the long-run availability of resources were raised in connection with the substantial resource use related to postwar reconstruction. In the USA, this led in 1952 to the creation of the President's Material Policy Commission (or Paley Commission, after its chairman). One of the consequences of the work of this Commission was the sponsoring of organizations and studies on growth and scarcity.

A very influential book within this framework was published by Barnett and Morse (1963). Their findings and views on the relationship between economic growth and depletion of nonrenewable resources stood in sharp contrast with those held previously. The opinion of Barnett and Morse is that technological developments have completely compensated for increasingly scarce, nonrenewable resources and can be expected to do so in future as well. The strong potential of technology development to solve scarcity problems was also emphasized in books by Maurice and Smithson (1984) and Diamandis and Kotler (2012). In 1979, a number of scientists reconsidered and nuanced Barnett and Morse's optimistic vision presenting a spectrum of different views on the subject of minerals' scarcity (Smith, 1979). In 1972, contradicting Barnett and Morse, Meadows et al. published *Limits to Growth* for the so-called Club of Rome, coming to the conclusion that per capita food and industrial output would collapse as a result of exhaustion of mineral resources and environmental degradation (Meadows et al., 1972). In 1992, Meadows and his coauthors updated their advice to the Club of Rome (Meadows et al., 1992), basically confirming their original point of view. The above described differences of view on scarcity reflect the discussion between the so-called resource optimists and resource pessimists. The resource pessimists support the so-called fixed stock paradigm. The Earth is finite, and so the amount of mineral resources is finite as well. However, demand will not stop growing so it is only a matter of time before supply cannot meet demand anymore. Resource pessimists include Meadows et al. (1972, 1992), Kesler (1994), Diederen (2009) and Bardi (2013), amongst others.

On the other hand, the resource optimists support the so-called opportunity-cost paradigm. The optimists do not deny that mineral resources will deplete gradually, but they have a strong belief that humanity will be able to cope with the effects of depletion. When demand outpaces supply, the costs will rise and – simultaneously – the pressure to find substitutes or alternatives for the depleted mineral. According to the resource optimists, the market will automatically solve the problem. Moreover, mostly – and unlike oil, natural gas and coal – mineral resources are not destroyed by using them. Recycling and reuse are possible. Finally, the total geological stock is enormous. It will always be possible to extract minerals, although the costs will be considerable. Resource optimists are for instance Hodges (1995), Gunn (2011), Simon (1980, 1981), Adelman (1990) and Beckerman (1995), Maurice and Smithson (1984), Diamandis and Kotler (2012) and Lomborg (2001).

The point of view of the resource optimists is shared by economists such as e.g., Goodland (1995), Perman et al. (2003), Dasgupta and Heal (1974, 1979), Heal (1998) and Solow (1974a, 1974b). They find that future exhaustion of mineral resources is not problematic *per se*, as long as the decreasing natural capital of depleting mineral resources is sufficiently replaced by increasing human capital, such as knowledge, infrastructure and adequate substitutes. Gaudet (2007) and Hotelling (1931) have the opinion that non-renewable resources must be "optimally" depleted. On the other hand, the view of the resource pessimists is supported by the International Law Association (2014) stating that future generations may have a legitimate expectation of equitable access to planetary resources.

Both resource pessimists and resource optimists acknowledge that mineral resources are exhaustible. The difference between them is that the optimists trust that humankind will find a timely solution by replacing scarce resources with substitutes. The pessimists, on the other hand, are of the opinion that humanity should not deliberately deprive future generations from scarce resources, regardless of whether they could be replaced by alternative resources. In the view of the authors, the optimistic and pessimistic visions are not mutually exclusive but are in fact reconcilable; humanity will be able to resolve mineral depletion problems, e.g. by replacement of scarce resources and by increasing recycling, but it is also the case that the current generation should not take away geologically scarce resources from future generations.

Hence it is essential that minerals are extracted in a sustainable manner. In order to ensure this, a sustainable extraction rate must be determined. An important question, in this respect, is how large the Extractable Global Resources of a given mineral are. According to the UNEP International Panel on Sustainable Resource Management (2011, page 1), the *"Extractable Global Resources are the amount of a given metal in ore that is judged to be extractable over the long term."* According to Skinner (1976), the upper limit of the extractable global resources would be 0.01% of the total amount of a mineral in the crust. Erickson (1973) and Rankin (2011) also use 0.01% of the total amount of a metal in the crust for estimates of the extractable deposits. In line with these authors, the UNEP International Panel on Sustainable Resource Management believes that an amount of 0.01% of the total amount available in the crust to 1 km depth is not an unreasonable upper limit of the Extractable Global Resources (EGR) of a mineral (UNEP, 2011, p 21 and 24).

