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Normative principles and the sustainable use of geologically scarce mineral resources☆

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ABSTRACT

The use of geologically scarce mineral resources needs to be reduced substantially in order to prevent future generations from being deprived of them. So far, there has been no international reaction to this growing problem. We argue that an international agreement on the sustainable use of geologically scarce mineral resources is necessary, and in particular that a number of normative principles of environmental governance, as currently codified in international environmental agreements, require such an agreement.

1. Introduction and methodology

For more than a century, the use of many non-fossil mineral resources has increased with annual growth percentages of up to 3% to 6% (USGS, 2015).

Current levels of extraction of certain mineral resources might result in an availability problem for future generations (Henckens et al., 2014). Once the most accessible ores are exhausted, humankind will – increasingly – become dependent on lower ore grades and more remote mines. Not only the extraction costs will rise, but the impact on the (natural and human) environment, in terms of water use, energy consumption, greenhouse gas production, waste generation and landscape destruction will become higher to the extent that mineral ores become scarcer. Environmental impact and exhaustion of minerals are closely interlinked. According to Northey et al. (2014), the critical issue for primary production of a metal may not be the availability of mineral deposits as such, but rather economic and environmental issues associated with exploiting remaining reserves. In separate papers we came to the conclusion that an international agreement on the conservation and sustainable use of geologically scarce minerals is necessary to secure that sufficient scarce resources will be available for future generations Henckens et al. (2016a,2016b). The need for international cooperation regarding global management of scarce mineral resources is supported by e.g. Nickless (2017), Ali et al. (2017), Bleischwitz (2012), Bleischwitz et al. (2012) and Andrews-Speed et al. (2012).

The goal of the present paper is to investigate whether such an international agreement on the conservation and sustainable use of geologically scarce mineral resources would also be necessitated by normative principles of environmental governance, as they currently exist in international environmental agreements.

We consider normative principles as foundations of principled environmental governance. While these principles are of an abstract nature, we are particularly interested in them insofar as they have been legally codified in international environmental agreements. The legal nature of normative principles gives them a grounded character, and adds a level of seriousness to proposed international policies (i.e., objectives which the international community seeks to achieve). *Vice versa*, once a normative principle is broadly accepted as a foundation for international agreements, its applicability to other, yet non-regulated problems can be assessed. That is what we do in this paper.

To this effect, we will analyze in Section 3 and Section 4 which normative principles have so far provided a foundation to the major international agreements on natural resources. The analysis will be based on the text of international environmental agreements and on literature. The resulting inventory will provide us with a set of normative principles which could form the foundation of an agreement on the regulation of the extraction of geologically scarce mineral resources. In Sections 5–8 we will assess the applicability of four selected

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normative principles to the problem of exhaustion of mineral resources. In Section 9 we will draw conclusions. First, Section 2 contains an exposition of the problem of geological scarcity of mineral resources.

2. Background

Discussions on the geological scarcity of mineral resources and the consequences of unsustainable use are nothing new. After influential publications of Malthus (1798), Ricardo (1817) and Mill (1848) on the limited capacity of the Earth to provide enough food and minerals to the world population and the warnings of the so-called Conservation Movement in the USA between 1890 and 1920 (Tilton, 2001), new concerns on the long-term availability of resources were raised after World War II 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) (Cooper, 1975). One of the outcomes 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), whose findings and views on the relationship between economic growth and the 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 co-authors updated their advice to the Club of Rome (Meadows et al., 1992), arguing along similar lines.

The above described differences of views on scarcity reflect the discussion between the so-called resource optimists and resource pessimists (Tilton, 2003). 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.

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. While not denying this point of view, the pessimists, on the other hand, are of the opinion that humanity should not deliberately deprive future generations from resources, regardless of whether or not they could be replaced by alternative resources: new discoveries could potentially result in the situation that a geologically scarce resource may become very important or even essential for next generations. Hence, resources have an intrinsic value for future generations.

