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Position Paper

Raw materials for the energy transition

Securing a reliable and sustainable supply

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Securing a reliable and sustainable supply

Preface

If Marion King Hubbert had been right, the US would by now hardly be producing any oil at all: The US geologist had predicted oil production to peak in 1971 (“Peak Oil”) before gradually decreasing, until the deposits would finally be exhausted. To this day, however, Hubbert’s predictions have not been fulfilled. He did not, for instance, foresee the success of fracking technology: With oil prices soaring, fracking suddenly has become profitable and allowed for the exploitation of new resources.

This example illustrates how market mechanisms and technological developments can bear upon the range of a raw material – not only in the case of fossil energy sources. With the technologisation of almost all areas of life, “exotic” minerals and metals such as gallium, indium, tellurium and rare earths have become valuable trade goods. In the meantime, the economy is reacting sensitively to developments on the metals markets. The economic boom China has known since 2003, for instance, has not only driven up prices, but has likewise led to supply bottlenecks. Geopolitical conflicts or export quotas on certain metals can have similar consequences.

High-tech metals are indispensable – not least in the energy sector: They are required for the expansion of wind power and solar plants, transmission and distribution grids and energy storage systems. Should an important metal be very expensive over a prolonged period or, indeed, be no longer available on the market, this might well bog down the energy transition. It is against this background that the present position paper illustrates how closely resource security and energy supply security in Germany are linked. This paper likewise presents measures that can contribute to securing the raw materials supply for the energy transition beyond the 2010 National Raw Materials Strategy.

This position paper is based on the results of the analysis *Raw materials for Future Energy supply. Geology – Markets – Environmental Impacts*, elaborated by the Working Group “Resources” of the Academies’ project “Energy Systems of the Future”. We would like to express our sincere thanks to the scientists and the reviewers for their commitment.

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Content

Abbreviations and Units

Abbreviations

BECCS	Bioenergy with Carbon Capture and Storage
BGR	Federal Institute for Geosciences and Natural Resources
CCS	Carbon Capture and Storage
CENELEC	European Committee for Electrotechnical Standardisation
CO_2	Carbon dioxide
DERA	German Mineral Resources Agency at the Federal Institute for Geosciences and Natural Resources
EEG	Renewable Energies Act
EITI	Extractive Industry Transparency Initiative
EROI	Energy Return on Investment, indicates the ratio of energy output and energy input
ICMM	International Council of Mining & Minerals
JOGMEC	Japan Oil, Gas and Metals National Corporation
LME	London Metal Exchange
LNG	Liquefied Natural Gas
GHG	Greenhouse gas
UFK	Untied financial loans
WTO	World Trade Organization

Units

g/kWh	grams per kilowatt hour
Gt	gigatonne
m^2	square metre
TWh	terawatt hour

Abstract

The energy transition affects Germany's raw material requirements. If it is successfully implemented, the consumption of fossil energy sources such as coal, oil and natural gas will decrease. Moreover, even during the period of transition towards a more sustainable energy system, carbon emissions could be reduced by replacing coal with natural gas. In addition, bioenergy could help offset the volatile feed-in of wind and solar energy, thus contributing to a stable energy supply based on renewable energies. At the same time, however, the expansion of renewable energy plants, storage systems and intelligent grids creates an increased demand for elements such as steel, copper, cobalt, lithium, rare earths, the platinum group elements, indium or tellurium.

From a geological point of view, there are sufficient metals and energy resources around the world to create a climate-friendly energy system by 2050. The crucial point, however, will be to ensure that the economic viability of the respective investments is not ruined by any sharp increase in the prices of the resources required. If the German economy is to secure its long-term supply of raw materials, a forward-looking political strategy is required. This position paper presents measures apt to contribute to a secure, affordable, environmentally friendly and socially acceptable supply of raw materials for the energy transition.

Ensuring a secure supply of metals

The number of elements required for products such as cars, consumer electronics and new energy technologies is steadily increasing. Major innovations or strong economic growth particularly fuel the demand for "high-tech metals" (e. g. gallium, germanium, the platinum group elements and steel alloy metals such as nickel and molybdenum). Unlike in other markets, production capacities tend to react slowly to such shortages and the respective price signals: Even under favourable political and administrative conditions, an average of ten years will elapse between the discovery of a metal deposit and the start of exploitation.

A rapid expansion of mining capacities would be, however, the more urgent the smaller the reserves of already extracted materials are. As a rule, companies using raw materials likewise need considerable time to adapt their production processes to a more sparing use of a scarce or expensive resource or to replace such a resource with other raw materials. It was not least due to this halting dynamism that the high-price phase for many metal raw materials, triggered by the economic boom in China in 2003, persisted for an unusually long period until 2013. This unexpectedly high demand on the part of many market participants led not only to price increases but, in some cases, even shortages and operational disruptions in the manufacturing industries. Also, access to important metallic raw materials on the global market tends to become altogether more difficult: With a dwindling number of countries and companies controlling an increasing share of the raw material supply, a growing power concentration ensues in these markets. As a result, individual countries such as China can significantly limit the global availability of raw materials by imposing export restrictions.

Countries are reacting differently to this challenge. Even governments of market-oriented and open economies, such as Japan and South Korea, increasingly tend to attribute almost equal importance to the respective metals as to oil and natural gas and pursue a strategic policy to secure resources. The German Federal Government has likewise responded to the exacerbated supply situation. With the 2010 National Raw Materials Strategy, it supports German industry in diversifying its raw materials sources, thus contributing to counteracting the formation of monopolies amongst raw material suppliers. In principle, however, the raw material processing industries have been counting on the availability of the metals on the global market since the 1990s. Nevertheless, should prices for high-tech metals soar or, indeed, supply bottlenecks occur in the next few years, the implementation of the energy transition might be slowed down.

The following measures could contribute to securing the metal supply in the long term:

- **Recycling:** Germany has large quantities of valuable metals in the form of end-of-life products such as cars, electronics (including mobile phones) and buildings. As yet, these resources have by no means been comprehensively used.

- **Mining in Germany and Europe:** There is some potential that new deposits may be discovered in Germany and Europe. Indium, germanium, tungsten and nickel from domestic deposits might reduce import dependency.

- **Raw materials from the sea:** An exploitation of the deposits in the deep sea could ultimately supply numerous metals of importance for the energy transition.

- **Diversifying supply sources:** By means of equity acquisition and long-term supply contracts, raw material processing companies can secure themselves access to important metals. Moreover, a state-funded mining company could develop deposits, while existing mines could be granted public subsidies enabling them to switch to the “stand-by mode” to bridge low-price phases. This could effectively counteract the formation of further monopolies. However, from a competitive economic standpoint, such approaches in which the government assumes a considerable entrepreneurial risk are viewed with much scepticism.

- **Stockpiling:** Temporary supply bottlenecks can be cushioned by foresighted stockpiling. Should public subsidies be granted to do this, private industry should be obliged to bear an adequate share of the expenses, for instance via some form of insurance premium.

- **Raw material data:** In order to obtain relevant data on raw materials, a legislation on raw material deposits could be introduced compelling companies to publish (after an appropriate waiting period) certain data they already provide to the mining authorities as part of their reporting obligations. This concerns, e. g., seismic research results or drilling data. International networking and an exchange of information on critical metals can likewise contribute to a sound raw material database.

- **International resource policy:** Bilateral commodity agreements can both facilitate access to raw materials

and contribute to high environmental and social standards. Such standards, incidentally, depend highly on effective transparency mechanisms.

Whereas **recycling** already covers a large part of the current demand in, e.g., steel or copper, the recovery rates in the field of rare earths and other high-tech metals remain low. This is partly due to the fact that the individual products contain only small quantities of these elements, necessitating complex special procedures for their recovery. In addition, only a small share of discarded consumer electronics is subjected to efficient recycling. Measures to increase the share and efficiency of metal recycling could be introduced along the entire process chain: Waste legislation could be focussed more strongly on the recovery of high-tech and special metals, while legal provisions could enforce the application of efficient recycling processes. Illegal exports of electronic waste can be prevented by means of improved export controls. Consumer-friendly collection systems would keep people from disposing of electronic devices in their household waste. A more recycling-friendly product design would make it easier to remove components with valuable elements in order to reuse them or to simplify their recycling.

There is **potential in Germany** for indium, germanium, tungsten, lithium and nickel that could lead to new discoveries. Regarding the prospecting for and exploration of raw material deposits and the metallurgical treatment of ores, we have, as yet, no technical procedures adapted to our domestic resources. Were such procedures developed, they could significantly facilitate the commercial use of known domestic metal ore deposits. To this end, university research capacities in metallurgy would have to be expanded.

In the sea, there are deposits of many of the potentially critical raw materials for the energy transition: cobalt, nickel, molybdenum, tellurium, indium and selenium. However, their exploitation in the deep sea is technically complex and requires further research and development. The German Federal Government has hence obtained exploration licenses from the International Seabed Authority for two areas where it will examine, e.g., the environmental impacts of industrial exploitation. In other countries, including China, Japan and Russia, we likewise find state-funded exploration. Should the Federal Government decide to include metals from the sea in a strategic concept to ensure the raw material supply, it would, from today's perspective, have to provide interested companies with financial support. However, the costs of marine mining are high and difficult to quantify. State-funded exploitation would therefore come at a considerable risk for the taxpayer.

By engaging in marine mining early on, Germany would be well positioned to ensure the global introduction of high environmental and safety standards for the exploitation of raw materials under the sea. A strategy for the future evolution of marine mining should include a so-called "pilot mining test". It would allow for test mining, better cost estimates and the record-keeping of the ensuing environmental impacts.

In the long term, however, German companies will have no alternative but to purchase some of the required metals on the world market. **Diversifying the sources** would help to secure a regular supply. With regard to elements such as rare earths, platinum group metals, tungsten or tantalum, two basic lines of action are open to raw material processing companies: They can either engage in mining themselves or else acquire interests in raw material projects with long-term supply contracts or pre-emption rights.

This could be facilitated by establishing a state-funded mining or raw materials company. Such a company could anticyclically acquire the rights to a deposit, initiate mining projects and develop deposits for which it could eventually find private investors. This, however, would burden the public sector with a significant investment risk, since involvement from the private sector cannot be guaranteed. Alternatively, the subsidised raw materials company could establish strategic partnerships with producers of raw materials and intermediates.

In order to bridge low-price phases, public subsidies could be granted to temporarily keep up existing mines on a care and maintenance basis, viz. in "stand-by mode". This would allow for a speedy reopening of disused mines at a later point in time. Temporary high-price phases, on the other hand, could be mitigated by **stockpiling**.

A public stockpiling system for critical metals – organised along the lines of the strategic oil reserve – would be a possible way of ensuring the supply even in the event of shortages. Some form of insurance premium could impose an adequate share of the costs on the raw material processing industry, ensuring that the selection and quantity of the stored resources is regulated according to demand.

However, measures such as government shares in mining companies and stockpiling systems, where the public sector becomes a raw material entrepreneur, should not be resorted to unless a real market failure occurs or is impending. This would be the case if, for instance, a supplier abused his monopoly, raising the raw materials prices way above the level to be expected in a free and transparent market. A still more extreme situation would arise if resources could no longer be physically procured, for instance owing to an export ban in the most important supplier country. High price fluctuations, on the other hand, while posing major challenges for raw material processing companies, would not constitute market failures.

Hence, if government intervention is considered, the following points need to be carefully examined: That (1) market failure has, indeed, occurred or is impending or highly probable, that (2) the measures under consideration are appropriate to counteract such a failure, and that (3) the costs of such an intervention are justified with regard to the economic damage to be expected should no intervention take place. However, preference should be given to measures aimed at creating free and transparent markets and preventing export restrictions in the supplier countries.

If such attempts are successful, the raw material processing companies are in a position to secure their raw material supply independently. Only in the event that such measures – e. g. in the form of trade agreements or bilateral and multilateral contracts – are not applicable, could the emergency solution of direct state involvement in the procurement of raw materials be considered.

In order to correctly assess the supply situation, companies require good **raw material data**. Information on high-tech raw materials obtained as by-products in the mining and smelting of other metals (e. g. indium, germanium, gallium, tellurium and the rare earths) is particularly scarce. Their markets are both very limited and highly opaque. More transparency could be achieved by establishing a network of governments, producers and consumers (along the lines of the *International Metal Study Groups*) under the umbrella of the United Nations. Such a network already exists for lead, zinc, copper and nickel.

The development of new exploration ideas and concepts in science and industry would profit from modernised legislation on raw material deposits ensuring an enhanced data basis: Companies in Germany could be compelled to publish, after a suitable waiting period, data on the exploration of the deep underground that they are forced to submit to the mining authorities in the concession contract. In addition, this would avoid double work and costs. It would further be desirable that the industry make the drill cores available to the scientific community after an appropriate period.

Globally consistent environmental and social standards on a high level are important both in mining and recycling: They can limit harmful effects on humans and the environment, ensure public consent for raw material extraction and enable fair competition on the global raw materials markets. At the global level, many regulatory options for a better, fairer and more sustainable dealing with resources have been considered in the past. Attempts towards an **international raw materials policy** include the establishment of an international expert body for the management of raw materials or the introduction of a global resource legislation. However, the interests of the relevant countries being very heterogeneous, global agreements are difficult to achieve. Bilateral raw materials agreements and partnerships are a more practical option. They can be implemented more promptly and are therefore more promising in the short to medium term.

Binding transparency mechanisms are an appropriate political instrument to trace trade and production processes. Especially in the case of resources from conflict zones, such mechanisms can uncover possible connections between companies, governments and armed groups deriving their funding from the mining and trading of raw materials. Thus, they can contribute to a more responsible commodity trade. Such transparency mechanisms can and should also take environmental and social criteria into account. Obtaining the “social license to operate” will be the greatest challenge in future raw material production.

Energy resources: biomass and natural gas

Although an increasing share of the energy demand will be covered by power from wind turbines and photovoltaics, combustibles will still be required – at least as long as there are no sufficient long-term storage systems. Biomass is easily storable and can be used flexibly for the generation of electricity and heat. Converted into bioalcohol, biodiesel or biomethane, it can also be flexibly used as fuel in the transport sector. However, the advantages and disadvantages of the use of biomass must be carefully considered: Biomass is, after all, not an unlimited resource and should be used where it is most beneficial to the energy system.

Only under certain circumstances is biomass a carbon-neutral energy source. In addition, the cultivation of energy crops in intensive agriculture generates additional greenhouse gas emissions (nitrous oxide) along with other environmental impacts. The overall greenhouse gas balance of bioenergy can vary widely, since it depends on several factors: the plants used and the quality of the soil, the method of cultivation and, in particular, possible land-use changes to enable the cultivation of plants. Whether the use of bioenergy makes sense is therefore also dependent on the other available energy sources and how they compare with bioenergy in terms of their greenhouse gas balance and other environmental consequences. Since biomass can be both cultivated in Germany and imported from a large number of countries, it can contribute to ensuring supply security.

As far as fossil energy sources are concerned, natural gas plays a particularly important role for the energy transition. Gas plants are flexible and come at low investment costs; they can thus compensate for the fluctuating feed-in from wind and solar energy sources. Moreover, gas has a lower carbon dioxide balance per kilowatt hour than coal.

The following measures could help to secure the supply of natural gas and sustainable bioenergy:

There are various measures apt to counteract the **environmental impacts of the cultivation of energy crops**. A first step would be to limit government subsidies for waste biomass and timber from sustainably managed forests. These tend to produce less greenhouse gas emissions and other environmental impacts than energy crops. A very comprehensive option would be to include the agricultural sector in the emissions trading system: This would make it possible to reduce not only the greenhouse gas emissions generated by energy crops, but by all agricultural products.

Alternatively, or in addition, sustainability requirements could be adopted for the cultivation and import of energy crops. Greenhouse gas emissions and other environmental impacts from agriculture could be further reduced by introducing a tax on fertilisers and adopting regulatory requirements for the cultivation of soils with high carbon concentrations (e.g. grasslands and moors).

Additional potential for sustainable bioenergy could be developed by using land unsuitable for the cultivation of food crops to cultivate grasses or shrubs. The use of waste for energy could also be expanded. The areas available for the cultivation of energy crops are not a fixed entity: They could be expanded if less food were wasted and the consumption of animal products were reduced.

In the case of **natural gas**, Germany is almost entirely dependent on imports from a very small number of supplier countries. One possibility for bridging supply bottlenecks is the further expansion of natural gas storage units. Their management could be realised by means of a government-controlled strategic gas reserve along the lines of the existing oil reserve. Such a solution, however, would entail high costs. Supply security could also be ensured by diversifying the supplier countries, which would imply expanding the pipeline and the liquefied natural gas infrastructure. Further options include the use of shale gas and natural gas from German coal seams or – in the long term – of methane hydrates from the deep sea.