According to calculations of the UNEP International Panel on Sustainable Resource Management, the EGR estimate of 0.01% of the amount in the upper 1 km of the Earth's crust is, on average, 35 times as high as the latest *"reserve base"* figures of the United States Geological Survey (USGS). The *reserve base* (RB) is defined as the part of an identified resource that meets specific minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness and depth. USGS used to provide reserve base figures until this service was stopped in 2009. Reserves are that part of the reserve base that could be economically extracted or produced at the time of determination. Because the average EGR/RB ratio is 35, the authors of the present paper feel confident that the UNEP estimate of the extractable quantity of mineral resources is not unnecessarily alarming. Therefore, the UNEP approach is adopted in the framework of the elaboration of an operational definition of sustainable extraction.

It ought to be noted that, after the depletion of an extractable mineral resource, 99.99% of that mineral still remains in the Earth's crust. However its extraction will be much more expensive than the extraction of the enriched top 0.01%. Enrichment factors of geologically scarce mineral resources are 100 s to 1000 s of times the average concentration of the mineral in the Earth's crust (Rankin, 2011). Hence, the extraction of a mineral resource from normal rocks will be 100 s to 1000 s of times more expensive than for the enriched ores of that mineral (Steen and Borg, 2002).

Once the extractable quantity of a mineral resource is determined, it is essential to choose a basis from which to determine whether the extraction rate of a mineral is sustainable. An extraction rate is considered sustainable "i*f a world population of 9 billion people can be provided with the resource for a period of at least 1000 years assuming that the average per capita consumption of the mineral is equally divided over the world's countries*" (Henckens et al., 2014). The assumption is made that the minimum conditions for an operational definition of sustainable extraction ought to take account of: (1) the long term continuity of delivery of the resource for a price that is in the same order of magnitude of the price that the current generation pays for the resource, (2) inter- and intra-generational equity and (3) knowledge on the amount of extractable global resources. 1000 years will be sufficient for humankind to organize a circular economy, in which the extraction of minerals from the Earth's crust will be minimal and sufficient resources are left for later generations. An order of magnitude smaller period (i.e. 100 years) would allow depleting certain mineral resources within a relatively short period of time depriving our grandchildren from those resources and without being certain that humanity is able to prepare for a fully circular economy so fast. On the other hand, a period of 10,000 years seems unnecessarily long. A population of 9 billion people has been used in the definition because, according to United Nations Statistics Division (2014) – estimates at the time of publication of the definition – the expected world population in 2050 would be 9 billion and would be more or less stable from then on (United Nations, 2011). Of course, a higher world population makes the depletion issue more urgent.

After analyzing the geological scarcity of 65 minerals – mainly metals and metalloids (Henckens et al., 2014) – it was concluded that the extractable global resources of 15 of these minerals will be depleted within about 350 years, with five due to be depleted within 100 years. Although for many mineral resources depletion is not imminent, for some minerals it is relatively nearby. Table 2 presents these 15 elements in order of geological scarcity. The mineral resources are subdivided in four groups according to their geological scarcity: (a) Very scarce, (b) Scarce, (c) Moderately scarce, and (d) Not scarce.

It should be noted that Table 2 may not be exhaustive. Only 65 minerals were included in the investigation. The selection has been derived from the work of the UNEP International Resource Panel on Sustainable Resource Management (2011). In the elaboration of an agreement on the conservation and sustainable use of geologically scarce mineral resources, all mineral resources need to be taken into consideration.

3. Objectives of an international agreement on the conservation and sustainable use of geologically scarce mineral resources

For a number of minerals, depletion of ores is relatively nearby, and a substantial extraction reduction is needed to make the use of these minerals sustainable. Therefore, it could be considered wise to create an international agreement on the conservation and sustainable use of geologically scarce mineral resources. The question arises why there has not been a similar urgency in the negotiation of an international agreement in response to the depletion of minerals as there has been with environmental issues such as biodiversity and climate change. The explanation might be that mineral resource depletion does not directly co-determine the *"safe operating space for humanity"* (terminology from Rockström et al., 2009), but it is primarily an economic problem (with the

Table 2
Remaining years until depletion of 15 elements in a business-as-usual scenario (3% growth until 2050, where after stabilization). Necessary extraction reduction compared to the extraction in 2010 and to the estimated extraction in 2050 (Henckens et al., 2014).

Element	Remaining years after 2050 until depletion	Grouping according to geological scarcity	Necessary extraction reduction for average world citizen compared to 2010 extraction (%)	Necessary extraction reduction for average world citizen compared to extraction in 2050 after 3% annual growth between 2010 and 2050 (%)
Antimony	−9	Very scarce	96	99
Gold	6	Scarce	92	98
Zinc	50	Scarce	82	95
Molybdenum	50	Scarce	81	94
Rhenium	80	Scarce	74	92
Copper	120	Moderately scarce	63	89
Chromium	150	Moderately scarce	57	87
Bismuth	160	Moderately scarce	55	86
Boron	200	Moderately scarce	44	83
Tin	230	Moderately scarce	35	80
Silver	240	Moderately scarce	33	80
Lead	250	Moderately scarce	30	79
Nickel	320	Moderately scarce	12	73
Iron	330	Moderately scarce	11	73
Tungsten	330	Moderately scarce	10	73

exception of mineral resources that are essential for life, such as phosphate). Nevertheless, this economic problem may become serious for future generations, if no action is taken. Once the ores of a mineral are depleted, extraction of this mineral from the Earth's crust will become 10–1000 times more expensive (Steen and Borg, 2002).