Furthermore, exhaustion of a mineral resource and the environmental impact of its mining are closely interlinked. A decrease of the ore grade leads to a higher energy and water use and waste production. A significant increase of the environmental impact of the extraction of a mineral resource is a symptom of exhaustion of that resource. Harmsen et al. (2013) show that a factor 2 decrease of the copper grade results roughly in a two fold increase of the Gross Energy Requirement. According to Swart and Dewulf (2013), the exhaustion of ores is not caused by lack of ore, but by changing ore characteristics, i.e. ore grade and ore depth. The lower the ore grade the more ore needs to be extracted to produce 1 kg of metal. Energy requirements, water use and waste production are directly connected to the ore grade. The world does not run out of elements as such, but certain resource reserves may become so low graded, so deep, so remote that the costs and –related – the environmental impacts of their extraction may become prohibitive. According to Mason et al. (2011), the extractability of a resource is determined by three criteria: (1) the availability of the resource (considering its geological characteristics and geographical distribution), (2) society's addiction to the resource, meaning the impact of a significant decline in the resource's availability to manufacturers and consumers taking into consideration the extent to which the affection of existing economic, social and environmental systems will be accepted by society, and (3) available alternatives (substitutability and recyclability).

In order to ensure that future generations keep sufficient access to primary minerals without being confronted with severe environmental impacts, it is essential that they are extracted at a sustainable rate. An important question, in this context, is how large the "Extractable Global Resources" (EGR) of a given mineral are.

We have assessed the quantity of extractable mineral resources in the Earth's crust on the basis of two different approaches in the literature:

- The extractable global resources according to an approach of a working group of the International Resources Panel of UNEP (2011)
- The extractable global resources according to an approach derived from Rankin (2011, p 303)

The two approaches are presented and elaborated in the Supplementary information. Additionally we have taken into account two different growth scenarios for raw materials production:

Scenario 1: the annual production increase of raw materials between 2015 and 2050 is equal to their annual production increase between 1980 and 2015; the annual production increase between 2050 and 2100 is assumed to be half of the 2015–2050 production increase; after 2100 no further production increase is assumed.

Scenario 2: the annual production increase of raw materials between 2015 and 2100 is equal to their annual production increase between 1980 and 2015; the annual production increase between 2100 and 2200 is assumed to be half of the 2015–2050 production increase; after 2200 no further production increase is assumed.

For both scenarios we have calculated the time period, within which the extractable amount of 33 mineral resources is exhausted. The combination of the two estimates for the extractable global resources and the two growth scenarios lead to four outcomes for the depletion period. Table 1 presents an indicative optimistic estimate of the exhaustion period after 2015 of the considered raw materials. For further details we refer to the Supplementary information.

The main conclusion of our assessment regarding potential scarcity of raw materials remains the same: for many mineral resources depletion is not imminent, but for some mineral resources it is relatively nearby.

A sensitivity analysis shows that even with eleven times larger amounts of extractable resources as compared to the UNEP approach, the extractable amounts of five raw materials may still be exhausted within 100 years after 2015 under the assumed scenarios: gold, antimony, copper, chromium and zinc. For the details of the sensitivity analysis it is referred to the Supplementary information.

Additionally it should be taken into consideration that the distribution of raw materials' consumption over the countries in the world is very unequal currently. The average citizen in industrialized countries consumes five times as much as the average world citizen and ten times as much as the average citizen in poor countries (Halada et al., 2008). If such unequal distribution is considered to be unsustainable in

Table 1
Time period after 2015 until depletion of the mineral resources of 33 raw materials. Own calculations based on data from UNEP (2011) and Rankin (2011) as shown in Table 4 of the Supplementary information.

Raw material	Indicative optimistic estimate for exhaustion period (rounded) (years after 2015)
Gold	80
Copper	80
Antimony	100
Boron	100
Rhenium	100
Bismuth	100
Molybdenum	100
Nickel	100
Silver	100
Indium	200
Zinc	200
Chromium	300
Cobalt	300
Niobium	300
Iron	400
Tungsten	400
Tin	400
Platinum Group Metals	600
Lithium	700
Cadmium	700
Lead	800
Manganese	1000
Arsenic	2000
Rare Earth Elements	2000
Strontium	3000
Aluminum	3000
Gallium	5000
Tantalum	5000
Magnesium	5000
Titanium	5000
Vanadium	5000
Germanium	200000
Selenium	200000

the long term and the consumption of raw materials per capita in the different countries of the world is supposed to become more equal, then industrialized countries need to make an extra effort. A global reduction of the extraction rate of a raw material of e.g. 50% means that industrialized countries have to reduce their consumption of raw materials with 90% compared to their current consumption in order to allow poor countries to catch up.

So even under very optimistic assumptions, the undisputable conclusion is that if humanity wants to conserve the scarcest mineral resources for future generations in all countries of the world, reduction measures must be taken for these resources, especially in industrialized countries.