1 Introduction

With the energy transition, Germany is facing major restructurings of the infrastructure in the coming decades. By 2050, Germany is planning to generate 60 percent of its primary energy and 80 percent of its electricity from renewable sources.[1] Coal and natural gas power plants are to be largely replaced by wind and solar power plants, and petrol and diesel cars by electric vehicles; intelligent grids and controllable loads will ensure that power generation, storage and consumption are optimally coordinated. In short, some decades in the future, the energy system will consist of completely different plants and use different forms of energy than today.

But how does this affect the raw material requirements? The most obvious consequence is, of course, the fall in the consumption of the fossil fuels natural gas, oil and coal. The diminishing dependency on these energy sources, mostly imported from abroad, is often considered a positive effect of the energy transition. Less attention is, however, given to the question of the raw materials required for the construction of the new plants. Here, metals play an important role.[2] Given the fact that the construction of renewable energy plants will require more raw materials per unit of energy than conventional power plants, we must expect a growing demand for metals for the energy system.

In addition to metals, building materials such as sand or gravel are required for the conversion of the infrastructure. The demand for these raw materials is covered by domestic production in Germany. They are basically unlimited and are not critical for the implementation of the energy transition. As regards their exploitation and processing, environmental aspects must be taken into account, e. g. nature conservation, drinking water protection or the energy required for the necessary processes.[3]

Although the share of the energy demand covered by electricity generated from wind power and photovoltaics is increasing rapidly, combustibles will continue to be required in the coming decades. In addition to fossil fuels, biomass can be resorted to both as a fuel and for the generation of power and heat.

A reliable supply of metals and necessary energy resources is an essential prerequisite for the success of the energy transition. This position paper indicates a number of measures apt to contribute to a safe, affordable, environmentally friendly and socially acceptable supply of raw materials for the energy transition.

A detailed analysis of the economic costs and benefits of the individual measures is beyond the scope of this position paper. Particularly such measures as would involve massive interventions in the economy should be examined in scenario analyses in order to assess their economic effects.

1 Federal Government 2010.

2 This also includes the semimetals, which, according to a convention in the commodity sector, are counted as metals.

3 Angerer et al 2016, pp. 103, 109.

2 Starting point: Important questions regarding the raw material supply for the energy transition

The following sections provide an overview of the raw materials required for the future energy supply and of the basic correlations in the commodity markets. More detailed information on the current supply situation and developments on the commodity markets can be found in the German analysis *Rohstoffe für die Energieversorgung der Zukunft: Geologie – Märkte – Umwelteinflüsse*[4] (English title: *Raw Materials for Future Energy Supply*[5]).

2.1 Metals required for the energy transition

The metals required for the new energy technologies are basically the same as those used for other high-tech products. Important elements are the so-called technology and special metals such as copper, cobalt and lithium, and the platinum group elements indium, tellurium, gallium and germanium and the rare earths.

The **platinum group elements** comprise platinum, palladium, rhodium, ruthenium, iridium and osmium. They are used for fuel cells and hydrogen electrolysis and are consequently significant in several possible key technologies for the energy transition – e. g. hydrogen-based electric mobility[6], long-term storage and power-to-gas. The **rare earths** include yttrium, neodymium, dysprosium, praseodymium, terbium, europium, cerium and lanthanum. They are required, for instance, in batteries, photovoltaic systems, wind turbines, motors and generators.

The supply of raw materials is becoming altogether more complex, as an increasing variety of elements is required for the production of high-tech products. Microprocessors are a very good example of this trend. Since they are nowadays an integral element of every machine or vehicle and are indispensable for measurement and control technologies,[7] they also play an important role in the conversion of the energy supply, including the smart networking of equipment and consumers.

Overall, the demand for many metals is expected to increase significantly in the future. An estimate of the raw material requirements for 42 future technologies is revealing: It shows that merely for the technologies considered, the amounts of germanium, cobalt, scandium, tantalum and neodymium/praseodymium likely to be required in 2035 equal their entire primary[8] production in 2013. In the case of lithium, dysprosium/terbium and rhenium, the 2035 demand could even correspond to double the primary production in 2013.[9]

However, it is rare that a metal has its major use in the energy technologies. Permanent magnets based on rare earths, for instance, while indeed being used in wind turbines (usually offshore), are currently mainly found in electric motors

4 Angerer et al. 2016.

5 Wellmer et al. 2018. The English translation of Angerer et al. 2016 is set to be published by Springer in July 2018.

6 Hydrogen-based electric mobility refers to fuel cell vehicles operated with electrolytically produced hydrogen.

7 According to the company Intel, a chip contained 12 different elements in the 1980s and 16 in the 1990s. Since the 2000s, the number of elements has increased to more than sixty (cf. NRC 2007, p. 38, fig. 2.3).

8 Primary production is production from mining. This means that production from recycling is not included.

9 DERA-1 2016, p. 13.

and hard disks in computers and other devices.[10] Since various industries are in competition for these metals, their availability for the energy system depends not least on the demand in other sectors, such as the automotive industry, the electronics sector and information and communications technologies.[11] Hence, many of the policy options proposed in this position paper with regard to metallic raw materials address the supply of metals in general.

2.2 Which energy resources will continue to be required in the future?

With the growing competition from renewable energies and the efforts to combat climate change, the importance of **fossil energy resources** will, in the long term, decline. Nevertheless, Germany will still need to cover 20 percent of its power demand and 40 percent of its total primary energy demand in 2050 with natural gas, petroleum or coal, even if the targets defined in the energy concept are achieved.

Natural gas could play a crucial role in the implementation of the energy transition: It has a lower carbon balance per kilowatt hour of generated energy than coal and oil. Moreover, natural gas power plants are particularly flexible and are therefore well-suited to compensate for fluctuations in wind and solar power generation.

Biomass, on the other hand, is a possible basis for several combustibles with similar properties to coal, oil and gas. Bioenergy can therefore be used in various functions in the energy system: While wood can serve as a solid fuel for indoor heating and thermal power plants, biofuels can be used in the transport sector and biogas could substitute natural gas in all of its current fields of application. However, there are also disadvantages to consider: More land area is required for the generation of a kilowatt hour of energy from biomass than from wind and solar sources. At the same time, the greenhouse gas emissions are higher. The cultivation of biomass can also affect both the biodiversity and the soil quality, while excess fertilisers may lead to water pollution. With cropland being scarce, biomass production tends to compete with the production of food and feed.

The cutting down of forests or the conversion of other carbon-rich ecosystems (e. g. tree savannas) into farmland for the cultivation of energy crops damages the climate. This is not necessarily a direct effect: In the event of energy crops replacing food crops, new farmland for food plants may be developed elsewhere. The options for action presented in this context aim at keeping these negative effects of the use of bioenergy at bay.

2.3 Origins of the raw materials used in Germany

There are two sources for **metals**: they can be produced by mining (primary production) or by recycling (secondary production). Since Germany stopped the mining of metal ores in 1992, it is forced to purchase primary raw materials or metal-containing intermediate products from abroad on the global commodity markets. Currently, the only “domestic” sources of metals are secondary deposits, i. e. raw materials from end-of-life products such as vehicles, computers, buildings, power lines and, potentially, landfills. The recycling of scrap is already widely used to obtain basic metals such as iron or steel, aluminium, copper, zinc or lead. This is due to the fact that the necessary processing is more energy-efficient and hence often cheaper than the extraction of primary ores. The recycling rates for

10 As a result of the spread of flash disks, this area of application is expected to shrink in the near future.

11 Moss et al. 2013.

many metals required for high-tech products, on the other hand, are very low. Here, Germany depends to a much greater extent on global demand, world market prices and exporting countries.

In the case of **energy resources**, Germany is likewise highly dependent on imports. 98 percent of its oil and 88 percent of its natural gas are imported[12], as well as the majority of its hard coal. As of 2018, subsidies for coal mining will be discontinued and the mines will be closed, so that Germany's import dependency will increase even further. Even as regards biomass, Germany is by no means independent, with 20 percent of its consumption covered by imports. The only raw material demand Germany can cover from domestic sources is lignite.

German supply security therefore crucially depends on the global development of supply and demand for raw materials. Were Germany able to mitigate its dependence on imports, this would contribute to a safer and more sustainable supply of raw materials. This is all the more relevant since the bulk of the various raw materials with an economically strategic value[13] is only imported from a small number of mostly non-European countries, for which there are no short-term alternatives.[14]

12 BGR 2015-1, p. 17.

13 Economically strategic resources are raw materials that must be kept available for future technologies and that have a great leverage effect for the economy. In the high technology sector, a relatively small quantity of these raw materials adds much value. These materials include, for instance, rare earth elements, electronic elements such as gallium, indium, germanium, platinum group elements or steel alloy metals such as molybdenum, nickel or niobium.

14 EC 2014-5, p. 8 sq.; DERA 2016-2.

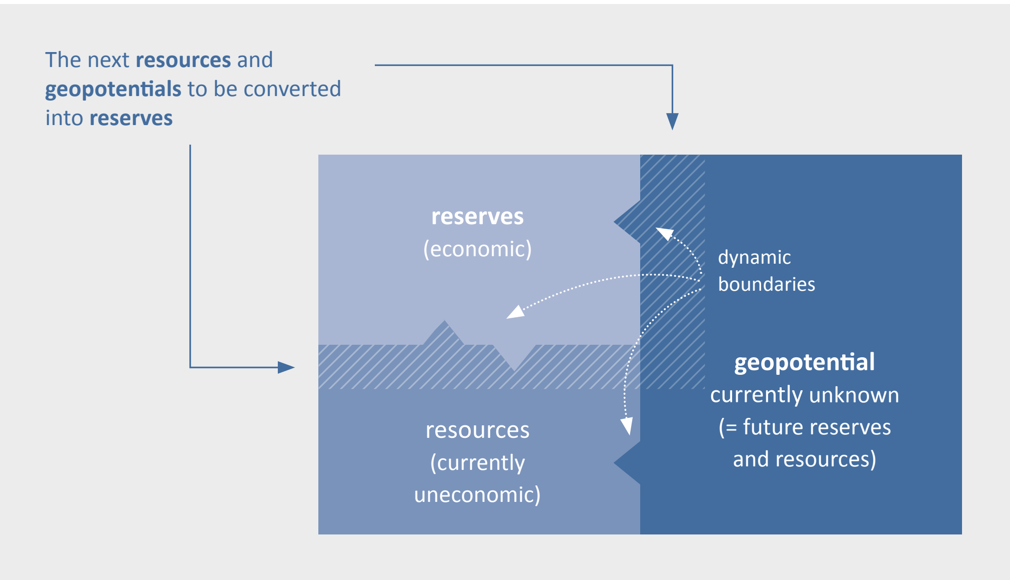

Figure 1: Raw material box. The boundaries between geopotentials, resources and reserves are blurred: Owing to explorations, progress in the extraction and processing technologies and rising market prices, new deposits are discovered and converted into profitably exploitable reserves.[15]

15 Translated and modified according to Scholz et al. 2014.

2.4 Primary raw materials soon to be exhausted?

In the field of primary raw materials, we distinguish between reserves, resources and geopotentials, cf. Figure 1. The boundaries are, however, blurred and can never be more than a snapshot of a dynamic system: Exploration activities reveal new raw material deposits, which means that geopotentials are converted into resources or reserves. Owing to innovations in the fields of extraction and processing technologies and – in the event of an increasing demand – rising raw materials prices, hitherto uneconomic resources become profitably exploitable reserves. Hence, reserves will typically increase with consumption.

Alongside geological deposits, recycling offers considerable potential for the production of metals.[16] Hard coal and lignite deposits are so vast that even in the event of a global increase in demand, sufficient quantities should be available in the medium term. By comparison, oil and natural gas are rather scarce. The increased production of shale oil and shale gas in the US, while contributing to the current price decline for natural gas and oil, does not eliminate this disparity. Until 2050, however, there is no geological indication that a shortage of energy resources might be expected.[17] No one knows exactly how many resources, viz. geopotentials there are below ground. However, on the basis of today's geological knowledge, we can safely assume that there will be sufficient metals and energy resources until 2050 and beyond to allow for the implementation of the energy transition in Germany – despite an increasing global demand.[18] The most likely field for a permanent scarcity to occur is bioenergy: The amount of energy crops that can be cultivated without undue environmental impacts on the limited land area available cannot be significantly increased.[19]

In order to assess whether the available raw materials can cover the demand, some studies use the “static range” indicator: It is obtained by dividing the reserves or resources by the annual consumption. The result is then interpreted as the number of years for which the raw material is expected to last. However, since this approach omits the dynamics of resources developing into reserves, it is misleading.

The ratio of reserves to annual consumption can, however, serve as a long-term warning signal with regard to the supply situation: A period of less than ten years, which is the typical lead time for the development of new deposits and the construction of new mines, can indicate that new reserves may not be developed fast enough to meet the growing demand. This can result in supply risks and price surges.

In order to enable mining companies to develop geopotentials into reserves (Figure 1), sufficient basic information such as geoscientific maps or models of the deposits must be available as a basis for commercial exploration. It is up to the public geological surveys and research institutes to provide such information. If the dynamics of successful exploration are to be maintained in the future, the public geological surveys will need to conduct continuous explorations at home and abroad (prior to industrial activities). This will have to be complemented by high-level research efforts.

16 Angerer et al. 2016; Wellmer et al 2016.

17 Only in the case of petroleum does the Federal Institute for Geosciences and Natural Resources (BGR) perceive a possible limit, BGR 2015-1.

18 Angerer et al. 2016; Wellmer et al. 2018.

19 Angerer et al. 2016; Wellmer et al. 2018; Leopoldina 2013.

2.5 What role can metal recycling play?

An intensive use of secondary deposits would help to reduce the dependence on imported metals. Unlike energy resources, metals are not consumed, but merely used. This means that, as a rule, metals can be obtained in the same quality from secondary materials as from primary sources (aluminium being one of a few exceptions). The advantages of using secondary materials lies in the energy balance: As often as not, less energy is required for recycling than for primary production.[20] Moreover, recycling generally requires shorter lead times and lower investments than mining projects. Beyond that, metal recycling is much more socially accepted[21] and has the added advantage of reducing the quantity of waste.[22]

How efficient the recovery is depends on the entire process chain: collection, dismantling, preprocessing and metallurgical processing. Until now, high recycling rates have only been achieved for main and precious metals[23].[24] In the case of rare earths and high-tech, and special metals such as indium, germanium, gallium, tellurium, cobalt or lithium, recycling rates are, on the other hand, still insufficient. The individual products often contain only small amounts of these elements and are so intricately compounded with other elements as to make the recovery very complex. It requires special processes to extract the original elements from their products and to refine them, once again, into fine metals.[25]

In the case of simple residues (e.g. production waste) or certain material compounds, there are established recycling methods even for these metals. The real challenge usually lies in the complex "multi-metal" products. For these cases, the metallurgical infrastructure for the recovery of the metals is not sufficiently developed, or there are, as yet, no suitable technologies available. However, in the case of many of these metals that are of great importance for future energy technologies, high losses occur even earlier, viz. when the products containing them are collected. Only a small share of consumer electronics, for instance, undergoes high-performance recycling. To achieve higher recycling rates, several conditions must be fulfilled: These include the availability and use of effective technologies, a sufficiently high price level for metals, legal regulations promoting recycling and a good logistical infrastructure to collect the end-of-life products.

However, even if the recycling rates of many metals can be significantly increased, recycling alone will not suffice to cover the demand for metallic raw materials. For one thing, a recycling quota of one hundred percent would be neither energetically possible nor, indeed, reasonable. For another, the metals can only be recovered at the end of a product's life. This can range from a few years (e.g. for mobile phones and vehicles) to several decades (e.g. in the case of building infrastructure). If the raw material demand increases, the quantities contained in the end-of-life products would therefore be insufficient, even if they were fully recovered.

20 Recycling pure metals is invariably less energy-intensive than their primary production. However, the lower the concentration of the metal in question and the more complex the composition of the product, the more energy-intensive the recovery tends to be.

21 Angerer et al. 2016; Wellmer et al. 2018.

22 BGR 2015-2, p. 21 sq.

23 Main metals are iron/steel, steel alloy metals, non-ferrous metals such as copper, lead, zinc, and the light metals aluminium and magnesium. Precious metals are silver, gold and the platinum group metals.

24 In 2014, Germany obtained about 53 percent of aluminium, around 42 percent of refined copper and some 45 percent of crude steel from secondary raw materials (BGR 2015-2, p. 22).