One could argue that the price mechanism of the free market system could lead automatically to a sufficient reduction of the use of geologically scarce mineral resources due to the inevitable price increase which results from growing scarcity (Dasgupta and Heal, 1979). However, so far, the increasing costs of extraction due to declining ore grades, increasing depths of the mines, more remote mining areas and smaller ore bodies, were neutralized by improving technology (Skinner, 2001; Bardi, 2013; Bleichwitz, 2010). For a long period of time the real prices of minerals have not increased. Moreover, according to USGS data (2015), the price development of geologically scarce minerals does not differ from the price development of geologically non-scarce minerals (Henckens et al., 2016c). The conclusion that real prices are not changing is supported by Krautkraemer (1998), Cuddington (2010) and Fernandez (2012). The market does not yet reflect the large differences of geological scarcity of mineral resources. It remains unclear how closely before depletion of a mineral resource the market will react on geological scarcity by structural and permanent price increases of the depleting mineral. It remains also unclear whether, at the near-depletion-stage, technological development will be able, again, to keep prices down at the same level as nowadays. It is also referred to the essay of Tilton (2003) in this respect. Summarizing, it is not certain whether or not the geologically scarcest mineral resources will be sufficiently saved for future generations, if humanity does not take measures to slow down the extraction of the geologically scarcest mineral resources.

It is for these reasons that an international agreement is proposed with the objective to achieve a situation of sustainable extraction and to equitably distribute geologically scarce mineral resources between the current and the future generations at the lowest cost. This section will discuss how this objective can be translated in concrete, implementable goals. Henckens et al. (2014) have elaborated what their definition of sustainable extraction of mineral resources would imply for 15 geologically scarce minerals (see Table 2 above). Comparing the two right columns of Table 2, the conclusion is that the longer humankind waits with starting-up extraction reduction, the more drastic the required extraction reduction will need to be; the sooner action is taken, the more gradual the necessary change can be.

Hence, based on the considerations in Section 2, the objectives of an international agreement on the conservation and sustainable use of geologically scarce mineral resources must address: (1) the selection of minerals for which extraction reduction should be made a priority, (2) the sustainable extraction rate, including the required extraction reduction and the required time span within which the required extraction reduction of the selected priority minerals must take place and (3) the division of the extraction reduction over the various mineral producing countries. This will be elaborated in the following sub-sections.

3.1. Selection of priority mineral resources

In order to determine those minerals for which the reduction of the extraction rate is a priority, it is obvious to select the scarcest minerals as priority minerals: antimony, gold, molybdenum, rhenium and zinc which, according to our estimate, will be depleted within about 100 years. Indeed, geological scarcity is an important criterion because the essential purpose of the agreement is to ensure that future generations are not deprived scarce natural resources. Other selection criteria could be relevant such as: the extent that a mineral is critical for our society, its economic importance, the stability of its delivery, its substitutability and its recycling potential. For an overview of criticality criteria, reference is made to an overview of criteria that have been used in 15 different criticality studies (Achzet and Helbig, 2013).

Elements which are essential for life and which cannot be substituted by other elements may need priority compared to elements which are not essential for life, for instance minerals used in fertilizer and micronutrients. Of the elements in Table 2, this concerns boron, molybdenum and zinc. In this framework, the exhaustion of phosphate, though not included in Table 2, will certainly need special attention as well. The majority of antimony's applications are in flame retardants. Hence, although antimony is a very scarce element, it can be relatively easily be substituted by other flame retardant systems. Molybdenum, on the other hand, is essential for the production of stainless steel and thus far, molybdenum seems to be hardly substitutable in this application. Therefore, even though molybdenum is less scarce than antimony, it may get more priority in view of a sustainable extraction than antimony (Henckens et al., 2016d, 2016b).

Another factor is the relative economic importance of an element for society in general or for specific countries. This depends on the strategic value of the applications. The overall weighing of these various factors is subjective and is influenced by the economic interests of the involved parties so the priority setting will necessarily be a political process. The political and societal insights with respect to priority setting of the minerals for extraction reduction may change over time. Therefore, an international agreement on the conservation and sustainable use of geologically scarce mineral resources will need to incorporate a priority setting procedure. Due to the potentially changing nature of the priority setting and the notoriously difficult processes involved in adopting amendments to treaties, the details of such a procedure are best elaborated in a separate protocol to ensure that it can be more easily altered to adapt to new realities.