3. Existing agreements

For *the short term*, in view of (uncertain) future crisis situations, some governments have decided to strategically stockpile certain raw materials. In EU Directive 2009/119/EC, EU Member States are obliged to maintain minimum stocks of crude oil and/or petroleum products (EU, 2009). After the end of World War I, the government of the USA started considering whether to maintain strategic stocks of a number of materials. The first strategic stockpiling in the USA was established in 1938 (Chappel, 2016). Many governments (including the European Union, Germany, France, Finland, the Netherlands, USA, Canada, Japan, Korea and Taiwan) prepared strategies based on so-called criticality studies on the short term availability of materials which are critical for the economy (Department for Environment, Food and Rural Affairs, 2012). The background of these strategies is principally geopolitical: the fear that monopolist producers might deliberately stop or reduce the production and delivery of certain materials for political or financial reasons.

However, for *the long term*, despite the depletion of geologically scarce mineral resources, no government has taken action thus far, nor has an internationally binding agreement limiting the extraction of geologically scarce mineral resources ever materialized. According to Brilha et al. (2018), the abiotic natural resources are persistently neglected in international and national politics. Nevertheless, some international declarations and charters have directly addressed depletion of mineral resources. Thus, the Declaration of the United Nations Conference on the Human Environment in Stockholm Declaration (1992) provides in Principle 5 that "*[t]he non-renewable resources of the earth must be employed in such a way as to guard against the danger of their future exhaustion and to ensure that benefits from such employment are shared by all mankind*". The UN World Charter for Nature (1982), for its part, provides in Principle II (d) that *"[n]on-renewable resources which are consumed as they are used shall be exploited with restraint, taking into account their abundance, the rational possibilities of converting them for consumption, and the compatibility of their exploitation with the functioning of natural systems"*. Finally, the UNESCO Earth Charter (2000) calls, in Principle II.5.f, on the international community to *"manage the extraction and use of non-renewable resources such as minerals and fossil fuels in ways that minimize depletion and cause no serious environmental damage"*. The 25-9-2015 Resolution adopted by the UN General Assembly on the 2030 Agenda for Sustainable Development includes Sustainable Development Goal 12.2: "*by 2030, achieve the sustainable management and efficient use of natural resources*".

While these declarations have not yet paved the way for the adoption of binding international agreements on the depletion of geologically scarce mineral resources, the normative principles which they contain remain relevant in the context of this paper because they might inform (future) customary and treaty law specifically aimed at regulating mineral resources depletion.

Additionally, there are some international agreements that address the *exploitation* (although not the *scarcity or depletion*) of mineral resources, namely the United Nations Convention on the Law of the Sea (UNCLOS 1982), the Protocol on Environmental protection to the Antarctic Treaty (1991), and the Agreement governing the Activities of States on the Moon and other Celestial Bodies (1979). However, these agreements are limited to areas outside national jurisdiction. There have also been international agreements on the conservation and protection of specific *renewable resources* such as biodiversity, endangered fish species, wild flora and fauna, and tropical timber: the Convention for the conservation of Antarctic Seals (1972), the Convention on the Conservation of Migratory Species of Wild Animals (1979), the Convention on Biological Diversity (1992), the Convention on the Conservation and Management of the Highly Migratory Fish Stocks on the Western and Central Pacific Ocean (2000), and the International Tropical Timber Agreement (2006).

In the next section we will investigate which normative principles, contained in existing international environmental agreements, could be relevant as a foundation for an international agreement on the conservation and sustainable use of geologically scarce mineral resources.

4. Normative principles in existing agreements and their relevance for mineral resources depletion

For the selection of relevant existing international environmental agreements we have primarily used the International Environmental Agreements database of the University of Oregon (Mitchell, 2016). This database comprises over 1100 multilateral and 1500 bilateral agreements. We specifically focus on agreements with broad international support, and on normative principles which are repeatedly used in such broadly supported agreements. Such principles may be considered to have broad international support as well. Hence, we have selected 29 multilateral agreements signed from 1960 onwards, with a (quasi-) global scope, which have been signed and ratified by a substantial

Table 2
Goal oriented normative principles in multilateral international environmental agreements signed from 1960 onwards with a (quasi) global scope.