25 Angerer et al. 2016; Wellmer et al 2018.

There is therefore no alternative to the import of primary raw materials; this is true for the current situation and will still be the case in 2050.[26] Regarding the contribution recycling can make towards supply security in Germany, yet another point must be taken into account: The imported raw materials are re-exported in the form of high-quality products. In terms of recycling, the processed raw materials are therefore lost to Germany. In addition, recycled raw materials are likewise traded on a global market. Metals collected in Germany will therefore not necessarily contribute to covering German demand.

2.6 How are supply security and raw materials prices evolving?

Since there is no geological lack of raw materials, the crucial question is whether the market offers **sufficient raw materials at competitive prices**. This is determined not only by the dynamism of supply and demand on the markets, but also by the structure of the mining industry and the strategic resource policies of supplier countries.

2.6.1 The dynamics of the global markets

As a rule, commodity markets react flexibly to changes in supply and demand. If, for instance, the price of a raw material rises due to its increasing scarcity, the supply will eventually increase too: Higher prices will allow for the profitable exploitation of deposits that are more difficult to access or of lower grade. In addition, high prices are incentives for further exploration efforts and for the development of new extraction and processing technologies that will serve to develop new deposits. In the event of shortages and high prices, companies will attempt to use the raw material in question more efficiently and sparingly, or will even try to replace it (substitution). The interaction of these market mechanisms is also referred to as the feedback control cycle of the raw material supply[27]. Over the past hundred years, this feedback control has ensured that the real prices of most commodities have, on average, hardly increased.

The lead times in the mining industry are, however, very long: Depending on the political and administrative conditions, about ten to twenty years will elapse between the discovery of a metal deposit and the start of exploitation. If necessary investments in technology and transport capacities are not made in time, the production may not keep up with the growing demand. Such a situation can result in temporary price peaks and, possibly, supply shortages. Even a small increase in demand of only a few percent somewhere in the world can trigger large price surges that will affect the supply in Germany.[28]

Therefore, from a short- and medium-term perspective, the commodity markets are rarely in complete equilibrium, oscillating between buyers' and sellers' markets[29] and high- and low-price cycles. The demand boom in China between 2003 and 2013, for instance, triggered an unusually long high-price period for many metal raw materials. The unexpectedly high demand on the part of many market participants had extreme effects: In addition to hardly controllable price surges, supply shortages occurred, which led to operational disturbances in the processing industry. Existing delivery contracts were cancelled, while limited freight capacities in international sea trade resulted in long delivery periods and soaring freight prices for raw materials.

26 Angerer et al. 2016, Box IV; Wellmer et al. 2018, Box IV.

27 Wellmer/Hagelüken 2015.

28 Even if there is no real scarcity, market concerns as to a presumed scarcity can lead to rapid price increases, as was the case for rare earths between 2010 and 2011 (Angerer et al. 2016; Wellmer et al. 2018).

29 A buyers' market is defined by the buyer, in other words, it is a surplus market where the buyer can exert downward pressure on prices. In a seller's market, on the other hand, the respective goods are scarce so that the seller can drive prices up.

Short- and long-term trends in the commodity markets

There are a number of indicators and warning signals of short-term bottlenecks in the raw materials supply that allow for an estimate of the market development for up to five years in advance:

- the market prices
- the stocks on the stock exchanges[30]
- the utilisation rate of mines, smelters and refineries
- the development of mining and metallurgical capacities (mining and metallurgical projects in the planning or construction stage vs. production capacities that are being phased out)
- supplier concentration (supplier countries and mining companies)
- geostrategic risks (country risks)
- technological innovations (The unexpected market entry of future-oriented technologies[31] can, for instance, suddenly increase the demand for certain metals. Owing to new extraction and processing technologies[32], previously unavailable deposits can be developed, increasing the overall supply.)

However, many measures to secure the supply, such as the expansion of mining or recycling capacities, have considerably longer lead times than five years. The development of technologies allowing for a more economical use of a scarce raw material in products usually takes several years. However, long-term supply contracts can only be concluded at reasonable prices in times of sufficient supply.

In the long term, therefore, the supply of raw materials can only be secured by means of anticyclical measures and strategies that do not follow short-term price fluctuations on the commodity markets. Indicators for long-term developments in raw material supply are:

- the reserves/consumption ratio
- analyses of previous raw material cycles in order to better understand the causes and duration of high- and low-price phases of certain raw materials
- scenarios for the long-term development of supply and demand, e.g. based on the economic development of different countries, or for technological trends such as the energy transition.

However, such global economic indicators generally do not provide much incentive for longer-term measures to secure the availability of raw materials. Hence, a comprehensive infrastructural transformation such as the energy transition requires a social dialogue to determine to what extent the government should assume responsibility for securing the supply of raw materials.

30 The raw materials traded at the London Metal Exchange (LME), the world's most important exchange for commodity transactions, are stored in more than six hundred LME-certified warehouses. The bulk of the metals traded at the LME are mass metals (including aluminium, copper).

31 The transition from the CRT to the LCD television, for instance, took only two years. Instead of barium and strontium, indium and tin were suddenly the key elements (Angerer et al. 2016, Chapter 3.3.2; Wellmer et al. 2018).

32 The invention of the Imperial Smelting Process in the 1950s made it possible to smelt mixed lead-zinc concentrates. Thus, deposits in which lead and zinc are so closely intergrown that they could hitherto not be separated during beneficiation, suddenly became workable.

In retrospect, however, the increase in demand assumed to come with the enormous economic growth in China was overestimated. The result was global overproduction, of which the current low-price phase[33] is a consequence. At the same time, it is doubtful whether, in the medium term, China's demand will continue to grow at

33 Situation in April 2016.

the same pace as in the past.[34] However, should other densely populated emerging and developing countries such as India, Indonesia or Brazil follow in China's footsteps, the global demand for raw materials could continue to rise even beyond 2050.[35]

The price developments on the commodity markets are not least influenced by purely speculative transactions. Futures contracts and hedging transactions, while having the rather positive effect of a protective mechanism for the real economy, also allow for purely speculative transactions. The role the latter play in the pricing process is controversially discussed. An analysis is indicated that might prove the necessity for regulation. Dominant speculative transactions pushing up prices would result in a sociopolitically undesirable transfer of wealth: Consumers would have to spend more on raw materials than corresponds to their real value.

2.6.2 When are raw materials "critical"?

Whether a resource can be considered secure depends on the reliability of the supplier countries. Indicators include their political stability, their control of corruption or the performance of their public sector. The risks are particularly high if the bulk of a raw material is supplied by a small number of countries with low reliability (weighted country risk). The term "critical raw material" is used for raw materials with high supply risks but major economic significance (e.g. because they cannot be replaced by other raw materials in important products or processes).[36] A study by the European Commission conducted in May 2014 names twenty raw materials that currently fall within this category.[37] The updated list for 2017 contains 27 elements or ores.[38]

A resource can likewise be classified as potentially critical if it is supplied by only very few companies that are virtually in a monopoly position. The three largest producers of niobium, for instance, hold 93 percent of the market; for palladium and platinum, it is 72 and 63 percent, respectively.[39] In the case of beryllium, a single supplier in the USA controls 92 percent of the world market.

Which raw materials for future energy systems will become critical in the coming years or decades depends both on future technological developments in the energy sector and on the commodity markets. Technological developments in other sectors competing with the energy sector for raw materials will likewise play a role. The assumptions as to how the demand for raw materials will develop likewise influence the evaluations, as does the method used for the assessment of a resource's criticality. In other words, different criticality studies on individual raw materials to some extent come to different conclusions.

In the case of **rare earths, the platinum group elements and the special metals indium and tellurium**, the assessments scarcely differ. Almost all current studies consider these elements

34 Until the end of the millenium, seventy to eighty percent of raw materials were used by the traditional developed countries. Since about 2003, however, China has become the largest consumer of all significant raw materials – with the exception of petroleum and natural gas. For steel, copper and aluminium, for instance, China's share of the global consumption increased from under ten to over forty percent between 1990 and 2012 (Angerer et al. 2016, Chapter 3.3.1; Wellmer et al. 2018).

35 Angerer et al. 2016; Wellmer et al. 2018.

36 Angerer et al. 2016, Chapter 2.3; Wellmer et al. 2018.

37 Antimony, beryllium, borates, chromium, cobalt, coking coal, fluorite, gallium, germanium, graphite, indium, magnesite, magnesium, niobium, platinum metals, phosphates, light rare earths, heavy rare earths, silicon and tungsten (cf. EC 2014-5, p. 4). In the European Commission's previous study from 2010, only 14 critical raw materials were listed, with tantalum being considered critical in 2010, but no longer in 2014.

38 Seven mineral, one gaseous, and one agricultural raw material were added: barite, bismuth, hafnium, helium, natural rubber, elementary phosphorous, scandium, tantalum and vanadium. Two mineral raw materials were deleted from the list: chrome and magnesite. Coking coal is a borderline case. Although it narrowly misses the economic importance threshold, the EU kept it on the list for 2017 for sake of caution (EC 2017).

39 DERA 2014.

to be critical or almost critical.[40] Regarding rare earths, China is in a particularly powerful situation, controlling more than 86 percent of the world mine production.[41] Platinum group metals are likewise mined in very few countries: More than 68 percent of the platinum supply is controlled by South Africa, and about 75 percent of the palladium is produced by Russia and South Africa.[42] For other elements, the situation cannot be assessed with the same clarity.

Elements such as nickel, the steel alloy metal niobium, the refractory metal[43] tungsten, gallium, germanium, selenium, vanadium, silver, graphite, rhenium and hafnium, for instance, are classified as critical or almost critical in some of the raw material studies. Others declare them to be uncritical. There is no likelihood of supply bottlenecks for **copper** and **lithium**, which play a major role for renewable energies.[44] To be sure, the quantity of lithium required for future technologies such as electric vehicles and lithium-ion batteries could increase significantly by 2035, up to four times the amount of its primary production in 2013.[45] However, production increases on this scale have already been achieved within twenty years: The production of cobalt and indium, for instance, increased fivefold between 1993 and 2013.[46] There is therefore no reason to assume that the commodity markets will not be able to respond to and meet a rising lithium demand. The situation for the raw materials phosphate[47] and helium[48], on the other hand, needs to be watched closely.[49]

Some of the metals required for the energy transition, for example elements used in electronics such as indium, germanium or gallium, are extracted as **by-products**[50] in the mining of other metals. In the case of these metals, the feedback control cycle of the raw material supply works only to a limited extent, since the quantity of the by-product is coupled with the extraction rate of the main metal. As a rule, a producer will not increase the production of the main metal merely because the by-product is scare. While the number of producers and buyers is often very limited, the market is also less transparent than for commodities traded on the large stock exchanges. This makes it difficult to estimate the future availability of such resources.

2.7 Strategic resource policy: What role can the government play?

The geological and geographic distribution of the deposits and the structures of the mining industry favour a geographic and entrepreneurial concentration. In other words, a dwindling number of countries and companies control an increasing share of the raw material deposits. There is a tendency towards the formation of oligopolies or even monopolies. Individual companies or countries are thus in a position to significantly influence the commodity market, for instance by imposing export restrictions. The resulting distortions of trade and

40 The authors of the analysis *Raw Materials for Future Energy Supply* (Angerer et al. 2016; Wellmer et al. 2018) which served as basis for this position paper, likewise consider these raw materials as potentially critical.

41 USGS 2015, p. 129; cf. likewise DERA 2014.

42 USGS 2015, p. 121; cf. likewise DERA 2014.

43 Metals with a relatively high level of corrosion resistance (at room temperature), a high melting point and high electrical conductivity.

44 This is the conclusion drawn by the authors of the analysis *Raw Materials for Future Energy Supply* (Angerer et al. 2016; Wellmer et al 2018) after a critical evaluation of various models and studies, including some that consider copper and/or lithium as potentially critical.

45 DERA 2016, p. 14.

46 DERA 2016, p. 293.

47 Phosphate is a non-substitutable raw material which is an irreplaceable fertiliser for plant growth and thus for the food supply.

48 Helium is a possible essential raw material for future energy technologies.

49 Angerer et al. 2016; Wellmer et al. 2018.

50 By-products occur in a compound with another primary raw material. Separating these elements is often very energy-intensive. The production of a by-product is therefore necessarily coupled with the extraction of the primary raw material. Hence, by-products are distinguished from raw materials, which occur independently in deposits.

competition are increasingly becoming a challenge in terms of resource security.[51]

The dependency on China in the field of the rare earths illustrates this point: When the Chinese government limited its export quotas in 2010, a massive price increase ensued. This is exacerbated by the technological leadership of Chinese companies along the entire value chain ("from the mine to the magnet to the MacBook"). China likewise controls an entire 75 percent of the market for the respective end products[52] (e.g. permanent magnets[53]). Even in the current low-price phase, there is hardly any competition with the Chinese monopoly on rare earths – a situation that could have a significant bearing on Germany and Europe both in terms of their economic growth and their technological leadership.

Western economies tend to leave the safeguarding of their raw material supply to the private sector. Against this background, the state capitalist model enables China to strategically expand its dominant market position in the rare earths market to an almost monopolistic position. The raw material consuming industry in Western countries is hardly in a position to overcome the resulting supply risk: Companies and investors have rather short time horizons (one to five years), which prevents strategic investments in the development of an alternative value chain for rare earth products.[54]

A trade conflict between China and Japan in 2010 has even sparked the fear that rare earths could be used as an economic and political lever against other countries in future conflicts.[55] Although Western governments have tried to change the structure of the rare earths market in response to the 2010/2011 peak, increasing their research efforts, resorting to international diplomacy and filing a complaint with the World Trade Organisation, these attempts have so far proved only moderately successful.[56]

For some metals, such as iron (steel), China has created massive overcapacities in recent years. These are subsidised by the Chinese government in an effort to keep production and jobs in the country. However, since this severely threatens the European steel industry, the EU initiated official anti-dumping proceedings against cheap imports in February 2017.

Raw materials are therefore not automatically available at competitive prices, despite sufficient geological potential. Although it is first of all up to the industry to develop protective concepts[57] and alternative strategies to secure the raw material supply, the government can make a decisive contribution. States increasingly tend to regard not only gas and oil, but also metals as a strategic resource worthy of protection. A comparison with other countries shows that this is not only true for state capitalist systems like China, Russia or the Arab countries. The democratically legitimised governments of comparatively market-oriented and open economies like Japan and South Korea are likewise pursuing a **strategic policy to secure resources**. In cooperation with the Japanese government and industry, the Japan Oil, Gas and Metals National Corporation (JOGMEC), for instance, is responsible for securing resources for the Japanese

51 BDI 2015.

52 Angerer et al. 2016; Wellmer et al. 2018.

53 Permanent magnets have a high magnetic energy density and are stronger than conventional ferrite magnets. They are used, for example, in electrical generators and loudspeakers.

54 Klossek et al. 2016.

55 Klossek et al. 2016.

56 Klossek et al. 2016.

57 An important aspect of such concepts is that the negative effects of shortages and price peaks can be cushioned as far as possible (resilience). The analysis *Towards a resilient energy system* presents measures apt to increase the resilience against supply shortages for platinum group metals and natural gas (cf. Renn 2017).

industry.[58] For certain critical raw materials, the JOGMEC has moreover established a strategic stockpiling system in order to protect the Japanese economy from supply interruptions and price fluctuations.

This raises the question of whether the German government should likewise expand its commitment in the field of resource security. There are two different approaches to be considered: On the one hand, the government could act at the political level to foster more open and transparent markets worldwide. This could be achieved, for instance, by establishing framework conditions (e. g. in the form of trade agreements) that give companies easier access to raw materials. A top priority would be to prevent export restrictions in the supplier countries. On the other hand, the government itself could become an active player in the commodity sector (e. g. by establishing a public stockpiling system or through state participation in a mining company).

In addition to parliamentary control, governmental intervention in the private sector requires the minimum legitimation of a weighing of the welfare losses to be expected should no intervention take place against the costs of such an intervention. Hence, if a government intervention is considered, it needs to be established that (1) a market failure has, indeed, occurred or is impending or highly probable that (2) the measures under consideration are appropriate to counteract such a failure, and that (3) the intervention costs compensate for the welfare loss.

Basically, markets balance supply and demand for a product at a certain price. A high price will occur if the demand exceeds the supply or, indeed, the supply is insufficient to meet the demand. Whether such an undersupply is triggered by anti-cyclical investments or is due to other reasons is immaterial. As long as the product can be bought or sold at some price, the market itself is functional. Highly fluctuating prices (volatility) testify to much uncertainty in the pricing processes and represent a particular challenge for market participants. This is especially true for players with an interest in the physical product (as opposed to those with merely speculative interests). However, as long as there is trade, even with high price volatility, we cannot assume a market failure.