3.2. Extraction reduction goal and phasing down scheme

How fast must, or can, the required extraction reduction take place? The answer depends on how fast society can change to production of substituting products, more material efficiency and a higher recycling rate without too much destruction of capital. Looking to history, relevant data may be derived from the phasing out of ozone depleting substances, the phasing out of asbestos, the ban of the use of certain chemicals in certain applications (e.g. PCBs and cadmium), the transition to cleaner and more economical cars, the emission reduction of greenhouse gasses and the emission reduction of acidifying air pollutants (e.g. SO_2 and NO_x).

Without going into too much detail, one can say that a phasing down period will be in the order of 5–10 years, at a minimum. Determining factors are the time needed for the technical development of suitable substitutes and recycling technologies, plus the time needed to realize the necessary industrial facilities. Private companies must get sufficient time to amortize existing facilities in order to prevent too much financial loss. The feasibility of a phasing down scheme needs to be separately assessed for each selected mineral. Because phasing down schemes are specific and may differ per mineral, these schemes should be elaborated in a separate protocol per mineral. This will need to be reflected in any framework agreement.

3.3. Allocation of annual extraction quota of priority minerals to resource countries

For the minerals that are selected for extraction reduction, the capped annual quantities that may be extracted will need to be allocated between the resource countries. The extraction reduction must – over a number of years – gradually arrive at the agreed level of sustainable extraction. For example, it is agreed that the extraction of a certain mineral resource must be reduced by 80% over a period of 10 years in steps of 8% of the original extraction. Assume that at the beginning there are 3 resource countries: A, B and C. The (known) reserves of the resource are respectively R_A, R_B and R_C, and their average annual extraction rates during the last x years are E_A, E_B and E_C. It appears obvious to allocate the extraction quota according to the known reserves in the resource countries. This starting point results in the following allocation A_{Ax} to country A in year x after the start of the extraction quota program:

$$A_{Ax} = (1-0.08x) * R_A * (E_A + E_B + E_C)/(R_A + R_B + R_C),$$

Now assume, new reserves are found in country D and country D decides to exploit the resource from year 8. In this case, the amount allocated to country D (A_D) in year 8 is equal to:

$$\frac{0.36R_D(E_A + E_B + E_C)}{(R_A + R_B + R_C + R_D)}$$

The globally agreed extraction reduction must go on, irrespective of the discovery of new reserves. This is necessary because the global extraction reduction scheme has already taken into account that most of the extractable resources have not yet been discovered (Henckens et al., 2014). That means that the quota of mineral extraction that have been allocated to the countries A, B and C will need to decrease proportionally to the new resource allocation to country D. 10% extra allocation to country D means 10% less allocation to the countries A, B and C.

To prevent the allocation system from being too restrictive, it must allow resource countries to trade within the allocated quotas. By allowing trading of allocated extraction quota, several objectives are achieved simultaneously: (1) flexibility of the system, (2) the final objectives are maintained and (3) extraction will take place in countries and mines with the lowest extraction costs. If resource country A cannot deliver, e.g. due to accidents, strikes or geopolitical events, then the other resource countries may be allowed to buy the extraction quota allocated to country A. Country A is allowed to buy back the quota again later on.

Extraction allocation pro rata of proven reserves is a rational approach, but other criteria might be taken into consideration as well, such as production capacity, historical production share, domestic consumption, production costs, dependence on export, population and external debt (see e.g. the discussion within the Organization of Oil Producing Countries (OPEC) on a quota system for oil production (Sandrea, 2003)).

The extractable reserves need to be evaluated regularly to assess whether these are still in accordance with the assumptions that were at the basis of the extraction reduction scheme. This is the task of a research body that must be installed as part of the international agreement on the conservation and sustainable use of geologically scarce mineral resources. The principle of annual extraction quota per resource country and the tradability of extraction quota amongst resource countries needs to be included in the framework agreement. The elaboration of the system requires further research and can be part of a separate protocol. In this framework the experience with existing quota systems, such as the OPEC system of quota for oil production, the United Nations Framework Convention on Climate Change (UNFCCC) CO_2 emission quota system, the emission trading arrangements in the framework of UNFCCC and the EU Emission Trading System, could provide a useful starting point.

4. Policy instruments for reducing the extraction of geologically scarce mineral resources

Once the geologically scarce mineral resources have been selected and the extraction reduction goals have been determined, technical measures must be defined to achieve these goals. Generally, the technical measures that are taken are: (1) substitution of the resource for another less scarce resource, (2) increasing material efficiency and (3) more recycling. In other publications the authors have demonstrated that the required reduction goals are technically achievable, even if they are very ambitious (Henckens et al., 2015, 2016d, 2016b). The question is which policy instruments are most appropriate. It is generally accepted that market oriented incentives are more efficient than a command and control approach which directly mandates what businesses or individuals should or should not do (Vogler, 2010; Helm et al., 2003; Europe Economics, 2008; Gerlagh and Van der Zwaan, 2006; Olmstead and Stavins, 2012; Molyneaux et al., 2010 and Goulder and Parry, 2008). The major market oriented incentives are taxing the production and/or use of geologically scarce mineral resources and “cap and trade” systems.