No	Year	Agreement	Conservation and/or sustainable use of resources	Protection of wild flora and fauna, environment and nature	Precautionary principle	Inter-generational equity	Intra-generational equity
1	1971	Convention On Wetlands Of International Importance Especially As Waterfowl Habitat		X			
2	1972	Convention For The Conservation Of Antarctic Seals	X				
3	1972	Convention For The Prevention Of Marine Pollution By Dumping From Ships And Aircraft		X			
4	1972	Convention On The Prevention Of Marine Pollution By Dumping Of Wastes And Other Matter		X			
5	1972	Convention for the Protection of the World Cultural and Natural Heritage				X	
6	1973	Agreement On Conservation Of Polar Bears		X			
7		Convention on international trade in endangered species of wild fauna and flora			X		
8	1973	International Convention For The Prevention Of Pollution From Ships		X			
9	1974	Convention On The Prevention Of Marine Pollution From Land-Based Sources		X			
10	1976	Convention On Conservation Of Nature In The South Pacific		X		X	X
11	1979	Convention On Long-Range Transboundary Air Pollution		X			
12	1979	Convention On The Conservation Of Migratory Species Of Wild Animals		X		X	
13	1980	Convention On The Conservation Of Antarctic Marine Living Resources		X			
14	1982	United Nations Convention On The Law Of The Sea	X	X	X		
15	1985	Convention for the Protection of the Ozone Layer (Vienna Convention)			X		
16	1985	Convention On The Control Of Transboundary Movements Of Hazardous Wastes And Their Disposal		X			
17	1992	Convention on biological diversity	X				
18	1992	United Nations Framework Convention on Climate Change	X		X	X	X
19	1994	Agreement Relating To The Implementation Of Part XI Of The United Nations Convention On The Law Of The Sea		X			
20	1994	1994 WTO agreement on the Application of Sanitary and Phytosanitary Measures			X		
21	1995	Agreement for the implementation of the Law of the Sea Convention relating to the conservation and management of straddling fish stocks and highly migratory fish stocks	X		X		X
22	2000	Convention on the Conservation and Management of the Highly Migratory Fish Stocks of the Western and Central Pacific Ocean	X	X	X	X	
23	2001	International Convention On The Control Of Harmful Anti-Fouling Systems On Ships		X	X		
24	2001	International Treaty On Plant Genetic Resources For Food And Agriculture	X			X	
25	2001	Convention on Persistent Organic Pollutants		X	X		
26	2004	International Convention For The Control And Management Of Ships' Ballast Water And Sediments		X	X		
27	2006	International Tropical Timber Agreement	X				X
28	2009	Agreement on Port State Measures to prevent deter and illuminate illegal, unreported and unregulated fishing					X
29	2013	Minamata Convention on Mercury		X			

number of relevant countries. For the selected agreements reference is made to Table 2.

Table 2 does not include agreements with a regional scope, except agreements on oceans and on the Antarctic and Arctic regions. We have not selected multilateral agreements on (nuclear) energy, radioactive material, weaponry and other military issues, creation of institutions, financing, patents, occupational health, training, confidentiality of data, communication, information management and public participation, disasters and emergence situations, sustainable housing, research and monitoring, meteorology, liability, industrial safety, human health related to tobacco, compliance and enforcement, cultural heritage, and transport. The remaining selection consists of the 29 international environmental agreements in Table 2. We have made an inventory of the normative principles included in the preambles of the 29 selected agreements. In the inventory we have distinguished (1) normative principles which directly pertain to solving an environmental problem and (2) normative principles which pertain to the acceptability of the agreement for the signatories. We have mentioned the first category: goal-oriented principles. From the inventory, five principles are considered to be goal-oriented principles:

- 1. The Principle of Conservation and/or Sustainable Use of Resources (in 8 out of 29 considered agreements)
- 2. The Principle of Protection of Wild Flora and Fauna, Environment and Nature (in 18 out of 29 considered agreements)
- 3. The Precautionary Principle (in 10 out of 29 agreements)
- 4. The Inter-generational Equity Principle (in 6 out of 29 agreements)
- 5. The Sustainable Development Principle (in 5 out of 29 agreements).

Table 2 indicates for every agreement which goal oriented normative principles are included in the agreement. These principles could also be the normative building blocks for an international agreement that aims to achieve the sustainable extraction of mineral resources.

The normative principles which are not directly related to the goal of the agreement, but which pertain to the acceptability of the agreement for the signatories are related to aspects such as fairness, burden-sharing, and responsibility assignment. It concerns the Sovereignty over Natural Resources Principle, the Intra-generational Equity Principle, the Principle of Priority for the Special Situation and Needs of Developing Countries, the Principle of Common but Differentiated Responsibilities in Accordance with Capabilities, the Principle of Equitable Contribution to Achieving the Goal of a Convention, the Principle that Activities may not Cause Damage to the Environment of other States and the Polluter Pays Principle (Kiss and Shelton, 2004). These normative principles are relevant as boundary conditions in an agreement on the conservation and sustainable use of mineral resources, determining the architecture of such an agreement.