If, on the other hand, individual suppliers have a monopoly and use their market power to make raw materials considerably more expensive than they should be in a free and transparent market, this is a clear case of a market failure[59]. In the extreme case, products would no longer be physically procurable. A physical supply bottleneck can, for instance, be caused by political changes. The export prohibition for raw materials recently adopted by Indonesia and the Philippines is a prominent example.[60] In such a case, the economic costs of a production stop would be high and governmental intervention might be justified.

2.8 The risks of raw material production for humans and the environment

Environmental and social standards in mining vary considerably between different countries. Accordingly, the effects on humans and nature are likewise different. In industrialised countries, for instance,

58 The JOGMEC is under the jurisdiction of the Japanese Ministry for Economic Affairs, Trade and Industry and provides Japanese companies with funds for the exploration and development of raw material projects. In addition, it takes over guarantees for risky projects and offers companies technical support in the field of raw material development (cf. JOGMEC 2015).

59 There are different definitions of market failure. According to the neoclassical theory of economics, the criteria for an allocative market failure are already fulfilled if the allocation of scarce resources deviates from the model of the perfect market. A collapse of the market, resulting in raw materials no longer being physically procurable, constitutes a particularly serious form of market failure.

60 Mining Journal 2016.

mining is carried out according to the current standards of technology and is, consequently, very safe: The average number of accidents in the German raw materials industry is lower than in the entire industrial sector.[61]

In many developing countries, on the other hand, labour safety standards are low. Small-scale mining, where the mining and processing of ore is done manually and with only the most basic techniques, is frequently particularly dangerous and harmful to the miners' health. Moreover, the local population does not always derive economic benefits from mining activities in the neighbourhood. Rather, we frequently witness the evolution of islands of economic activity that cement or even exacerbate social differences within the population without having a positive impact on the overall development of a region or country.[62]

In developing and emerging countries, mining, and particularly small-scale mining, also often causes serious environmental damage, which is not least associated with considerable health risks. If mine- and wastewater from the processing of ores is not properly stored and treated, the soils and waters risk contamination with heavy metals and other pollutants. The use of mercury for the processing of ore in small-scale gold mining, for instance, causes serious health damage.[63] Due to the high number of basic, individually operated small-scale mines, the monitoring and enforcement of environmental regulations is fraught with difficulties, especially in remote regions. Also, as often as not, neither operators nor workers have received professional training.[64]

Mines that are simply abandoned after the end of their exploitation, instead of being properly dismantled and reclaimed, present a further major problem. The environmental threats due to acid and metalliferous mine drainage persist for many years after the end of the mining activities.[65]

Although in industrialised countries, mining nowadays causes much less damage to the environment and constitutes but a temporary interference with nature, accidents do occasionally occur. A particularly serious example are dams bursting in the storage ponds for tailings.[66] Regarding the exploitation of energy resources, oil tanker accidents and exploding oil rigs such as the Deepwater Horizon in 2010 count among the most serious accidents.[67] Overall, however, the amount of oil spilt into the sea as a result of such accidents has decreased by a factor of 15 since the 1970s.[68]

Operating the facilities for the production and processing of raw materials also has an impact on the environment. Large production systems for opencast lignite mines or the exploitation of oil sands interfere on a large scale with landscapes and ecosystems. To some extent, moreover, pollutants are released into the environment: In Canada, for instance, waters near tar sand production facilities were found to contain higher concentrations of 13 pollutants (including mercury, lead and cadmium) than waters further

61 DGUV 2000-2012; DGUV 2014.

62 Misereor 2013.

63 MPI/BGR 2016, p. 90 sqq.

64 MPI/BGR 2016, p. 89.

65 MPI/BGR 2016, p. 73.

66 In 2010, for instance, the dam of a waste reservoir in an aluminium plant in the Hungarian city of Ajka burst. Three villages and an area of about forty square kilometers was flooded with red mud containing heavy metals; ten people died and 150 were injured (cf. MPI/BGR 2016, p. 59 sqq.).

67 The explosion of the drilling rig Deepwater Horizon in the Gulf of Mexico claimed the lives of 11 workers and seriously injured 16 more. It was the most serious oil spill of all times, with 700,000 litres of crude oil escaping into the sea, entailing devastating consequences for the ecosystems and the local fishing industry. In 2011, a US expert committee concluded that the accident was the cumulative result of a series of technical deficiencies and wrong decisions, and that significant improvements were necessary in deep sea oil production. In the aftermath, several oil companies joined ranks to elaborate emergency plans to prevent such serious accidents in the future (cf. World Ocean Review 2014, p. 38 sqq.).

68 World Ocean Review 2014, p. 39.

away. Seven of these substances exceeded the guideline values for the protection of aquatic organisms.[69]

In the processing of rare earth ores, poisonous wastes and radioactive substances are generated, which must be prevented from seeping into the ground and groundwater. In 2002, Mountain Pass, the only active rare earth mine in the USA until recently, was shut down – not least due to negative environmental impacts. Toxic and radioactive wastewater had leaked into the groundwater and potentially harmful concentrations of rare earths as well as radionuclides had been found in the soil as well as in the air. The high water consumption had also led to a lowering of the groundwater level. After extensive restructuring, the mine was put back into operation in 2010. The waste treatment was enhanced to prevent any future leakage of harmful substances. In addition, a recycling process succeeded in reducing water consumption by ninety percent.[70]

The frequently high level of water consumption constitutes a further challenge in connection with the production of raw materials: Many production sites being located in arid areas, the consumption of large quantities of water results in shortages in the agricultural sector or the drinking water supply.[71]

69 Kelly et al. 2009.

70 However, the mine was shut down again in 2015 when rare earth prices collapsed (cf. adelphi 2015).

71 MPI/BGR 2016, S. 52.

Protection of human rights in mining

In the past, the mining industry has been responsible for more human rights violations than any other sector.[72] Particularly in the early phases of a mining project, there is a high risk that the interests of those negatively affected by the project are disregarded. It is therefore important that prior to any activities, the residents affected by a project are thoroughly informed and included in the planning and that projects are not launched without their consent. During the construction of a mine or opencast mine, human rights are particularly often infringed in connection with resettlement measures. Once a mine is in operation, it is primarily in the field of environmental and health issues that human rights violations occur – for instance, when soils and waters are contaminated with pollutants due to the extraction and processing processes.

Several conventions have already been adopted to ensure that human rights do not suffer from the production of raw materials. It is their implementation and enforcement that remains the challenge. Even though breaches of human rights tend to occur outside Germany, political measures can, at least indirectly, support an environmentally and socially acceptable mining system.

When negotiating the terms of new raw materials agreements, for example, the Federal Government ensures that the protection of human rights is taken into account.[73] Also, every country can adopt guidelines for the global actions of its domestic companies and oblige them to comply with these provisions. It is therefore good news that on 21 December 2016, the German Federal Cabinet adopted a national action plan on the Economy and Human Rights, which implements the guiding principles[74] of the UN.[75]

72 UN (2008), quoted in (MPI/BGR 2016, p. 17), assigns about 28 percent of all human rights violations committed by companies to the raw materials sector.

73 While the implementation of environmental and social standards in raw material production features prominently in the Federal Government's raw materials agreements with Kazakhstan (Federal Government 2012) and Mongolia (Federal Government 2011), the term "human rights" was entirely omitted. In the agreements with Chile (Federal Government 2013) and Peru (Federal Government 2014-1), on the other hand, the subject of human rights is broached, with Peru even making specific assurances regarding indigenous peoples.

74 DGCN 2014.

75 Federal Foreign Office 2016.

In conclusion, the situation presents itself as follows: Most of the serious environmental and health risks connected with mining could be avoided by using the best technology available[76]. If, on the other hand, one is willing to accept high levels of pollutant emissions and low social standards, valuable materials can be produced at a much cheaper price. Against this background, global environmental and social standards are crucial to prevent production from being shifted to countries with low standards.

Moreover, populations affected by a mining project increasingly tend to protest against negative environmental and social consequences. As a result, companies are increasingly confronted with the challenge of obtaining public consent for their mining projects ("Social License to Operate").

Minimising the negative consequences of mining is thus not least in the direct interests of the raw materials industry. Every mining company should therefore set aside sufficient funds during a project to cover rehabilitation measures at the end of the project to minimise any adverse effects.

Nevertheless, mining projects necessarily interfere with the landscape and ecosystems. A social dialogue struggling to assess the legitimacy of a project will have to weigh the use of raw material extraction against its negative consequences.

76 In international mining, it is referred to as Best Available Technology (BAT).

3 Policy options: Metallic raw materials

Despite currently low metal prices, we nevertheless require long-term strategies to secure raw materials. In the following section, possible measures regarding metallic raw materials will be presented and discussed with regard to their effectiveness, feasibility and costs. Their advantages and disadvantages will be outlined along with the role the respective stakeholders would play (especially the industrial sector and the government). The options include existing as well as new instruments that can be implemented individually or complementarily.

3.1 Expertise and knowledge transfer

In order to react as flexibly as possible to fluctuations in the commodity markets, companies require sound and reliable data. The Federal Institute for Geosciences and Natural Resources (BGR)[77], the German Mineral Resources Agency (DERA) and the geological surveys of the Länder[78] provide information on geological questions as well as on economic and ecological issues in the field of raw materials.

The geological surveys provide basic information on raw material potential in order to identify areas that might harbour deposits. These data serve as a basis for resource and spatial planning policies. The raw materials industry can also use geological maps indicating the location and depth of deposits in individual countries as a basis for their own prospections[79] thus reducing their exploration costs. An analysis of the global economic aspects can be found in the resource monitoring published by the DERA.[80] This includes a screening of the price, supply and demand developments. Analyses are carried out on price developments, country risks[81], supply concentrations in the markets, intermediate products and value chains and the demand for key and future technologies. DERA also publishes detailed risk analyses for individual raw materials and discusses the results with relevant industrial stakeholders.

In order to enable government information centres and raw material consuming companies to cooperate, raw materials expertise is required on both sides. Government institutions need the knowledge to draw up the information, while the companies must be in a position to correctly interpret and react to the effects the supply situation can have on their business.

77 The BGR is the national geological survey in Germany. Organisationally, the institute is an administrative unit of the Federal Ministry for Economic Affairs. DERA is part of the BGR.

78 The tasks of the Geological Surveys of the Länder include the preparation, editing and archiving of geoscientific information on the composition of the geology and the raw materials in the underground.

79 The geological prospection works the BGR conducted in the North Sea from 1957 to 1964, for instance, laid the foundation for the subsequent commercial exploration of local oil and gas deposits.

80 The German Mineral Resources Agency, a subunit of the BGR, has developed a traffic light system for five criteria: current supply and demand situation (market balance, stocks, capacity utilisation in mining and in smelters/refineries), production costs, geostrategic risks (country concentrations and country risks), market power (company concentration), supply and demand trends (projected market balance in five years, extent of exploration, planned investments).

81 Cf. section 2.6.2.

3.1.1 Obligation to disclose geological data

According to the German Raw Material Deposits Act (Lagerstättengesetz), companies may keep the data on their explorations of deep underground permanently confidential. Hence, valuable geological information largely remains dormant in the archives. **Modernised legislation on raw material deposits** (as has been adopted, for example, in Norway, Sweden, Finland, Serbia, the Netherlands, Canada, Australia and New Zealand), requiring all data to be made public (after a suitable waiting period), could be of great economic benefit.

With an optimal database, science and industry could develop new exploration ideas and concepts. This would greatly benefit a future-oriented scientific evaluation, not least with regard to the exploitation of the underground by future generations. The experiences in the above-mentioned countries show that exploration and extraction activities have not suffered from such legislative regulations.

3.1.2 International networking

Currently, every nation collects and manages information on global raw material deposits. Closer international networking could generate synergies and save costs. The project Minerals4EU[82] is one of the first successful steps in this direction: Launched as part of the EU Raw Materials Initiative[83], it is currently being implemented by 17 geological surveys in Europe with a view to building up a European knowledge network.

This includes, for instance, the development of an online platform on which data regarding the raw material supply in Europe is merged and edited according to consistent standards. An annually updated *European Minerals Yearbook* provides a comprehensive overview of the situation in Europe. Political, economic and technological developments as well as long-term trends on the commodity markets are to be summarised in regular analyses which shall serve as a basis for decision makers in politics and industry.

Building on its successful launch, the project could be taken further fairly quickly and at a low cost in order to permanently strengthen the European knowledge base on important raw materials. The necessary structures already exist in the form of **EuroGeoSurveys**, the association of all European surveys. EuroGeoSurveys was founded in 1995 to advise the EU and the governments of the Member States. The result would be a regular and better version of the *European Mineral Yearbook* (comparable to the reference book *Mineral Commodity Summaries* published by the United States Geological Survey) and of further analyses. The financing, as yet realised with EU project promotion funds, should be converted into an institutionalised standard funding with regular evaluations.

At the national level, a **merger of the databases** of the **various Geological Surveys of the Länder** could likewise improve the availability of data. This is of particular relevance with regard to cross-border deposit issues.

Providing information on those high-tech metals that are obtained as by-products and have an economically strategic value (such as indium, germanium, gallium, tellurium, but also rare earths) proves to be a particular challenge: These markets are very limited and at the same time highly opaque. Here, the situation could be improved by resorting to the model of the **International Metal Study**

82 Minerals4EU 2016.

83 The EU Raw Materials Initiative is intended to promote free access to raw material deposits in third countries, a sustainable supply of raw materials from European sources as well as resource efficiency and recycling, cf. EC 2016-1.

Groups[84]. Working under the umbrella of the United Nations, these working groups, constituted of representatives of governments, producers and consumers, have already succeeded in making the markets of some metals more transparent. At the European level, the *European Rare Earths Competency Network*[85], initiated by the EU Commission, could provide a basis to be expanded to further high-tech metals. Whether the prospective benefit of a study group for high-tech metals would be attractive enough to encourage a sufficient number of producers and raw material processing companies to participate actively and provide information would have to be put to the test.[86]

3.1.3 Enhancing German raw materials expertise

Universities and research institutes play an important role in maintaining and expanding raw materials expertise. In the 1990s, it was mostly assumed that the international markets would, in the long term, easily cover the raw material requirements. As a result, the training and research capacities in the relevant geo- and engineering sciences were greatly reduced.

In order to more actively control the supply situation, raw materials expertise is required. This is particularly important with a view to reinforcing the German and European mining sector as well as the processing sector for some critical metal raw materials (as discussed in section 3.2.2). In order to maintain and expand the existing expertise, the **research and training capacities in Germany should be revived**. The founding of the Helmholtz Institute for Resource Technologies in Freiberg in 2011 (as part of the National Raw Materials Strategy) and the establishment of the Fraunhofer project group IWKS for recyclable materials and resource strategies constituted a first step in this direction.

These two non-university research institutions have already succeeded in establishing a network with the most important university experts from the RWTH Aachen, the TU Clausthal and the TU Bergakademie Freiberg. This network, which operates under the name German Resource Research Institute (GERRI), is to realise synergies – above all, with view to a successful participation in the EIT Knowledge and Innovation Community Raw Materials, which was established in 2015 with EU funds. This community aims at sustainably fostering innovation and training in the European raw materials sector.

In the field of exploration, there is currently sufficient teaching capacity available, which needs to be maintained. Regarding the beneficiation and metallurgical processing (including bioleaching) of metal raw materials and the field of raw materials economics, on the other hand, we are facing a lack of capacity.

A further approach could be to reinforce the **expertise of the Geological Surveys** of the German Länder. At the moment, the bulk of their services consists of collecting, editing and archiving geoscientific and pedological specialist information. However, they also advise the mining authorities in the assignment of mining permits to national and international mining companies. In order to be able to decide on a sound basis, the surveys require the requisite raw materials expertise, particularly concerning international developments on the commodity markets.

84 There are already study groups for lead zinc, copper and nickel. They are profit-oriented, and neither participation or consulting products are free of charge. In 2013, the fees Germany paid for the BGR's membership amounted to between EUR 15,000 to 27,000 per study group, cf. BMWi 2015-1.

85 ERECON 2015.

86 Instead of establishing a new study group for high-tech metals, an institutional connection to the existing structure of the Lisbon-based International Study Groups could be considered.

3.2 Supply Security

The dependence on a small number of supplier countries can be mitigated by resorting, to a greater extent, to domestic resources. Diversifying the supplier countries can also contribute to increasing the supply security.

3.2.1 Recycling

Since Germany commands extensive secondary deposits, i. e. large stocks of scrap metal, a comprehensive and efficient recycling system can constitute an important element of a more sustainable and secure supply of metallic raw materials for the energy transition. In order to improve the recycling rates for certain metals, we will have to consider not only the technical procedures, but also the legislative and logistical conditions, as well as consumer behaviour. We will not succeed in recovering more than the current rate of valuable raw materials unless we devise a comprehensive and logistically stringent approach, setting both economic and consumer-friendly incentives for companies[87] and consumers. In short, the recycling of metals must become more attractive, simpler and more efficient.