Applied on resource extraction, a cap and trade system fixes the maximum amount that is allowed to be extracted, but it allows for flexibility in the pricing of the extracted resource. A tax system fixes the price of the extracted resource but leaves the extracted quantity uncertain. There is much literature comparing the two systems with each other. This literature is mostly centered on the merits of either system for Green House Gas emission reduction. Criteria that are being used can be divided by the following three dimensions (i.e. Konidari and Mavrakis, 2007; Mees et al., 2014)

– Performance (e.g. goal achievement, effectiveness etc.)
– Political acceptability (e.g. costs-efficiency, equity/fairness, flexibility, stringency for non-compliance, legal certainty/predictability/credibility, transparency controversy etc.)
– Ease of implementation (e.g. feasibility, accountability, transparency, complexity etc.)

Some authors come to the conclusion that cap and trade is better (Murray et al., 2009; Keohane, 2009). According to other authors taxing systems are better (Avi-Yonah and Uhlmann, 2009). Several authors plea for hybrid systems, combining taxes and cap and trade systems including price floors and price ceilings, banking and borrowing (Molyneaux et al., 2010; Mandell, 2008 and Vogler, 2010). According to others (Goulder and Perry, 2008; Goulder and Schein, 2013), no instrument is best along all criteria. The conclusion is that a comparison of taxing systems and “cap and trade” systems does not unambiguously lead to a clear conclusion that either of the two systems is better.

The present publication elaborates on a global cap and trade system to achieve a sustainable extraction of geologically scarce mineral resources. The argumentation for this choice is that cap and trade offers greater certainty that the required extraction reduction is achieved. The cap and trade system is successfully applied in the framework of the US Acid Rain Program for the emission reduction of Sulfur Dioxide, and it is also already being applied at an international scale in the EU Emission Trading System for the reduction of the emission of greenhouse gases. Thus far, taxing systems for environmental purposes are only employed at a national scale.

Striving after a global cap and trade approach does not necessarily hamper or withhold concerned user countries to formulate and implement their own resource saving policies in advance. This will have the advantage of offering flexibility to States as to which policies they pursue, such as policies based on taxing or other instruments such as directly imposing or promoting substitution of geologically scarce mineral resources in selected applications and recycling and arranging (voluntary) agreements with or between sectors of industry or society. To the extent that a global cap and trade system would be implemented, such national or regional fall back options may be loosened or abolished again, may work in parallel or compliment a global regime.

Ideally, the approach for solving the problem of geologically scarce mineral resources is global. Geological scarcity is not a local or a regional problem; it is a problem of humanity as a whole, particularly for future generations. However, the climate change problem shows how difficult and time-consuming it can be to agree on a workable and practical solution that is acceptable for all countries despite the fact that the technical pathways are known and feasible. Nevertheless, a global approach is the ideal way to safeguard geologically scarce mineral resources for future generations. In addition, countries and regions may decide to go faster and implement unilateral measures to save geologically scarce mineral resources in advance of a global agreement.

A practical argument in favor of a global approach is the role of the resource countries. Without their cooperation, it will be very difficult or even impossible to substantially reduce the extraction of geologically scarce resources within a limited period of time. The system must include a mechanism that makes resource countries wholeheartedly stand behind an agreed extraction reduction. If not, there is a serious risk that an extraction reduction that is not supported by all resource countries leads to flooding of the market with scarce resources, decreasing their price and frustrating the objectives of the agreement.

5. Principles of an agreement on the conservation and sustainable use of geologically scarce mineral resources

The objectives of the international agreement discussed in section 4 refer to what Henckens et al. (2016a) would refer to as “goal orientated principles” of international environmental agreements. “Goal orientated principles” are the principles that are directly connected with the seriousness of the problem to be solved, such as the principle of sustainable use of resources. These can be distinguished from the “design oriented principles” of international environmental agreements which are related to the architecture and execution of the agreement, such as the sovereign right and equity principles (Henckens et al., 2016a). The present section deals with these “design oriented principles”, hereinafter referred to as “*principles*”.

Principles are preconditions of an agreement. Without adequate principles accepted by the parties of the agreement, the objectives of an agreement cannot be achieved. The aim of these principles is to satisfactorily comply with the justified interests of various partners of the agreement. Relevant principles for an agreement on the conservation and sustainable use of geologically scarce mineral resources are the sovereign right principle, the common concern of mankind principle, ethical principles (intragenerational equity, priority for the special situation and needs of developing countries and fairness), responsibility assignment principles (such as the common but differentiated responsibilities principle) and the polluter pays principle (Henckens et al., 2016a).