While the five goal-oriented normative principles buttress the analyzed international agreements, they are not necessarily all *relevant in* the framework of an international agreement on geologically scarce mineral resources. Notably, the Principle of Protection of Wild Flora and Fauna, Environment, and Nature seems less relevant, as scarce mineral resources have no value of their own without further utilization, certainly when compared to endangered species and beautiful landscapes. As far as we know, mineral ores in the earth do not have a specifically important role as habitat. Their stock, outside ores, is very large, so that absolute depletion of a mineral is not at stake, and unlike landscapes, mineral ores do not have a specific beauty. Accordingly, the Principle of Protection of wild Flora and Fauna, Environment, and Nature is not a principle relevant for an international agreement on the conservation and sustainable use of geologically scarce mineral resources. In Sections 5–8 we apply the four remaining normative goal-oriented principles to the problem at hand.

5. The principle of conservation and/or sustainable use of resources

In this section we investigate whether the Principle of Conservation and/or Sustainable Use of Resources would be applicable to an international agreement on the conservation and sustainable use of geologically scarce mineral resources. Thus far, the Principle of Conservation and Sustainable Use in existing international environmental agreements has concerned specific (types of) *renewable* resources, such as the conservation and sustainable use of fish, biodiversity, and tropical timber. These resources are only renewable on the condition that their use is in balance with their natural recovery. Irreversible, global and short-term disappearance was feared if no urgent action was taken at the international level as their consumption rate was exceeding their recovery speed. The conservation and sustainable use of *non-renewable* resources (such as mineral resources), on the other hand, has only been included in non-binding declarations and charters. Therefore, let us compare the gravity of extinction of endangered biotic resources and species with the gravity of depletion of geologically scarce mineral resources.

The gravity of an environmental problem is characterized by three main elements: the size, the seriousness, and the urgency. We have analyzed the pre-ambles of the 29 selected international agreements on the presence of sentences relating to these elements of gravity. The conclusion is that the main elements of gravity are composed of several sub-elements. These sub-elements are presented in Table 3. As for the sub-elements we assume that certain thresholds (or a combination of thresholds) must be exceeded for an international agreement to be contemplated and concluded. It is difficult to design a generally accepted quantitative measuring stick composed from the elements in Table 3 along which a mineral resources scarcity problem can be put, and that would enable a mathematical determination of whether it is grave enough to necessitate an international agreement. However, for

Table 3
Elements for assessing the gravity of a resource scarcity problem in view of the potential justification of a global agreement.

Elements of gravity of a resource scarcity problem	Sub-elements
Potential size of the problem	– The number of countries affected (spatial dimension) – The proportion of the resource that is endangered (volume dimension) – The extent that future generations are affected (temporal dimension)
Potential seriousness of the problem	The potential extent of – (Ir)reversibility – The Impact on human life, directly or indirectly – The Impact on health, safety, and survival of the living environment (animals, plants, natural cycles and equilibria, eco-systems, natural tipping points, food chains, biodiversity, and habitats) – The Impact on the uniqueness of the endangered resource – The impact on economy and welfare
Potential urgency of the problem	– Available time span to redress the developments in order to prevent the problem from becoming too grave to be adequately solved

at least four gravity sub-elements, we consider the gravity of depletion of geologically scarce mineral resources to be comparable with the gravity of the problem of extinction of endangered biotic resources and species, namely the affected number of countries (all countries), the extent that future generations are affected (for five resources starting within 100 years), the irreversibility (ores can only be extracted once), and the impact on economy and welfare. The potential impact of depletion of mineral resources on economy and welfare is substantial, because after ore depletion, the extraction of the resource from the earth's crust is only possible against much higher costs. The material delivered by the resource will still be available to some extent, through recycling, but the available amount will slowly decrease over time, since recycling is never hundred percent. A perfectly circular economy is not possible. New applications of the mineral resource will be hampered because of its increased costs and the flexibility and degrees of freedom of future generations will be less than without depletion of the resource. Our conclusion is that the normative Principle of Conservation and Sustainable Use of Resources requires an international agreement on the conservation and sustainable use of geologically scarce mineral resources.