The systematic recycling of waste streams

The recycling chain covers several process stages: collecting, sorting, dismantling, preprocessing[88] and metallurgical recycling. The first stage involves the consumers, who bring end-of-life products to the recycling centre or discard them into the appropriate collection containers. At the end of the chain, on the other hand, there are but a handful of metal smelters for all of Europe where all waste material is metallurgically processed. Hence, the waste streams are largely merged towards the end of the recycling chain.[89]

Although there are efficient recovery processes for almost all substances along this chain, they are, in many cases, not sufficiently applied. Hence, substances are still lost at all process stages: due to inadequate or faulty collection of waste[90], during the mechanical processing or in the subsequent metallurgical treatment.[91] It is therefore crucial to systematically record the waste streams in order to ensure that they remain in the chain until the final metallurgical treatment. This, however, requires that sufficient metallurgical processing capacities are not only available in Germany and Europe, but are, indeed, used. In other words: We need to switch from "waste" management to "resource" management.

Waste legislation can be a lever to improve the situation.[92] Currently, however, the regulations claim purely mass- and weight-based recycling quotas, which, moreover, refer not to the yield at the end of the recycling chain, but to prior stages (e. g. processing). As a result, the main focus is the recovery of the mass raw materials steel, aluminium, plastic and glass. The precious and special metals occurring in much smaller quantities are virtually irrelevant for the fulfilment of a mass-based quota. The Federal Government's Resource Efficiency Programme, *ProgRess I* (2012) and *ProgRess II* (2016), already identifies improvements in the recycling of precious and special metals as a necessary step.[93]

87 EC 2014-1.

88 The processing refers to comminution (e. g. shredding) and pulping, followed by mechanical-physical separation processes (such as magnetic separation, density separation, optical sorting).

89 Hagelüken 2015.

90 The collection of secondary raw materials is partly carried out by unregistered companies/traders.

91 For instance, if components containing valuable elements are not removed in time: Once an old car is shredded, the magnets containing rare earths can no longer be removed.

92 The waste disposal legislation includes the Waste Management Act, which is primarily aimed at packaging waste, the Electrical and Electronic Equipment Act, the End-of-Life Vehicles Directive and the Act on the placing on the market, return and environmentally sound disposal of batteries and accumulators.

93 BMUB 2012; BMUB 2016.

It recommends that producers and waste disposal companies should be given access to information on the high value mineral content. Also, waste streams with a similar metal composition should be pooled. This would imply the development of suitable collection systems.[94]

A more extensive approach could include establishing binding **technical recycling standards**[95] across Europe for certain product groups or fractions with a particular relevance regarding resources. In addition to the quality of the recycling processes, these standards should likewise consider the criteria of economic viability as well as environmental and social aspects. Along the recycling chain, the processing of the respective products/fractions containing precious and special metals would hence be reserved for plants that have been audited and certified according to these standards. This would ensure the use of state-of-the-art technologies to maximise recycling efficiency. Such technical standards would be especially appropriate for complex products containing many different valuable metals (e.g. printed circuit boards or lithium-ion batteries). Not least, technical standards can be quickly adapted as the recycling technologies continue to evolve.

94 BMUB 2016, chapter 7.4.6.

95 Together with Eurometaux and the European Electronics Recyclers Assiciation, leading metallurgical companies have already developed an technical standard for the metallurgical processing of electronic fractions. It includes specifications for a minimum recycling quota for several metals. The European Committee for Electrotechnical Standardisation (CENELEC) is currently turning the standard into a "Technical Guideline". For the processing of waste electrical and electronic equipment, there already is a CENELEC standard. As yet, these standards are, however, not mandatory.

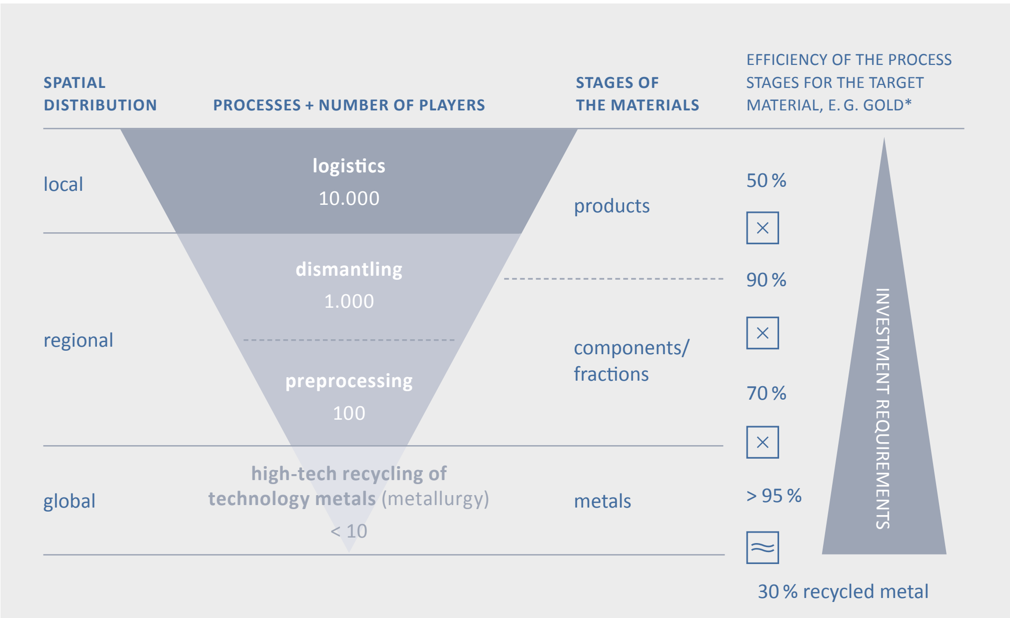

Figure 2: Exemplary recycling process chain for consumer goods: Recycling technology metals from printed circuit boards.[96] The overview shows the complexity of the process chain and the ensuing challenges.

* The effective recycling rate (recycling efficiency) for a metal is the product of the efficiency of the individual stages. In the example, 50 percent of the relevant end-of-life devices are collected (collection efficiency). In the course of processing, 30 percent of the gold is lost in "wrong" fractions (steel, plastic, dusts, etc.). These figures are realistic for the extraction of gold from consumer electronics in Germany and Europe.

96 Hagelüken 2014; updated percentages based on Wellmer et al. 2018.

In Europe as elsewhere, recycling contracts are currently awarded mainly according to financial considerations; the actual quality of the recycling processes still does not receive its due attention. This would be particularly necessary in the case of complex mixtures of recyclable materials and pollutants, as found, for instance, in electronic products. Here, high-quality recycling is more expensive than “cherry-picking” only a few recyclable materials (which, incidentally, comes with high pollutant emission rates). The current low raw materials prices tend to enhance the cost pressure still further, with the result that many recycling materials end up in inefficient recycling plants. This problem exists in processing as well as in metallurgical treatment – at both process stages better recycling would be possible if the resulting costs could be passed on. If for all of Europe the recycling of certain complex product streams were reserved for certified plants, fair, quality-based competition would ensue without negative effects on environmental standards or the raw material yields.

In the case of simple residues (e. g. production rejects) and certain metal combinations, recycling processes have been established even for many special metals. Usually, it is the complex products and element combinations that constitute the real challenge. Here, further progress must be made in the processing technology in order to allow for individual components or materials to be separated from products before undergoing the appropriate metallurgical processes. Examples include gentle digestion procedures and pre-shredding technologies for separating batteries, printed circuit boards and magnets, as well as identification and sorting processes for the separation of different aluminium alloys. Further difficulties arise in the subsequent metallurgical treatment: The challenge is to obtain rare earths and high-tech and special metals such as indium, germanium, gallium, tellurium, cobalt or lithium from complex “multi-metal” mixtures – in some cases without any established technologies at hand. This calls for the **development of suitable metallurgical processes** and process combinations.

A better control of the recycling chain as a whole could be realised by providing the respective authorities with recycling expertise, just as the mining authorities have the necessary knowledge of the production of primary raw materials. Staffed with the right experts, these authorities could monitor the reporting obligations regarding minimum technical requirements and environmental and social standards. Their responsibilities would range from recording the waste streams to certifying recycling facilities, as well as assisting port controls to prevent illegal exports of electronic waste. In addition, these units could cooperate with the Federal Environment Agency to certify products according to their resource efficiency. Thus, consumers could be given information as to their products’ recyclability – along the lines of the EU efficiency label, informing consumers as to the energy efficiency of household appliances. This would require the coordinated efforts of the Federal Government and the Länder. Such a measure would also underline the equal importance of primary and secondary raw materials.

Toward a more user-friendly collection system design

Only if consumers are motivated to actually return their end-of-life products instead of “hoarding” them or disposing of them via the residual waste can sufficient valuable resources be recovered. Although there are quite a few options for returning electronics in Germany (recycling centres and recycling containers, battery bins in supermarkets, etc.), customers do not always use them. This is mainly due to the fact that the effort involved is frequently considered out of proportion (e. g. a long drive to the recycling centre). The possibility of giving back end-of-life products in the shops of large electronics retailers[97] is likewise not yet sufficiently attractive for customers.

If this is to be changed, we need either specific financial incentives or a very simple return process involving little effort on the part of the consumer.[98] For some electronic products, **deposit systems** or **leasing models** could be a conceivable approach.[99] In the case of leasing, consumers would not pay to possess, but only to use the device. Upon return, the deposit would be reimbursed or the (monthly) leasing fee would end. However, the introduction of deposit systems would require corresponding regulations. In the long term, leasing models covering the entire life cycle of a product could be more interesting for all parties concerned, as they could generate further synergies.[100] In addition to the return incentives, the decisive advantage of deposit or leasing systems is that the ownership of the end-of-life products would be limited to a few professional manufacturers, leasing companies or fleet operators. These would have a critical mass of end-of-life products at their disposal and could conclude direct recycling contracts with professional recyclers, thereby supporting transparent material flows and high-quality and cost-efficient recycling.

Preventing illegal electronic waste exports

The amount of waste from electrical and electronic devices[101] has dramatically increased in recent years. In 2016 alone, an estimated 93.5 million tonnes, amounting to a value of around 20 billion US dollars, accrued worldwide.[102] According to estimates, 25 to 30 percent of Europe's electrical and electronic scrap is illegally exported to regions without an adequate recycling infrastructure. Due to the toxic components of the waste (such as mercury or lead) and/or the hazardous emissions resulting from primitive recycling processes (cyanides, dioxins), considerable environmental and health damage will frequently ensue in these areas.[103] From the European perspective, the illegal scrap exports do not only imply economic losses, but also represent a growing security problem, since criminal organisations make a lot of money from such transactions.[104]

Since European ports are the main hub for transports of this type, **reinforcing the port controls** could be an effective countermeasure. More staff and additional container scanners would make it easier for the port control authorities to discover illegal transports. If the shipment of such transports were restricted to certain ports, the transporters could not switch to other ports with fewer controls.

97 The new version of the Electrical and Electronic Equipment Act adopted in October 2015 obliges electronics retailers with a sales area of four hundred square meters or more to take back end-of-life devices free of charge.

98 For example, by making it possible to give back end-of-life appliances in shops consumers will regularly frequent. In France, for instance, end-of-life mobile phones can be dropped off in laundries.

99 Hagelüken 2015.

100 In the case of consumer electronics, the manufacturers could achieve more customer loyalty: Consumers could be given the choice between the most recent model or an older model against cheaper fees (in a "user cascade"). Hardware and software updates could be organised centrally. In the case of expensive products such as electric vehicles, intelligent CarSharing models could significantly increase the use of the vehicles, thus reducing costs (Ellen McArthur Foundation/McKinsey 2015).

101 Regarding quantities, one must bear in mind that the bulk of electrical and electronic equipment consists of white goods (e.g. refrigerators, washing machines) and household appliances such as coffee machines, toasters, tools, toys, etc. These contain only a few precious and special metals. Prominent amongst the devices rich in precious and special metals are information and communications technology products (mobile phones, computers) as well as cameras, audio and video devices. Although the number of these products is rising, the recoverable quantities of precious and special metals do not necessarily increase to the same extent, owing to the miniaturisation of the devices and the decreasing precious metal content per unit.

102 2014 ex-ante estimates (Opalka 2014).

103 UNEP 2015.

104 According to the European police force, Europol, there is a risk that electronic waste will become a "Key Criminal Commodity of the Future", EUROPOL 2015, p. 24.

The **system of customs tariff numbers** could be modified so as to include the information as to whether the goods are new or used in the customs declaration. This would facilitate the additional controls. So far, goods are only classified according to product groups.

Furthermore, it could be stipulated that electronic waste can only be delivered to certified recycling plants.[105] A significant increase in penalties for the illegal export of electronic waste might have a deterrent effect. Also, additional measures should be considered that might be apt to effectively combat illegal exploitation structures in the target countries. The police and development cooperation organisations might work together in this field.

On the whole, the illegal trade in electronic scrap testifies to a lack of transparency along the raw material chain. In order to effectively counter this problem, we need to establish improved reporting obligations and control measures.

Incentives for more recycling-friendly product design

Resource efficiency, on the other hand, begins with product design. The more electronic components with precious and special metals are used, the more important it is that these metals can be recovered at the end of the respective product's lifetime. If, for instance, modern electric motors contain magnets with rare earths, these electric motors should be accessible in a vehicle, while a reasonable technical effort should suffice to remove the magnets from the motors. The same applies to batteries and rechargeable batteries or printed circuit boards. However, nowadays the material compounds of electronic products are often so complex that it is hard to reach the relevant components.

105 Eurometaux 2015, p. 10.

One basic option to tackle this problem would be rules for a more recyclable product design and/or a **recyclability label** along the lines of the energy efficiency label for electrical appliances.[106] Also, the service life of products should be prolonged, for example by minimising wear and improving their repairability. This, however, requires **consistent and binding European rules and product standards**. These should always be adapted to the technical feasibility of current recycling processes. Well implemented, a recycling-optimised product design could make an ecologically and economically sustainable contribution to the creation of an efficient recycling economy.

3.2.2 Diversified sources of supply

The more raw material providers there are, the better failures of individual providers can be offset. However, for several years the metal raw materials markets have been witnessing a dwindling number of raw materials companies concentrated in fewer and fewer countries. In the case of some metals, the situation is already virtually monopolistic, with only few alternative suppliers.[107] For many raw materials required for the energy transition, there are far less supplier countries than for petroleum.[108] Importers of raw materials or intermediate products could improve their supply security by diversifying their supply sources. This would also benefit the evolution of the global market structures. However, as importers usually choose the best-priced suppli-

106 Cf. also German Resource Efficiency Programme II, policy option 7.3.3: Including resource conservation in product development processes, BMUB 2016, p. 55.

107 The markets for niobium (90 percent of global production in Brazil), rare earths (86 percent of global production in China) or platinum (68 percent of global production in South Africa) are examples of monopolised commodity markets.

108 For rare earths, for instance, the Herfindahl-Hirschman Index, which is used to gauge the country concentration, lies above 7,000, for vanadium and lithium over 3,000. For oil, on the other hand, the Index is only 2,093, even if OPEC is counted as a single country. Rare earths also have a high country risk. This means that the supplier countries are rated as unreliable (DERA 2016).

er, existing monopolies – e. g. regarding the rare earths from China – tend to be exacerbated.

In this context, it must be remembered that only a few metals, primarily copper, lead, zinc, nickel, aluminium and precious metals, are traded on the stock exchange. Many metals of importance for the energy transition, including the rare earths, the platinum group metals, silicon, lithium, indium and tantalum, are not that easily accessible. Raw material processing companies must begin by securing themselves access to these raw materials. One option for companies such as technology corporations, manufacturers of wind power and photovoltaic plants or their suppliers is to either engage in mining themselves or else acquire interests in raw material projects with corresponding long-term supply contracts or pre-emption rights. Thus, companies can enhance their control over the first stages of value creation. This is referred to as backward integration.

The German government already supports the German economy within the framework of its 2010 National Raw Materials Strategy.[109] This includes various financial instruments to **hedge raw material projects in other countries against political and economic default risks**, such as:

- investment guarantees for projects in emerging and developing countries
- guarantees for untied financial loans[110] for the financial protection of raw material projects abroad against default risks,
- export guarantees (Hermes cover) to hedge export transactions against payment defaults by foreign customers.

While some of these measures, such as the untied financial loan guarantees, were well accepted by the industry,[111] the **exploration support programme**[112] the German Federal Government had relaunched in 2013, was discontinued on 31 March 2015 due to a lack of demand. The exploration subsidy was included into the National Raw Materials Strategy for the express purpose of incentivising the industry to identify suitable, sustainable exploration projects worthy of promotion that could be suggested for state funding. However, the number of applications did not meet these expectations.