Most of these principles relate to burden sharing in connection with the agreement. The formulation and elaboration of these principles is essentially a political process and can therefore end up being a bottleneck of any agreement. The present section shall elaborate on the compensation of resource countries and how to address the special situation and needs of developing countries. In the Supplementary Data background information is provided on the “sovereign right” principle, the “common concern of mankind” principle, the “common but differentiated responsibilities” principle and the “polluter pays” principle in relation with the issue of depletion of geologically scarce mineral resources.

5.1. *Compensation of resource countries and establishment of an annually fixed resource price*

When a resource country loses sovereignty over certain portions of its natural resources (and the related income) by being obliged to reduce the extraction of these resources for the purpose of serving a common concern of mankind, it should be compensated. Compensation of resource countries is justified because not only are their sovereign rights affected but also their income. The price increase that is probably caused by the obligatory extraction reduction of resources is not certain and may not be sufficient to compensate for the decreased production and export of resources. Without a guaranteed compensation for lost income, there is a substantial risk that resource countries may not want to participate in the international agreement, in which they play a crucial role.

The compensation principle is already being brought in practice in the UN REDD compensation programme on Reducing Emissions from Deforestation and Forest Degradation which compensates (developing) nations for not logging their forests. The compensation for extraction reduction of mineral resources is discounted in an increased resource price. To compensate the resource countries, the resource price needs to be increased proportionally to the decrease of the extraction rate. Therefore, from the moment on that extraction reduction is implemented, a resource tonnage price needs to be fixed annually, directly reflecting the imposed extraction decrease.

The compensation of resource countries must be such that their income with an agreement on the conservation and sustainable use of geologically scarce resources is equal to their income without such an agreement. A resource country should not get more compensation than the income that it would have received without international agreement. Corrections of the general approach may be necessary because the reserves in a country may be near to depletion. It is not necessary to compensate a country for lost income when this country would not have had this income anyway. The principle of the compensation mechanism needs to be part of the framework agreement. The detailed elaboration of the mechanism can be arranged in a separate protocol, since the outcome will be partly the result of political negotiations and may change over time.

5.2. Addressing the special situation and needs of developing countries

The solution of the geological scarcity problem may encompass substantial extra costs for all countries, including poor countries. Increasing scarcity of mineral resources is mainly caused by developed countries. Developed countries were able to generate welfare for their people and to build up a physical infrastructure co-based on the massive extraction and use of mineral resources. When limiting the further extraction of geologically scarce mineral resources, developing countries would be confronted with substantially higher costs for these resources, even though they have not yet been able to build up an infrastructure at the same level as developed countries and the majority of people in their societies have not yet been able to enjoy the services provided by these resources to the same extent of a citizen of the average developed country. It will be difficult to expect that developing countries would unconditionally agree with a system that leads to higher costs for their inhabitants without considering that they are not responsible for geological scarcity in the first place. Moreover, without the consent of these countries, an international agreement on the conservation and sustainable use of geologically scarce mineral resources cannot be globally ratified. This means that the role and position of developing countries needs special attention. The interest of the developing countries in this perspective is twofold: (a) that their access to geologically scarce mineral resources remains attainable and (b) that the costs for solving the scarcity problem are acceptable for the developing countries from a historical perspective.

a. Equitable distribution of geologically scarce mineral resources

Geologically scarce mineral resources can be considered as part of the "*ecological space for humankind*". The right to equitably share the ecological space of mankind can be considered a fundamental human right (Hayward, 2006). From a certain point on, when a resource becomes very scarce, it looks justified to take steps to equitably share such a resource. There are several ways in which geologically scarce mineral resources could be equitably distributed to countries, e.g.:

- Equal amount per capita
- Equal amount per unit of GDP
- Grandfathering: the distribution is based on the existing amount of resource that is used in a country in a reference year
- Contraction and convergence: convergence from the status quo to equal per capita emission rights over an agreed period of time
- Contraction and convergence with accounting of past use, e.g. from 1990. Countries that have used more than the global average use per capita until an agreed moment in time have to reduce their consumption by this amount in a later period

Pan et al. (2014) provide an overview of 20 alternative allocation schemes for CO_2 emission rights which – in principle – are also applicable for the ways in which geologically scarce mineral resources can be distributed. The distribution system will be the subject of bargaining during the genesis of the international agreement. The agreed distribution system will be laid down in a separate protocol.

b. Lower costs for developing countries

Each of the user countries – developed or developing – will pay the same fixed tonnage price for the amount of resources that is distributed to it. This resource tonnage price is annually fixed by an international body in the framework of the agreement and is universal for all countries. User countries will be allowed to trade the allocated quota of mineral resources. They may sell the resource for a price that the market (usually mineral processing companies) is prepared to pay. Because of the global extraction reduction, scarcity is artificially increased during the phasing down period. The market price of the resource, that the user countries will be able to receive, will probably become higher than the fixed tonnage price that the user countries have paid. The gross effect of this system will be that the costs of the proposed system are relatively higher for countries with a high consumption of the scarce material and relatively lower for countries with a low consumption of the scarce material.