6. The precautionary principle

In this section, we investigate whether the precautionary principle would require an international agreement on the conservation and sustainable use of geologically scarce mineral resources. According to many authors (i.e. Sirinskiene, 2009; Sandin et al., 2002; Tickner et al., 2003; Tickner and Kriebel, 2006; Sachs, 2011), there is sufficient state practice and *opinio iuris* to support the position that the Precautionary Principle has already crystallized into a rule of general customary international law. Still, some scholars and politicians, especially in the United States, consider the Precautionary Principle as incoherent, internally inconsistent, and having a paralyzing effect on industrial and economic development. They therefore strongly oppose an application of the (stronger versions of) the Precautionary Principle (Sunstein, 2005). Nonetheless, the Precautionary Principle has been broadly adopted as a cornerstone of international and national declarations, agreements, and regulations on the environment, both binding and non-binding.

Criteria for invocation of the Precautionary Principle that are shared in most Precautionary Principle definitions are the threat of serious or irreversible damage (Rio Declaration, 1992), the potentially dangerous effects (European Commission, 2000), the fact that scientific evaluation of the risk cannot be determined with sufficient certainty (European Commission, 2000), and the reasonable foreseeability of damage falling short of conclusive scientific proof (International Law Association, 2014).

The irreversible damage of the depletion of mineral resources that we foresee is economic: Once ores have been depleted, the extraction of mineral resources will become 10–1000 times more expensive (Steen and Borg, 2002). Thus, the access to resources that are currently easily available may become much more difficult for future generations. This (economic) damage can be considered serious because it regards humanity as a whole and because future generations will be deprived of certain mineral resources potentially encompassing substantial economic costs. The damage is irreversible because ores will be definitively depleted. In light of our considerations in Section 2, our conclusion is that there is a reasonable foreseeability of depletion of geologically scarce mineral resources, although there is a debate on the seriousness of the consequences.

We acknowledge that the *scope* of the Precautionary Principle is generally limited to the protection of the environment and human, animal, and plant health. This includes the protection and conservation of biotic resources such as biodiversity. Trouwborst (2007), p. 190 writes that *"the Precautionary Principle has, from the outset, been an environmental principle"*. However, non-environmental problems need not necessarily be excluded from the scope of a broadly defined Precautionary Principle. In international humanitarian law, for instance, the principle informs the constant care which States shall take, in the conduct of military operations, to spare the civilian population, civilians, and civilian objects (Article 57 Additional Protocol I to the Geneva Conventions, 1977). Precaution could similarly inform economic decisions. The European Commission (2000) stresses in a Communication, in rather general terms, that *"the Precautionary Principle goes beyond the problems associated with a short or medium term approach to risks. It also concerns the longer run and the well-being of future generations"*. Also, in the 2002 EU Regulation on state aid to the coal industry (EU, 2002, Preamble, para 7), the EU extended the scope of the Precautionary Principle beyond the environment only, in the context of broadly defined energy security: *"Strengthening the Union's energy security, which underpins the general Precautionary Principle, therefore justifies the maintenance of coal-producing capability supported by state-aid"*. From these instruments it could be gathered that at least the EU is willing to include the well-being of future generations in general, including economic security, into the Precautionary Principle.

Economic theories, concerned with future uncertainty, in any event do rely on some version of the Precautionary Principle (see for instance the publications of Gollier and Treich, 2003; Gollier et al., 2001; Gollier, 2010a, 2010b; Farrow and Hayakawa, 2002). According to these theories, irreversible developments (e.g., the depletion of mineral ores), as well as uncertainty and lack of knowledge regarding the consequences and size of future risks (such as the risks of climate change), lead to a loss of flexibility for future generations and therefore have a cost. Golllier (2010a, 2010b) submits, in this respect, that uncertain future costs must be discounted to a net present value using lower discount rates to the extent that decisions regard a future further away and the uncertainty is bigger. While in economic theory, precaution in principle informs market participants' decisions, earlier research (Henckens et al., 2016b) has demonstrated that the market may not take sufficient precautions in the face of future or even imminent depletion of mineral ores. *Regulatory* precautions to prevent economic loss as a result of depletion may instead have to be taken. An economically flavored Precautionary Principle may show the way here.

Nevertheless, one has to admit that there is no international consensus on the scope and invoking criteria of the Precautionary Principle or on the potential seriousness of the consequences of resources depletion. The conclusion is therefore that the applicability of the Precautionary Principle to the problem of depletion of geologically scarce mineral resources is not sufficiently unambiguous to lend itself to grounding an international agreement on this issue.