This experience shows that even with governmental support schemes, the German raw material processing industry is not so easily persuaded to invest in exploration and the long-term securing of the raw material supply. The Alliance for a Secure Raw Material Supply[113], founded in 2012 at the initiative of the Federation of German Industries, was likewise prematurely discontinued in December 2015 due to a lack of demand in the industry. The aim of the alliance had been to join forces with several large German companies to found a raw materials company that was

109 BMWi 2010.

110 Untied loan guarantees are state guarantees the Federal Republic of Germany gives to hedge the creditors (banks) of raw material projects abroad against economic and political credit default risks. A prerequisite is that the funded project will result in the long-term importation of a raw material assessed as politically eligible into Germany.

111 For example, a total of 18 requests were made for untied loan guarantees in 2014, ten of which regarded metallic raw materials. At the end of that year, the Federal Government took over guarantees for four raw material projects (untied loan guarantees 2014).

112 The guidelines on the granting of conditionally repayable allocations to improve the supply of critical raw materials (Exploration Support Directive) came into force on 1 January 2013. The aim was to support German companies in the exploration for potentially critical non-energetic mineral resources and in the acquisition of new interests in raw material projects. Applicants had to 1) be legally independent companies, 2) be technically and economically able to carry out the project, 3) have their headquarters and business operations in Germany and 4) fulfil the requirements to conduct their ow business activities.

113 The Raw Materials Alliance became the company Rohstoffallianz GmbH (Raw Materials Alliance). The founding members and shareholders of the Raw Materials Alliance included Aurubis, BASF, Bayer, BMW, Bosch and Volkswagen.

to build up a portfolio of interests in raw material projects, mainly abroad.

There are manifold reasons for industry's reluctance to get involved in securing the raw material supply. On the one hand, the current low raw materials prices suggest a relaxed supply situation. On the other hand, mining is capital-intensive and harbours higher risks than the manufacturing industry.[114] A further obstacle is the lack of know-how in metal mining ever since all German metal mines were closed down and the foreign interests were sold in the 1990s.

Since raw materials prices are likely to rise again in the future and supply bottlenecks are possible, more public provision efforts could be economically judicious. Considering the energy transition as a project of national interest, this is especially true for raw materials required for the conversion of the energy system. Here, we need to establish an appropriate balance between an autonomous industry and macroeconomic, resource-strategic considerations. It must further be taken into account that securing the raw material supply in the long term (for instance by investments in mining projects) is best done anticyclically, i. e. in low-price phases, to keep the costs at bay.

Establishment of an internationally active German raw materials company

Until the beginning of the 1990s, German industry was able to obtain materials such as zinc, lead or germanium from its own sources. Also, supported by the first public exploration support programme[115] between 1970 and 1990, mining and exploration companies, particularly the Metallgesellschaft AG, had succeeded in establishing extensive possessions of foreign mines and equity. The dealer network the company built up over decades was pivotal in safeguarding its success. In 1993, as a result of financial imbalances, the company sold all of its foreign interests; the know-how was lost. The German metal ore mines had already been shut down in 1992 due to a lack of profitability – despite the fact that only a few non-ferrous metal deposits in Germany were completely exhausted.[116] Since then, there have been no significant domestic metal ore mines, nor any major German raw materials companies.

However, it is advisable to extend one's time horizon when considering the raw material supply for future energy systems. Strategically, it could therefore be an advantage for Germany to be, once again, home to **an internationally active raw materials company**. However, the experience of recent years (including the failure of the Raw Materials Alliance) shows that there is little chance that such a company will be established from purely private sector initiatives. If the practical realisation of raw material security is classified as a national interest, that might justify state intervention.

The reticence of German industry in the field of raw material production is partly due to the discrepancy between investment appraisal methods used in business management and the cycles of the commodity market. A period of seven to ten years and a great deal of capital are required before a deposit can be exploited. During this time, the deposit will usually run up losses, which can only be compensated by profits in the production phase. Investments are evaluated by means of the net present value method in which the (net) payment flows of each period – e. g. each year – are discounted to the present

114 Wellmer 1986.

115 The Federal Government's exploration funding programme *Measures for improving the supply of the Federal Republic of Germany with mineral raw materials* aimed at improving the supply of the German industry with raw materials. The programme supported German companies in the acquisition of interests in foreign metal mines and mines of non-metalic raw materials of special interest, enabling them to partially produce and process raw materials themselves (backward integration).

116 For example, the Rammelsberg mine near Goslar, which was shut down in 1988.

value and added up. In the case of investments in a deposit, the situation is comparable to that of a start-up: Inevitable losses in the first years will be followed by a first production period fraught with uncertainties as to the achievable sales price. Only if a sufficiently high sales price is to be expected does the investment have a positive capital value and can be financed.

Predicting future prices is invariably fraught with uncertainties. In the commodity markets, this situation is exacerbated by the fact that in the case of most raw materials, the stock exchanges are unable to provide transparent price histories.[117] If statistical procedures are used to extrapolate current prices into the future, the level of the expected prices will be higher if the extrapolation is realised during a period of high prices. However, in markets punctuated by cyclical developments, high-price periods are followed by low-price periods. In the case of agricultural raw materials, for instance, these cycles are primarily due to the respective crop quality, while the pivotal point for industrial raw materials is the economic situation. In both cases, the situation on the world markets is a further determining factor.

During the low-price phases, the extrapolated prices will not be realised, and the investment projects will consequently no longer be financed or discontinued for lack of profitability. Due to the ensuing expectation of a shortage in the supply of the respective raw materials, the price will then increase, starting the cycle all over again. The nickel price, for example, increased from just below US $12,000 per tonne in late 2005 to $51,600 within two and a half years, before falling back to its previous level within a year and a half. Such price changes have a major impact on investment activity. In the case of non-exchange-traded resources, such as rare earth elements, the lack of pricing transparency further intensifies the described effects.

A possible approach to address the described cyclical dilemma would be the establishment of a state-subsidised mining or raw materials company. Two approaches to governmental participation in such a company will now be discussed.

Case 1: In this model, the state-funded mining company acts as an initiator in the field of primary production. This model would constitute an evolution of the Federal Government's concept for marine raw materials (cf. chapter 3.2.3). In the case of the marine raw materials, the Federal Government secures concessions for a possible future industrial exploitation via the Federal Institute for Geosciences and Natural Resources (BGR). Currently, the provisions the raw material processing industry makes to secure the long-term supply of necessary resources from the primary raw materials sector (mainly metals) are scarcely sufficient and the financial incentives are too small in the short term, particularly in times of low raw materials prices. It must therefore be considered what role the government could play in the establishment of a national mining company for onshore raw materials. A precondition would be that the start of any financial commitment is limited to periods of low raw materials prices (low-price phases in the raw material cycles). Experience shows that in low-price phases, the prices for advanced projects tend to be cheap, whereas high-price phases often come with exorbitant premiums (cf. 3).

117 The six non-ferrous metals of the London Metal Exchange and the agricultural commodities of the Chicago Stock Exchange are an exception, as the prices of the six metals are accepted as reference prices worldwide. It however, depending on the quality of the traded raw material, these reference prices are marked up or down. These changes are, in turn, intransparent and not systematically recorded. Nickel, for instance, is traded at a quality level at the LME which is used in industry only to a very limited extent. The more frequently used ferro-nickel (FeNi) is traded at a variable discount to the LME nickel price.

A comparatively low initial state funding of around 500 million euros would suffice to subsidise a mining company for seven to ten years. In other words, this approach establishes something like a "stock of deposits for booms and busts". However, one cannot acquire mining rights and claims to deposits and then simply "sit" on them. Rather, any such purchase comes with an obligation to develop the respective mines or deposits, if necessary up to the feasibility studies[118]. Hence, such funding is necessary – not least in order to be an attractive partner for owners of deposits with critical raw materials. On the one hand, therefore, the goal should be to use low-price phases to enter into attractive projects. On the other hand, these low-price phases, during which the German industry is not interested in raw materials as the supply situation is relaxed, must be bridged until the respective materials become, once again, scarce enough to rekindle the companies' interest.

During this period, about five to ten workable deposits could be developed internationally. The state-owned mining company should always attempt to limit its activities to "start-up initiatives" and find private sector solutions as soon as possible (such as external funding, new partners, financial contributions by raw materials processing companies in return for long-term supply contracts, etc.). The state company could then withdraw, and the deposits could be privately developed and production launched. The development of a deposit right up to the feasibility study without any private funds should therefore only be a fallback position if no partners are found. Even foreign companies could be considered as private partners as long as they agree to take on certain commitments for the raw material supply for German industry.[119]

118 The feasibility status is the basis for obtaining a financing committment for a project from a bank.

119 This would follow the model of the so-called junior companies in Canada or Australia, which frequently resort to unconventional ideas to develop a newly-discovered deposit, securing the support of often large companies. Depending on the success of the project, the latter must gradually increase their financial contributions in order to acquire shares.

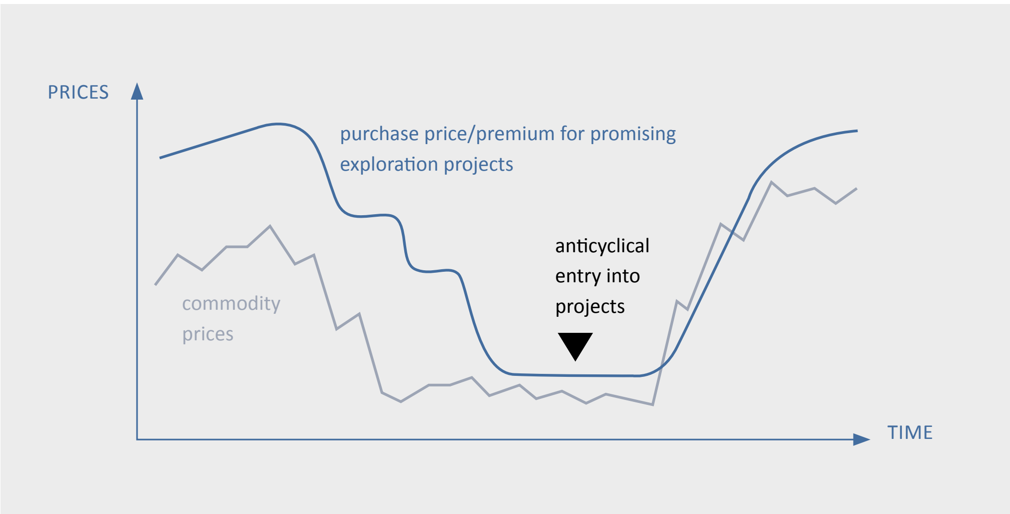

Figure 3: Model for anticyclical investments in raw material projects: Premiums for promising exploration projects in relation to the phases of the raw material cycle.[120]

120 The premiums paid for exploration rights in deposits do not simply mirror raw materials prices. They are also influenced by moods or fashions in the industry (which raw materials are currently "in vogue"?) or by recent exploration successes.

This model could be used to ensure the supply of several raw materials for which the market concentration is currently particularly high and which would be especially required for the energy systems of the future and for new mobility concepts (e.g. rare earths, lithium, cobalt, the platinum group metals, copper, etc.). The government can keep both the costs and the number of interests at a reasonable level with a few simple measures: At the start of the project, business partners must be found that commit to purchasing raw materials or intermediate products; also, the shares must be gradually resold over time. If, however, the investment sum is too small, it might not trigger a long-term private sector commitment, annihilating the effects of a secure long-term raw materials supply.

Case 2: In this model, the state mining company acquires interests in the form of equity stakes of or direct investments in existing raw materials companies and intermediate product manufacturers. In this case, they can resort to investment guarantees and guarantees for untied financial loans by the Federal Government. This model is similar to the activities of the Japan Oil, Gas and Metals National Corporation (JOGMEC). Since the German manufacturing industry tends to resort directly to products from the higher value chain, strategic partnerships with further suppliers – apart from those in mining (as of feasibility study) – would be expedient. This is particularly the case for suppliers at the first value creation stages (refining, production of alloys, additional early processing stages) that are already in production. In this case, a national raw materials company would strategically invest in projects under construction or existing producers by means of direct investments and by resorting to existing federal subsidies such as investment guarantees, Hermes covers and guarantees for untied financial loans.

Usually, other partners are involved in major projects of this kind: banks, associated companies, companies from related sectors, and customers for the raw materials and intermediate products. The risks are thus spread. Such a tool could benefit from the existing federal subsidies. In 2015, for instance, the construction of a highly modern smelter for the production of silicon metal in Iceland was co-funded by means of an untied financial loan, albeit without any direct participation of the German Federal Government.[121]

The JOGMEC is a good example of the successful implementation of direct government investments. It secures raw materials for the Japanese economy in cooperation with foreign partners by means of a holding. For the steel alloy metal niobium, for instance, JOGMEC works together with the most important niobium producer worldwide, the Cia. Brasileira de Metalurgia e Mineração in Brazil. Owing to JOGMEC, major Japanese companies are able to secure shares in many of the very productive new deposits. By means of minority interests, the flow of raw materials from these deposits to Japan is secured in the long term.

In both models, an important factor for success is for the respective raw materials company to act anticyclically – in other words: to use low-price phases to cheaply buy claims for German companies to use upon joining the enterprise. If, as in the case of the failed Raw Materials Alliance, such activities are taken up in high-price phases, access to raw materials comes at the price of high premiums. Since even players who already hold an oligopolistic position buy deposit shares anticyclically,[122] the anticyclical commitment of a German raw mate-

121 Euler Hermes Corporation 2016.

122 For instance, public and semi-public Chinese companies are buying shares in rare earth deposits, such as Kvanefeld in Greenland and Catalão in Brazil (in Catalão, niobium and phosphorus are produced, but there is a great potential for rare earths).

rials company could not least counteract a further supplier concentration, for example in the case of the rare earths.

A state mining company acting anticyclically would invest (in case 1) in deposits or exploration projects with a negative (expected) capital value. If during the development of the deposit the market price for the products rises, the capital value changes and the investment can become profitable. However, the commodity sector is fraught with risks and the success of a project depends on many unpredictable factors. For the government, such a high level of investment therefore represents a considerable economic risk.

When sold to the private sector, the deposit would have to achieve a price that compensates for past risks. However, since high-price phases in the commodity sector correlate with expansive economic performance which, in turn, usually entails rising real interest rates, the transfer of the deposit will tend to be a comparatively expensive business for the private sector. The sale of a deposit is an uncertain affair even in the high-price scenario.

Should prices stagnate or decline, for instance because substitutes for the raw material are found due to technical innovations, the investment will not pay off and the state mining company will be left deficient with regard to this raw material.

These considerations apply mutatis mutandis to Case 2. However, the absolute level of the investment being lower and the duration of the capital commitment shorter, the measure will, predictably, be less effective. At the same time, the risk is likewise lower than in the case of a state-funded development of deposits.

In both cases, a further point must be taken into account: While it is easy to identify ex post when the price of a raw material is in a high-price or indeed a low-price phase, this is invariably unclear in the respective situation, i. e. “in real-time”. It is always uncertain whether a price will rise further, fall or whether a turning point has been reached. Any calculation based on the principle of investing at very low raw materials prices and later selling the respective resources at high prices is therefore too optimistic, since in practice this scheme will hardly ever work out with sufficient certainty.

There is also a further, fairly significant risk to be considered, i.e. that public companies tend to be inefficient. There are two major reasons for the comparative inefficiency of state-owned enterprises: private companies are not only a) generally profit-oriented (and therefore have an interest in optimising the efficiency of their production), but also b) controlled and disciplined by the financial and capital markets. Public companies, on the other hand, often do not have a clear profit target, but several possibly conflicting goals, such as an affordable supply for the demand side, the realisation of profits or political objectives. The problematic point is that this makes it difficult to clearly gauge their success, and virtually impossible to verify whether set goals have been achieved. Also, management positions are frequently filled with political appointees. To this must be added that state companies are less subjected to the pressure of the capital markets and tend to operate under rather soft budget constraints that “provoke” productive inefficiency, i. e. inefficient production and investment behaviour.

While private companies are often monitored by major shareholders, investment funds or even family owners, all of which have a strong interest in efficient management, public enterprises are supervised by (political) officials, municipal dignitaries and other representatives who are meant to protect the interests of the taxpayers (as proprietors). These state-appointed supervisory bodies are, in turn, more or less efficiently controlled by the parliaments (and the media), which are controlled by the voters.

In many cases, the politically appointed supervisory bodies have neither the competence nor the incentives for effective control. Together with the multi-level control concept[123], this results in the management of state companies being de facto less effectively supervised than that of private companies.