The per capita consumption of mineral resources is positively related to GDP (Graedel and Cao, 2010). The per capita consumption of mineral resources in developing countries is lower than the per capita consumption of mineral resources in developed countries. With an equal amount per capita distribution system this implies that – under the agreement – developing countries would get more mineral resources distributed to them than they actually use or need. This creates a net profit for these countries, as is demonstrated in detail in section 5 of the Supporting Material. In this way, developing countries are compensated for the higher costs of the services of the resource in the future and for their contribution to saving of geologically scarce mineral resources currently and in the past.

The extraction quota that are allocated to resources countries must be distinguished from the distribution quota of extracted resources that are allocated to user countries (see Fig. 2). In our

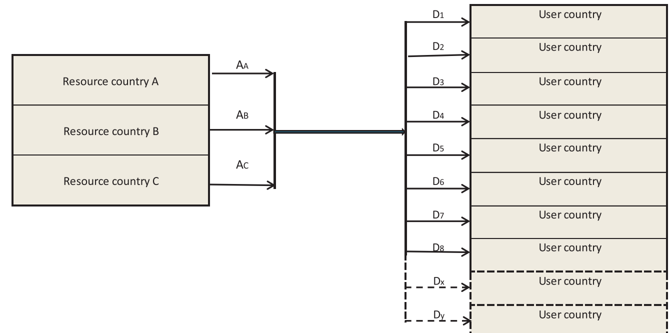

Fig. 2. From extraction to distribution. A = allocated amount of resources that may be extracted by resource countries. D = distributed amount of resources to user countries.

proposal both types of quota are tradable. The allocated quota that is extracted by resource countries may be traded between resource countries; the resources that are distributed to user countries after extraction may be traded on the market.

Although geologically scarce mineral resources are equitably distributed to countries, it will remain the sovereign right of each country to determine how to manage the distribution of costs and benefits in its own country for its own citizens.

6. Costs of the agreement and financial flows

The costs of an international agreement on the conservation and sustainable use of geologically scarce mineral resources can be split up in three elements:

- The higher costs for substituents, increased recycling and better material efficiency compared to the current situation and the higher market price for the original resource. These costs will vary per mineral resource and per application and it is not easy to make a precise estimation of these costs in general. The optimal mix of substitution, material efficiency measures and recycling will differ per resource and per application. Moreover these costs will depend on the required reduction rate. The lower the required reduction of the extraction rate of a primary material is, the easier it will be to realize the necessary reduction of the use of that primary material and the less the market price of the original material will increase. These types of costs will be paid by the ultimate consumers of the products, within which the scarce resources are included. This is fair, because in this way the extra costs will be distributed according to the use of the resource. The economical consumer will incur fewer costs than the wasting consumer.
- The additional costs to compensate the resource countries for their loss of income. These costs will be incurred by the user countries and must be included in the annually fixed tonnage price that the user countries pay to the resource countries. The annually fixed tonnage price is paid to the administrative body that is in charge of the execution of the agreement and transferred by the administrative body to the resource countries. In return for the paid compensation costs, the user countries should gradually and proportionally become owner of the saved reserves. In this way, from a certain moment on, the remaining reserves are owned by the user countries and compensation does not need to be paid anymore.
- The costs for the international administrative bodies that will be in charge of the implementation and monitoring of the agreement. These are called the transaction costs. Usually these types of costs will not be permitted to exceed some percent of the total market value of the original amount of resources on an annual basis. These costs must be shared by the user countries in proportion to the amount of resource distributed to each of them. These costs are paid together with the fixed tonnage price to the international body that is in charge with the execution of the agreement.

The buyers (the processing industry) will pay the market price to the user countries. However, it will be necessary to establish a minimum for the market price for preventing the market price to become lower than the annually fixed tonnage price. The minimum price should be equal to the annual fixed tonnage price plus the transaction costs. The purpose of setting a minimum price is to ensure that a user country, whatever the market price will be, will not suffer any costs if it sells any scarce resources that it received through the distribution system.

The mechanism is presented is Fig. 3.