7. The inter-generational equity principle

In this section we investigate whether the Inter-Generational Equity Principle would require an agreement on the conservation and sustainable use of geologically scarce mineral resources. The Principle of Inter-Generational Equity is included in many international conventions, including the Rio Declaration on Environment and Development (1992) and the United Nations Framework Convention on Climate Change (1992). Inter-generational equity embodies care for future generations. It means that the current generation just "borrows" the earth from future generations.

Inter-generational equity is a legal principle and means that future generations may have a legitimate expectation of equitable access to planetary resources (International Law Association, 2014). According to Padilla (2002), p 81, "*we should recognize and protect the future generations' right to enjoy at least the same capacity of economic and ecological resources that present generations enjoy*". According to Shelton (2007), p 643, "*[t]hose living have received a heritage from their forbearers in which they have beneficial rights of use that are limited by the interests and needs of future generations. This limitation requires each generation to maintain the corpus of trust and pass it on in no worse condition than it was received*". It is a matter of justice that an intergenerational community gives a voice to voiceless future generations. In this respect, as Agius et al. (1998), p 11 have pointed out, "*future generations are similar to those that our society has declared legally incompetent*". It is undeniable that previous and current generations irretrievably and inevitably deplete(d) mineral resources. As a result, the options for future generations are gradually constrained and their flexibility is reduced. It will ultimately be a political decision, though mandated by the legal Principle of Inter-Generational Equity, how the current generation leaves the earth for the future generations.

Inter-generational equity needs to be distinguished from *intra-generational* equity. Intra-generational equity does not limit the *use* of resources as such, but it governs the *distribution* of resources and the distribution of the costs and benefits between people and peoples of the same generation. There is surely a tension between intra-generational and inter-generational equity: the wish to distribute resources more equitably over the current generation could imply that there is pressure to use more resources than justified on the basis of inter-generational equity. One cannot impose austerity on the current poor for the sake of the future rich. Both now and in the future, intra-generational equity will be an important condition to be able to reach an international agreement on the conservation and sustainable use of geologically scarce mineral resources. It will be difficult to obtain a global arrangement on the conservation and sustainable use of geologically scarce mineral resources without taking intra-generational equity into account. The availability of geologically scarce mineral resources will need to be limited for all countries and people, also for poor people and poor countries that have never had an abundant access to these resources. However, for mankind it is important to also obtain the consent of poor countries for conservation and sustainable use. Without intra-generational solidarity it will be difficult to ask poor countries for inter-generational solidarity. Intra- and inter-generational equity complement each other. The World Commission on Environment and Development (1987) reconciles the Inter-Generational and Intra-Generational Principle in its definition of sustainable development.

For *non-renewable* resources such as mineral resources, an equilibrium in which the resource does not decrease in quantity and quality would imply a zero use. This would deprive the current and future generations of the resource, however. In this sense, the sustainable extraction of mineral resources is an oxymoron. Anyhow, in light of the expected depletion of mineral resources at current extraction rates, the needs and rights of future generation compel the current generation to deal as economically (or sustainably) as possible with mineral resources in general, and especially with geologically scarce mineral resources. The conclusion is that the inter-generational equity principle requires an international agreement on the conservation and sustainable use of geologically scarce mineral resources.

8. The sustainable development principle

In this section, we investigate whether the Sustainable Development Principle would require an agreement on the conservation and sustainable use of geologically scarce mineral resources. The most influential substantive definition of sustainable development, and also the most followed one, is certainly the one formulated in 1987 by the so-called Brundtland Commission in its report "Our Common Future": *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (World Commission on Environment and Development, 1987). As many natural resources are not sustainably managed, this has led to the introduction of the concept of sustainable use and sustainable development in a substantial number of environmental agreements. It has also been argued that the Principle of Sustainable Development has risen to the level of a customary international legal norm (Sands et al., 2012, p 206 and 208). At the very least, it operates as a hermeneutical tool which helps in the interpretation of existing legal norms (Barral, 2012, p 398). Various international courts and tribunals have invoked the concept.[2]

The exact status and content of sustainable development remain somewhat unclear. Different approaches to sustainable development continue to abound. Johnston et al. (2007) estimated some 300 definitions of sustainability and sustainable development existed in the domain of environmental management and associated disciplines. Two main conceptions of sustainability can be identified: a weak and a strong one (Hansson, 2010). According to the *weak sustainability* concept, elements of sustainable development are inter-changeable as long as (economic) development and welfare as a whole do not diminish. In this vision, maintaining sustainability is a matter of assuring that total capital (human plus natural) does not diminish. We may pass on less environmental resources to coming generations as long as we pass on more human-made capital instead. Or in Hansson's (2010), p 275 words:*"If we hand over to coming generations new technologies that reduce their needs of natural resources, then according to this view we can deplete more resources now and yet comply with the precepts of sustainability"*. According to Van Den Bergh (2010), adoption of the weak concept of sustainability for mineral resources is no problem as long as the environmental externalities are fully taken into account.