These supervisory concerns are amply illustrated by numerous public infrastructure projects.[124] The experience in various sectors also shows that due to these incentive structures, a state-owned company, once established, is difficult to abolish or to transfer to private-sector structures. This creates long-term costs for society.

To be sure, there are examples of state-owned mining companies operating successfully in a private-sector environment.[125] However, the risk that a public enterprise, however well-intentioned it may be, will ultimately suffer from a lack of effective supervision and operate inefficiently, is great. If, therefore, public involvement is envisaged, the state should essentially limit its role to initiating mining projects, and taking care to transfer its shares as quickly as possible to private investors.

The basic question remains whether and why default risks, which are, currently at least, successfully borne by companies, should be transferred to the state or to society in the first place. A state-owned mining company is inevitably fraught with risks that are mainly due to the difficult predictability of future demand. If no market failure can be diagnosed for a raw material, a government intervention is therefore difficult to justify.

However, as soon as a market failure becomes manifest, such an intervention is too late. Hence, a strategic decision is required: The risk exposure a state mining company incurs must be balanced against the probability of a market failure entailing a supply crisis and against the possible consequences of a supply disruption (not least for the conversion of the energy system).

So, is the probability of a future market failure sufficiently high to justify a comprehensive government intervention? From an economic point of view, the sector appears, so far, to be able to cope with these risks. Similar to other markets characterised by price cycles and long investment horizons, the commodity sector basically has a portfolio of well-functioning, albeit partly risky, business models. Companies can moreover resort to various financial instruments to safeguard against default risks. With regard to raw materials that are not traded on a stock exchange, it would, however, be expedient to establish mechanisms for more transparent pricing.[126]

However, the crucial point is not only whether the markets are currently able to deal with the risks, but also whether we can say with sufficient certainty that they will remain so in the future. Indices used to quantify the criticality of raw materials show that the supply situation for rare earths, for instance, is becoming increasingly tense.[127] There is also evidence that access to raw materials could be encum-

123 In economics, this is referred to as a multi-level principal-agent problem.

124 Cf., for instance, Flyvbjerg 2005, Flyvbjerg/Sunstein 2015, Flyvbjerg 2014, Anzinger/Kostka 2015, Shapiro/Lorenz 2000.

125 Examples are CODELCO in Chile, the largest copper mining company in the world, or LKAB, the state-owned Swedish iron ore company, which, despite difficult conditions, successfully exploits deposits in the far north of Sweden (World Bank 2011).

126 One approach could be the Study Group for rare earths described in section 3.1.2.

127 A detailed discussion of the indices for the criticality of raw materials, including the Herfindahl-Hirschman Index and the weighted country risk, can be found in Angerer et al. 2016 and Wellmer et al. 2018.

bered by the raw materials policy of the supplier countries: The increasing number of Chinese oligopolies – a consequence of their purchasing deposits, particularly in Africa – and the recently imposed ban on exports of nickel ore from Indonesia and the Philippines are cases in point. The endeavours undertaken by market-based Western economies to break the Chinese dominance in the rare earths market through intensified research efforts, diplomacy and a complaint against China at the World Trade Organisation, have so far had little effect on the market structures.[128]

In order to assess the likelihood of a future market failure as well as the damages a supply crisis would probably inflict on the German economy, the existing early warning system at the German Mineral Resources Agency (DERA) could be expanded as part of DERA's Raw Material Monitoring Programme. This should cover the following factors: price development, price volatility, market volume (traded goods), market concentration, physical availability (exploration, production, stockpiling), an assessment of the political risks of primary production, as well as other aspects such as temporal changes in international commodity trade or a more detailed analysis of the development of demand trends. The crucial point is that the early warning system is not meant to evaluate short-term market signals[129], but to assess the long-term risk. Thus, it is to support the strategic decision as to whether government measures are indicated. Commodity experts, political scientists as well as economists should be involved in the development of this tool. It would provide a scientific basis for the decision for or against the establishment of a state mining company or similar measures financed from public funds.

However, the benefits of such a preventive mechanism are probably difficult to gauge and will not be directly quantifiable. For a significant impact on supply volumes and prices, such a state-funded raw materials company would have to obtain substantial market share. Even if such a venture succeeded, the company itself would, considering the strong concentration in many commodity markets, probably join the ranks of the oligopolists. However, experience from various economic sectors shows that despite government controls, there are strong incentives for state oligopolists or monopolists to deliberately keep supply volumes tight so as to demand high oligopolistic prices. In the medium term, this might (more than) counteract any short-term improvements in supply security. At the same time, the costs to the public could rise to a comparatively high level. This is particularly due to the incentive problems described above and to the fact that the government would undertake a task that would probably be uneconomical in the medium term.

In summary, it can be stated that there may indeed be a strategic need for action in the commodity sector. From an economic point of view, however, it is questionable whether and under what circumstances a government participation in a mining company can be justified and promising as a preventive measure against possible future bottlenecks. Therefore, a comprehensive examination of the advantages, disadvantages, opportunities and risks for the respective raw materials and the considered models of state participation is essential.

If a state subsidy is chosen, it could be attached to conditions such as compliance with high environmental and social standards and the use of the best available technology. In this way, a German raw materials company could also contribute to a wider use of environmentally and socially acceptable mining practices.

128 Klossek et al. 2016.

129 For the distinction between long-term and short-term trends, cf. p. 20 (box).

Bridging low-cost phases through care and maintenance

The following measure, not yet featuring in the National Raw Materials Strategy, is promising in the case of unusually low raw materials prices or dumping prices by individual suppliers: Mines which, as a rule, operate viably but are under pressure from extremely low prices, could be granted public subsidies. Depending on the economic necessity, the operator would stop all activities except the necessary maintenance (**care and maintenance**).[130] In other words, the mine would be in "standby mode". The government could financially support the exploration works. With this model, a mine could be kept alive, which would facilitate access to the deposit once raw materials prices rise again. Reopening a completely shut down mine would, in any case, be more expensive than temporary financial support on a care and maintenance basis. Thus, monopolisation tendencies could be counteracted.

The example of the tungsten mine Mittersill in Austria demonstrates that in the rationale of a raw materials strategy, such a procedure can make sense: Despite the collapse of tungsten prices in 1992/93, the mine received state aid to be kept open on a care and maintenance basis. The Austrian government limited its support to the exploration activities. All other operating and personnel costs remained the responsibility of the mine operator. Today, the Mittersill mine is once again a major tungsten producer in the EU. Tungsten being classified as a critical raw material by the EU Commission, this measure can be seen as a contribution to European supply security.

At the international level, it would likewise be conceivable for the EU to maintain certain mines outside of Europe on a care and maintenance basis in return for financially attractive long-term supply contracts. The downside of such government interventions in the market is, of course, the risk of competitive distortions. In addition, as in the case of a state mining company, the government runs a considerable economic risk, for it is unpredictable when and to what extent commodity prices will rise again. It also needs to be considered which mines are to benefit from state aid and for how long. In the end, this is a political decision that must take business considerations as well as economic and strategic aspects into account.

Mining in Germany and Europe

There is potential in Germany for indium, germanium, tungsten, lithium and nickel that could lead to the discovery of new primary deposits. In addition to recycling, these could enhance the share of raw materials from domestic sources. The following measures could contribute to a commercial exploitation of these deposits:

- Research as groundwork for commercial exploration.[131] The fact that even in a country with a long mining tradition, new exploration methods can lead to the discovery of hitherto unknown, workable deposits, is exemplified by the important tungsten deposit Mittersill in Austria: It was discovered in 1967 on the basis of a scientific concept.

- There are known metal deposits in Germany – mainly in Saxony – which could be economically viable if the technical problems in processing were solved. The tin-tungsten-fluorite deposit Pöhla in Saxony is a case in point.[132] Increased research efforts are required to solve the existing problems of mechanical treatment and metallurgical processing.

130 Care and maintenance includes the maintenance of the infrastructure of a mine, e. g. pumping systems, water retention, backup and safety operations, as well as exploration works.

131 The *r⁴-programme* of the Federal Ministry of Education and Research is the first support scheme since the 1980s to fund research on the exploration of primary raw materials.

132 It contains tungsten and fluorite – two raw materials that are considered critical by the EU.

- Tax incentives to support investments in mines.

In the European context, the establishment of a voluntary **"European fund for critical raw materials"**[133] could also be an option. By funding the exploitation of promising European deposits[134] it could contribute to diversifying the supply chains for rare earths or other potentially critical raw materials. A further possibility would be a joint financing by private and public sponsors, which would make it possible to run such projects in the long term.

An important question is how far mining projects in Germany and Europe are endorsed or at least tolerated by the public.[135] Studies in the context of energy projects show that the way in which projects are communicated and planned greatly influences their acceptance. The more and the earlier a functioning communication and participation in the planning and decision-making processes are ensured, the greater the chances of finding a solution acceptable to all.[136] In this context, it is not least of great significance that the legal framework for approval procedures take transparency and participation processes into account.[137]

133 ERECON 2015, p. 84.

134 For instancee the rare earth deposits Norra Kärr in Sweden and Kvanefjeld in southern Greenland.

135 As part of the funding initiative r⁴ – *Innovative Technologies for Resource Efficiency – Research on the Provision of Raw Materials of Strategic Economic Importance* by the Federal Ministry of Education and Research, the project *GORmin – Governance options for the acceptable production of resources of strategic economic importance from primary and secondary deposits in Germany* was launched in 2015. The project aims at analysing lines of social conflict in the context of mining projects in Germany and attempts to develop possible solutions. The project runs from 2015 until 2018. Results are not yet available.

136 Renn 2015, p. 59.

137 Legal strategy advice for politics and the economy regarding raw material exploitation in Germany is elaborated, for instance, by the Government Commission of the State of Lower Saxony *European Environmental Policy and Project Planning*, or more precisely by the Commission's working group *Acceptance and Efficiency in Project Planning* (Ministry for Economics, Labour and Transport of Niedersachsen 2017).

3.2.3 Marine resources

If the global demand for metallic raw materials continues to rise in the future, marine resources could be considered an additional source of supply. In the deep sea, there are presumably rich deposits that are still undeveloped. These include polymetallic nodules ("manganese nodules"[138]), cobalt-rich iron-manganese crusts[139] and hydrothermal sulfide ores[140]. They contain many metals that are important elements for the energy systems of the future.

However, it is not yet clear what role marine raw materials can play. Several companies are currently attempting to improve and automate existing mining technologies. Accordingly, machines are already being tested in great water depths.[141] However, the expenses coming with the exploration and mining of raw materials in the deep sea might far exceed the costs for onshore deposits. Whether it might, one day, be profitable for companies to mine metals in the sea, it thus depends above all on the conventional raw material supply and on price developments: If enough reasonably priced metals are available on the world market, the cumbersome and expensive development of marine deposits is not very attractive.

Nevertheless, the *National Masterplan for Maritime Technologies*, which the Federal Ministry for Economic Affairs pub-

138 Polymetallic nodules (manganese nodules) are small black-brown tubers of about one to ten centimetres in diameter. They grow very slowly in sediment-covered areas of the deep sea in a water depth of 4,000 to 5,000 meters. The largest deposits are found in the so-called manganese nodule belt in the Clarion-Clipperton zone in the Central Pacific. They contain the valuable metals copper, nickel and cobalt.

139 Cobalt-rich iron manganese crusts are coatings or crusts of manganese-iron oxide of only a few centimetres thickness, which are deposited on the surfaces of hard rock formations in the deep sea. In addition to higher cobalt concentrations, they can contain valuable trace metals such as platinum, tellurium and tungsten.

140 Hydrothermal sulphide ores occur along volcanic structures (oceanic ridges, island arcs) in different depths of the sea. They can contain increased concentrations of copper, zinc, gold, silver, indium and germanium.

141 Wiedicke et al. 2012; OECD 2016.

lished in 2011, lists marine mining as an option for securing Germany's raw material requirements.[142] If it is indeed to become a pillar of the German raw materials strategy, we will have to consider how research efforts can be intensified in the fields of mining, processing and environmental compatibility. Above all, we would require more information on the effects of mining methods on the sensitive ecosystems of the deep sea, as well as on consequences for the fishing industry and humankind. German companies and research institutions could also make an important contribution to the development of environmentally compatible production, processing and smelting technologies for metallic raw materials from the deep sea. And: the sooner we have reliable information, the sooner the future costs can be assessed and the exploration of new raw material deposits begun.

In 2006, the Federal Institute for Geosciences and Natural Resources took the lead by acquiring a licence area of about 80,000 square kilometres in the Central Pacific from the International Seabed Authority in order to research polymetallic nodules. The aims of this research project, which is scheduled for a period of 15 years, include the collection of environmental reference data to assess the impact of a subsequent industrial exploitation of the nodules.[143] Germany signed a further license agreement in the Indian Ocean in 2015, allowing for the exploration of sulfide deposits in an area of approximately 10,000 square kilometres southeast of Madagascar. On their expiry, both exploration licenses can be converted into mining licenses.[144]

With the acquisition of the exploration licenses, the above-mentioned research activities and its contribution to the development of a Marine Mining Convention[145] within the framework of the United Nations Convention on the Law of the Sea, Germany has already made significant investments in the development of marine mining. The question now is whether and how the transition to a commercial use of the deposits in the deep sea should be realised. A so-called "pilot mining test" would be an important instance in order to test production methods and to assess the ensuing environmental impacts. However, the examples of the exploration support programme and the discontinued Raw Materials Alliance attest to the difficulties of persuading German industry to get involved even in conventional onshore deposits.[146] In the case of non-conventional raw materials from the sea, industry involvement is therefore hardly to be expected without further government start-up support.

In the future, this situation could result in a competitive disadvantage vis-à-vis those countries that are currently also active in exploring the raw material potential of the seas for later exploitation:[147] China, Japan, India, South Korea and Russia have likewise acquired licences and are implementing state-funded exploration programmes[148] in order to secure a good starting position for future commercial exploitation. Under the jurisdiction of the International Seabed Authority, public or semi-public companies from China, India or Japan will probably be the first to exploit marine raw materials outside their respective exclusive economic zones[149].

142 BMWi 2011.

143 BGR 2014.

144 BMWi/BGR 2015.

145 The Marine Mining Convention sets out rules for future marine mining activities.

146 Cf. section 3.2.2.

147 International Seabed Authority 2015.

148 International Seabed Authority 2014.

149 According to the United Nations Convention on the Law of the Sea, the exclusive economic zone is an area stretching out 200 nautical miles from the baseline of the coast. Within this zone, the respective coastal state has sovereign rights regarding the exploration, exploitation and use of the living and non-living resources of the sea, seabed and underground (UNCLOS 1982, articles 55-57).

From the point of view of a German raw materials strategy, continuing and expanding the current commitment, for instance by developing innovative technologies, is therefore definitely an option worth considering. Moreover, Germany would be well positioned to work towards the global introduction of high environmental and safety standards for marine mining in order to protect marine ecosystems.

The model of state subsidies largely corresponds to case 1 described in section 3.2.2 for a German mining company. The arguments questioning the advisability of such a state subsidy that were discussed in that context also apply to the case of marine raw materials and must be weighed against resource-strategic considerations.

3.2.4 Stockpiling

A further lever for reducing supply risks is stockpiling. As a rule, the companies decide at their own discretion what raw materials they stock (depending on the current or expected world market prices), in what quantities and for what periods of time. In the case of critical raw materials, however, the government may also be interested in having sufficient national reserves at its disposal. There are two conceivable alternatives for a public stockpiling strategy: Either subsidies or tax incentives are used to encourage the industry to stock more raw materials, or the government itself implements a centralised stockpiling system.

Japan[150] and South Korea[151], for instance, have programmes for a joint public-private stockpiling system for strategic metals. However, this type of intervention could be interpreted as a subsidy to the advantage of certain companies. Moreover, once the public subsidies for the stockpiling expire, the raw materials could be instantly resold. The desired effect, i. e. that the industry builds up reserves over a longer period in order to have a sufficient stock of raw materials in high-price phases, would evaporate.

Alternatively, the government itself could undertake to organise centralised stocks.[152] Along the lines of the Federal Government's strategic petroleum reserves, critical metallic raw materials could be stocked under public or semi-public management over a longer period of time. The German government – or, in the case of a European solution, the EU – would thus enter the commodity business and actively contribute to increasing the supply security. Such a model is found, for example, in the US.[153] It would have to be determined how and to whom the public metal reserves would be distributed in the event of a tight

150 Japan has a programme called *Rare Metals Stockpiling*. It establishes national reserve targets, according to which the state is to store raw materials for 42 days and the private sector for 18 days. The metals in question are chromium, cobalt, manganese, molybdenum, nickel, vanadium and tungsten. Due to the risk of speculation, the exact amount of the strategic reserves is not publicly known (JOGMEC 2014). In addition, the situation on the commodity markets is monitored regarding gallium, indium, niobium, platinum, rare earths, strontium and tantalum (TU Clausthal/BGR 2013, p. 75).