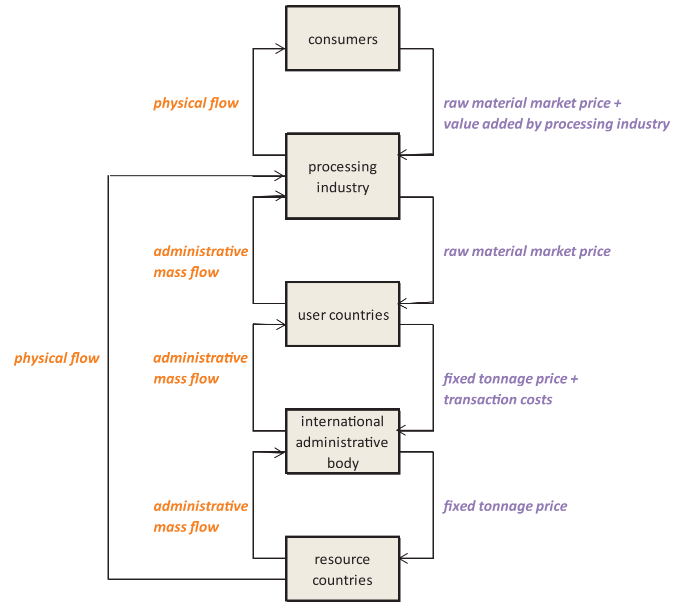

Fig. 3. Physical mass flows, administrative mass flows and financial flows in the context of the proposed international agreement on the conservation and sustainable use of geologically scarce mineral resources.

7. Core elements of an international agreement on the conservation and use of geologically scarce mineral resources

The present paper examines the set-up of an International Agreement on the Conservation and Sustainable Use of Geologically Scarce Mineral Resources. The focus is on the objectives, principles, set-up and mechanisms of the agreement.

7.1. Objectives

The objectives of an agreement on the conservation and sustainable use of geologically scarce mineral resources are:

- The sustainable use of geologically scarce mineral resources
- Equitable distribution of geologically scarce mineral resources between the current generation and future generations.

7.2. Principles

The principles, on which an agreement on the conservation and sustainable use of geologically scarce mineral resources is based, are:

- The sovereign right principle
- The concern to mankind principle
- Compensation of the resource countries for their willingness to reduce the extraction of geologically scarce mineral resources
- Equitable distribution of geologically scarce mineral resources to the world's countries

7.3. Set-up

The set-up is a cap and trade system and consists of:

- A priority setting methodology that results in a list of geologically scarce mineral resources, of which the extraction must be reduced with priority
- A procedure for the determination of an extraction reduction goal for the selected mineral resources and a phasing down scheme

– A system for setting annual extraction quota of the selected mineral resources and the allocation of these quota to the resource countries
– A system of equitable distribution of geologically scarce mineral resources to user countries for a fixed price per ton

7.4. Financial mechanisms

The financial mechanism of the proposed agreement consists of:

– A system of comcser countries for reducing the extraction of geologically scarce mineral resources.
– A system to annually fix a resource price that includes the compensation for the resource countries and the transaction costs for the implementation of the international agreement
– A system that makes the user countries owner of the not extracted mineral resources to the extent that they have paid compensation to the resource countries
– The right for the resource countries to trade the extraction quota between the resource countries
– The right for the user countries to sell the distributed resources on the free market
– An international body for the conservation and sustainable use of geologically scarce resources that is responsible for the transfer and appropriate administration of the necessary payments to the extraction countries, and for inspection, monitoring, evaluation and research.

7.5. Protocols

For each of the above mentioned set-up elements and financial mechanisms, separate protocols will be needed to elaborate the agreed systems

7.6. Institutional bodies

The following institutional bodies will need to be set-up:

a. Conference of Parties for international cooperation and decision taking
b. Secretariat
c. Administrative body for scientific and technological advice
d. Body on implementation, monitoring and evaluation

A draft of a framework Agreement on the Conservation and Sustainable Use of Geologically Scarce Mineral Resources is included in Section 6 of the Supplementary Data.

8. Recommendations

In this paper the main lines of an international agreement on the conservation and sustainable use of geologically scarce mineral resources were laid out. The details of the proposed agreement need further research. This concerns especially:

– The factors that (may) hamper the genesis of an international agreement on the conservation and sustainable use of geologically scarce mineral resources and how these hampering factors could be addressed.
– An analysis of the interests of various partners to the agreement (resource countries and user countries, developed countries and developing countries) and other stakeholders (mining companies, processing industry)
– How to deal with countries that do not ratify the agreement. The draft framework agreement in the supplementary data contains a tentative article on this subject, but this approach needs more research
– The methodologies for priority setting of geologically scarce mineral resources for the determination of the extraction reduction goals and for the phasing down schemes
– The system for the allocation of annual extraction quota to resource countries
– The system of distribution of regulated mineral resources to user countries
– The system of compensation of resource countries for their loss of export opportunities. In this framework, existing compensation schemes, such as the REDD compensation scheme, need to be evaluated.
– The set-up of a system of periodic evaluation of extractable reserves per resource country
– The ownership system of non-extracted resources
– The lessons that may be drawn from the creation, the implementation and the execution of existing international environmental agreements and other relevant mechanisms, such as existing quota systems (oil-OPEC, CO_2-UNFCCC), emission trading schemes (UNFCCC and EU RTS) and compensation schemes (REDD)
– A study on how to harmonize an international agreement on the conservation and sustainable use of geologically scarce resources with existing WTO agreements.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.resourpol.2016.04.010.

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