In contrast, the *strong sustainability* concept in its pure form sees human-made and natural capital as different categories that are not interchangeable and that must be preserved separately. In the most extreme version of the concept of strong sustainability, every species and resource must be preserved since it cannot be replaced. Further extraction of exhaustible resources would not be possible anymore.

The strong concept is widely considered as not practicable, whereas the weak notion of sustainability has been criticized to be too lax because it enables depletion of resources provided that this is compensated for by increases in other resources, for instance better health care (Hansson, 2010). Therefore, Ayres et al. (2001) suggest a compromise: the strong concept of sustainability should focus on critical ecosystems and on environmental assets that cannot be replaced by anything else, while the weak sustainability concept should apply to mineral resources. Ultimately, it appears that the interpretation of the Sustainable Development Principle and the connected obligations of States are evolving over time (Barral, 2012).

Moreover, the Principle of Sustainable Development does not seem to be a stand-alone principle. According to the Brundtland definition, it is an integrative principle, which includes previous principles described in this paper, notably the sustainable use of resources, intra- and inter-generational equity (see also Sands et al., 2012), and the Precautionary Principle (United Nations Economic Commission for Europe Region, 1990).

Due to the vagueness, the divergent interpretations and the evolving character of the Sustainable Development Principle, it is in our view not unambiguously clear whether the Principle of Sustainable Development requires an international agreement on the conservation and sustainable use of geologically scarce mineral resources as such.

9. Conclusions

Two normative principles from existing international environmental agreements require an international agreement on the conservation and sustainable use of geologically scarce mineral resources: the Principle of Conservation and Sustainable Use of Resources and the Inter-Generational Equity Principle. No definitive conclusion can be drawn whether or not the precautionary principle is relevant, due to its

[2] e.g., Gabcíkovo-Nagymaros Project (Hungary v. Slovakia), Judgment, ICJ Reports (1997) 7, at para. 140; Award in the Arbitration regarding the Iron Rhine ('Ijzeren Rijn') Railway between the Kingdom of Belgium and the Kingdom of the Netherlands, 27 RIAA (2005) 35, at para. 59; Case Concerning Pulp Mills on the River Uruguay, ICJ, Judgment, 20 April 2010, para. 177.

ambiguity in connection to economic problems, nor can a conclusion be drawn as to the applicability of the Sustainable Development Principle, due to the vagueness of its application.

Given the esteemed gravity of the mineral resources depletion problem, the normative principles of (1) conservation and sustainable use of resources and (2) inter-generational equity are applicable to the depletion of geologically scarce mineral resources, because:

– the resources depletion problem is big (all countries will be affected, a large proportion of some resources is endangered, future generations will be affected permanently)
– the resources depletion problem is serious (depletion of resources is irreversible, the potential impact on the interest of future generations is substantial)
– the resources depletion problem is urgent (the available time span to address depletion of some resources has become short).

Once the necessity and urgency of an international agreement on the conservation and sustainable use of geologically scarce mineral resources is accepted by the international community, the design of such an agreement becomes important. According to us, at least the following issues would need to be considered in a balanced way to reach agreement within the international community on the architecture of the agreement:

– The sovereignty of resource countries over their natural resources and a compensation mechanism for resource countries for their loss of income
– The Intra-Generational Equity Principle and the special position of poor user countries

There is an area of tension between, on the one hand, the sovereignty of States to exploit the natural resources on their territory and, on the other hand, the sustainable use of these resources which represents a more important need than the immediate interests of any single State or even of any single generation. It cannot be expected that resource countries would voluntarily limit the production of mineral resources, losing their economic advantages and without any further advantage instead. Hence, compensation of the resource countries for their lost income is necessary. This is not new. One could compare it in this respect with the compensation of developing countries for not logging forests in the framework of the UN REDD compensation programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (United Nations REDD, 2016).

In conclusion, we see the need for an international agreement on the sustainable use of geologically scarce mineral resources. We argue that the gravity of the mineral resources depletion problem is such that the normative Principles of Conservation and Sustainable Use of Resources and Inter-Generational Equity necessitate such an agreement.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.resourpol.2018.08.007.

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