151 The Korean Resources Corporation (KORES) is a state-owned energy and raw materials company, operating worldwide to secure raw materials for the Korean economy. KORES is responsible for the procurement of a total of eight strategic raw materials: iron ore, zinc, bitumen, coal, uranium, copper, nickel, rare earths and other rare metals. The organisation also keeps stocks of rare metals (KORES 2013).

152 At the end of the 1970s, the Federal Republic of Germany planned to establish a state reserve. With the support of the KfW Kreditanstalt für Wiederaufbau (German state-owned promotional bank), private companies were to extend their stocks of chromium, manganese, vanadium, cobalt and blue asbestos to last for a year. The interests (an estimated four hundred million DM) were to be borne by the Federal Government. Due to austerity plans, the project was in the end not realised.

153 DLA 2016.

supply situation. One option would be to privilege strategically important industrial sectors with high consumption (in the case of rare earth magnets, e. g. offshore wind turbine manufacturers, in the case of platinum metals only industrial uses, not jewellery production). Those industry sectors that were hit particularly hard by the last commodity crisis could serve as a reference.

The disadvantage of this type of stockpiling would be that the government would use tax money to take over a part of industry's tasks. As a rule, however, industry is much quicker and more efficient than the government when it comes to implementing the economic decisions connected with the commodity trade. Whereas we can confidently assume that petroleum will not lose its strategic economic importance in the coming years and decades, this does not necessarily apply to all metallic raw materials. It is possible that individual metals lose their significance within a few years as a result of technological advances, while the demand for other metals may increase. The government would certainly be in greater danger of stocking the wrong metals than a company which can, of course, better assess its own future requirements. Since stockpiling is expensive,[154] the state would run a significant economic risk. At the same time, it might erode the willingness of industry to make sufficient provisions themselves. This would diminish the effect of stockpiling.

The general question is whether and under what circumstances a state participation in stockpiling is justified from a macroeconomic point of view. As discussed in section 2.7, a physical supply shortage, caused, for instance, by export bans, constitutes a genuine market failure. Strongly fluctuating prices, on the other hand, do not necessarily indicate a market failure, but merely a high uncertainty in pricing.

Strictly speaking, public stockpiling to mitigate high-price phases would therefore not correct a market failure, but rather serve as a mechanism for smoothing the price situation. The government would purchase and store raw materials in low-price phases. In high-price phases, the raw materials are then passed on to the private sector at prices below the respective current market level. As long as these prices do indeed compensate for the accumulated costs of raw material procurement, storage, administration, insurance, etc., as well as for the interest gains a different use of the capital would have yielded, this measure is cost neutral for the government. The risk, however, is that the raw materials are not purchased at the lowest prices or that the storage costs cannot be totally recovered, for instance in the case of prolonged storage due to a very slow price increase, or if the requirements of the industry turn out to be lower than expected.

Doubtless, extreme price fluctuations constitute a particular challenge for market participants, especially for those with an interest in the physical product (as opposed to speculative market participants). However, even against this background it appears doubtful whether, in the absence of a market failure, default risks that are currently successfully borne by companies should be transferred to the public, i. e. to society at large. After all, just like other sectors with similar characteristics, the commodity sector seems to have developed good protective mechanisms, e. g. by resorting to financial tools. A market failure in the sense of a supply crisis, for instance, is currently unlikely. At present, therefore, the social costs would tend to exceed the benefits.

154 According to experts, the annual German consumption of the potentially critical elements tellurium and indium and of the potentially most critical rare earth elements neodymium, dysprosium and praseodymium equates to approximately seventy million euros. In the case of platinum group elements platinum, palladium and rhodium, the consumption of only three months is estimated to correspond to some 160 million euros.

A different approach is indicated in the event of impending physical supply shortages, for example due to export restrictions. In the occurrence of a supply bottleneck, the private companies' own reserves will be rapidly exhausted, since in times of tight supply chains ("just in time delivery") their raw material reserves are very limited. In this case, the expected economic costs of a production stoppage are high and an effectively organised state intervention could be justified. In principle, bilateral and multilateral treaties and trade agreements (particularly if they include sanction mechanisms) could be a cost-effective means of establishing a sound legal framework that can prevent or amend such politically induced shortages. They are therefore a first-best option.

Should this be impossible, a public stockpiling mechanism could function as a "lender of last resort" in order to temporarily maintain the production capacity. The establishment of such a public emergency reserve would, however, require the previous definition of distribution and pricing mechanisms. It should also be considered that such stocks – which should only be resorted to in real emergency situations (viz. complete suspensions of delivery) – will in all probability make losses, since such situations are bound to occur but rarely. In addition, they can provide only temporary relief (shorter or longer depending on the quantity of stocks, but never permanently).

Since public stockpiling serves as a "physical insurance" for the private sector, it would be conceivable to oblige the industry to make a significant contribution, for instance by introducing some form of insurance premium or by selling supply options for times of crisis. If there is no demand for such options, it can be assumed that the expected costs of a possible supply disruption will be lower than the costs of public stockpiling. In this case, the government should refrain from any such undertaking.

The sale of supply options for times of need would have the further advantage of concentrating the costs of public stockpiling on the beneficiaries and not passing them on to society at large. Moreover, the respective demand for such options can indicate which raw materials should be stocked and in what quantity, allowing for needs-based management. In the absence of such a control mechanism, there is a risk that the products in stock may not meet the requirements of the private sector in terms of type, quantity and quality.

If, on the other hand, public stocks were to be sold in situations where prices are only perceived as high, there is a risk that very high or low prices would be misjudged in the respective situation. In the event of prices rising (or falling) any further, this may result in "premature" sales (or stockpiling). Moreover, as in the case of state mining companies, there is a risk of inefficient management, owing to the basic incentive and control problems in state enterprises and organisations.

With a view to the necessarily limited size of such storage units, it is similarly doubtful whether in the medium term, they would have any effect on supply security at all. If storage is possible on a larger scale and the respective storage units are operated by a public company, there is, once again, a considerable risk of strong incentives to deliberately keep supply volumes tight in order to demand high oligopolistic prices. This, in turn, could overcompensate for the short-term improvements in supply security. The various costs would ultimately be borne by taxpayers.

3.3 Resource efficiency

The measures presented so far approach the question of raw material efficiency from the supply side only. However, raw material efficiency must be considered from both the supply and demand side, as well as with regard to the production processes themselves. After all, the dependence on critical resources can also be mitigated by reducing consumption. Efficient raw material production can likewise help to reduce energy and water consumption and other environmental effects.

3.3.1 Exploration, exploitation and processing

As a rule, we exploit those deposits first that yield the raw materials most easily and cost-effectively. As a consequence, the metal content in the exploited deposits will decrease over time and the ores will become more complex in their composition. This, in turn, increases both the technical complexity and the costs of the exploration and exploitation of the raw materials. In order to nevertheless meet the growing demand for high-tech metals in the future, the technical procedures for the exploration and extraction of raw materials must evolve continuously – for obvious reasons: For one thing, raw material deposits that are difficult to access frequently require the use of new production technologies. Raw materials from marine mining (marine raw materials) and other deposits at great depths are cases in point: Suitable technologies for their exploitation remain to be developed and tested. For another thing, the increasing costs associated with poorer deposits can only be countervailed by continuously improving the production technologies. Without perpetual technical optimisation efforts, it would have been impossible to keep the real prices of many commodities at a roughly constant level over the last hundred years.[155]

Also with regard to environmental compatibility, technical processes must be continuously developed. The more fine-grained and complex the ores are, the more energy is required for their processing. Without technical advances, the energy demand would continue to rise where there is no choice but to resort to increasingly poor deposits. Mining already accounts for about eight percent of global energy demand and carbon emissions.[156] High energy consumption and carbon emissions rates for the extraction of metallic raw materials will not least relativise the advantage of the "green technologies" produced with these metals. In other words, the more energy-intensive the raw material production at the beginning of the production chain, the smaller the environmental advantage of the renewable energy plant.

Sustainable mining also includes provisions for the time after the mine is shut down. It should be ensured that healthy ecosystems can be reestablished, that the land is usable again, and that no dangers arise from the abandoned mine. Since this has not always been the case in the past, it is also necessary to repair any existing mining damages. An exemplary elimination of the traces of mining can contribute to enhancing the social acceptance of mining projects ("social license to operate").

Since the metals are usually mined outside Germany, the environmental impacts often affect other countries. If, for instance, the exploitation of rare earths in China for use in wind power plants in Germany results in massive environmental damage in China, this will greatly reduce the environmental benefits of the turbines.[157] The same applies to other regions where simple and energy-intensive technologies are used to extract raw materials subsequently used in the western industrialised countries.

155 Angerer et al. 2016, Fig. 3.2.2; Wellmer et al. 2018.

156 Angerer et al. 2016; Wellmer et al. 2018.

157 Yang et al. 2013.

Policy options for a more cost-efficient and environmentally compatible raw material production include the promotion of **research and development** for more efficient technologies. On the other hand, political efforts can help to ensure that **efficient technologies are used worldwide**.

The depths of the earth harbour the greatest potential for new deposits. **New exploration techniques** can contribute to their development. For deposits very deep down, systems have been developed that enable electromagnetic signals to penetrate a depth of several hundred meters (e. g. audio frequency magnetics). These state-of-the-art methods allow for the penetration of depths of around 600 meters. In the future, the signals will be able to penetrate rock layers up to 1,000 meters beneath the ground.[158]

Like other industrial sectors, mining has begun to resort more frequently to **robotisation and connectivity**. This can save costs.[159] In the future, the increased use of remote-controlled mining machinery could enable us to access areas that would be too dangerous for humans to penetrate. Some experts expect the mines of the future to be virtually invisible on the surface, fully automatic, highly efficient, environmentally friendly and operate without human presence.[160]

The **consumption of fresh water** can be reduced by using brackish or salty water. The climate footprint of mining companies could be improved by adapting production to the fluctuating power supply of the sun and wind. Companies could, for instance, specifically use cheap surplus power from wind and solar sources in order to process ores with particularly low metal content.[161]

Via bilateral development cooperation structures, Germany could contribute to promoting more energy-efficient and ecological mining around the world. The aim is for Germany to serve as an example at the global level and to provide technological support in partner countries, for instance by promoting energy efficiency measures in the mining industry.

Various measures to increase efficiency in the fields of exploration, extraction, processing and recovery of raw materials are already listed in the context of the research funding programme *F4 Innovative Technologies for Resource Efficiency – Research on the Provision of Raw Materials of Strategic Economic Importance* and *in the High-Tech-Strategy*[162] of the Federal Ministry of Education and Research. This shows efficient raw material extraction to be not only a technical but also a crucial political issue. Due to the increasing demand for raw materials, resource efficiency will gain in importance. Here, public policies can make an important contribution. They can promote the development of energy-efficient and environmentally friendly technologies and foster their international use. This could minimise the environmental impacts of mining, especially in developing countries.

158 Angerer et al. 2016; Wellmer et al. 2018.

159 McKinsey 2015-2.

160 Lieberwirth, 2015; Arvidsson 2005. In the fluorspar mine Niederschlag, a large part of the processing is already done underground (Saxon Mining Authority 2014).

161 Many opencast mines are already operating two stockpiles of different qualities to be able to react to fluctuating raw materials prices.

162 BMBF 2012.

3.3.2 Use in industry and households

On the user side, raw material efficiency can be increased in basically two areas: on the one hand, on the side of the final consumers, whose purchasing decisions determine the demand for various appliances (e.g. cars, mobile phones). On the other hand, in industry, since the production methods bear upon the amount of raw materials required for the manufacture of the appliances.

In industry, the most promising steps are technical measures to increase material efficiency, and substitution measures. The term "material efficiency" refers to an efficient (economical) ratio between the material used for a product and its benefits in the product. In the case of substitution, one material or element is replaced by another (material substitution). One possible reason for such a replacement could be that certain materials are more expensive or difficult to obtain. In certain components, for instance, the automotive industry replaces permanent magnets containing rare earths (neodymium-iron-boron compound) with ferrite magnets. While these are less efficient, they do not require any rare earths.[163]

The influence of private consumers on raw material requirements is above all a social problem. As a rule, every consumer uses a variety of electrical and electronic devices containing numerous metallic raw materials. Current consumption patterns have the effect of continuously shortening the life cycle of electrical appliances.[164] By changing his or her consumer habits, everyone can contribute to a more economical use of raw materials (buying fewer devices, choosing more resource-efficient and easily recyclable technologies, using devices until the end of their life or, possibly, having them repaired[165], giving away or selling still functional devices).

Policy makers can resort to various instruments to promote sustainable consumer behaviour. These include information campaigns, interventions in the choice of architecture[166], influences on product prices (for example by means of taxes) and regulatory measures, i.e. prohibitions or directives.[167]

One "hard" option the government could resort to in order make the use of raw materials more efficient is a **resource tax**. Both in academia[168] and politics[169], this idea has its supporters and is regularly discussed. The aim is to stabilise prices and reduce the overall consumption of resources in the industry by taxing the energy and primary resources at a certain percentage. This is to contribute to protecting the environment while also creating incentives for the development of a more advanced recycling system.

A further argument for a resource tax stresses the fact that raw materials prices do not reflect the environmental costs; according to this reasoning, prices are lower than the actual costs imposed on the overall economy by the production and utilisation of raw materials. A raw materials tax could compensate for these external costs.[170] For this reason, countries such as the United Kingdom, Denmark and Sweden

163 ERECON 2015, p. 26.

164 This effect is amplified not only by consumption patterns propagated in the media, but also by a production culture putting quantity before long-lasting quality. Time and again, this is punctuated by the allegation of "planned obsolescence", which accuses industry of deliberately incorporating material-specific weaknesses into their products in order to expedite their collapse and replacement (UBA 2016).

165 Concepts such as the "fairphone", which strives for the most transparent manufacturing processes possible and allows for the modular replacement of the installed components, are good approaches towards improving the material input and extending the life of electronic devices.

166 An example of a choice architecture fostering recycling is collection containers in places consumers will regularly frequent, such as drugstores, supermarkets or bakeries.

167 An overview of various consumer policy measures in the context of the energy transition is given by Renn 2015.

168 Weizsäcker 2016.

169 Bündnis 90/Die Grünen 2015.

170 Meyer 2012.

impose resource taxes on primary construction materials. Together with other policy measures, these taxes have contributed to increasing the use of recycled construction materials.[171]

However, it should be borne in mind that there is a hierarchy regarding the value of raw materials. For the energy transition, energy resources are rated higher than bulk raw materials for the construction industry. Consequently, a tax on construction materials ranging at the end of the hierarchy could negatively affect the insulation level of buildings, since the gain due to energy savings would be reduced if insulation is more expensive. In the worst case, the tax can result in construction materials being substituted for the enhanced use of energy resources. This would be counterproductive in terms of climate protection. Whether this case would, indeed, occur, depends not least on the applicable construction requirements.

While the objective of a less resource-dependent economy is, as such, desirable, the actual steering effect a resource tax would have in the field of metallic raw materials is controversial. In principle, commodity prices evolve cyclically, which means that after a certain period of time prices will invariably rise and fall (price volatility). Hence, if a resource tax is to stabilise prices, it has to take into account the entire range of price fluctuations. So far, however, all price stabilisation measures on the commodity market (for instance the Tin or Rubber Agreements[172]) have failed. Even the idea of using the *Integrated Programme for Commodities* of the United Nations Conference on Trade and Development as a framework for the attempt to stabilise the prices of a number of raw materials was not pursued after the failure of the Tin Agreement in 1985.[173]

Experience has also shown that significant breakthroughs in material savings are mostly achieved in times of very high raw materials prices, such as the 2010/11 peak in rare earths prices. A "moderate" taxation of resources would therefore probably not result in a significant savings effect.[174] A tax high enough to incentivise resource efficiency even in periods of low market prices would, however, constitute a very heavy burden for the economy, particularly in times of high market prices.

If the primary aim of the tax is to compensate for the environmental costs of raw material extraction, a tax imposed per tonne of raw material would not be the point, for the environmental consequences of the extraction of a raw material can differ considerably from mine to mine.

Also, a resource tax would have to be levied globally to avoid disadvantages for individual nations, especially export-oriented countries like Germany. Given the diverging interests between developing countries, emerging economies and industrialised nations, and unclear responsibilities at the international level, an agreement on a global resource tax is, at present, unlikely.

171 Meyer 2012.

172 In these agreements, attempts were made to stabilise prices via export quotas and a stockpile, which was to buy and sell anticyclically (Gocht 1983, pp. 168–175).

173 Gocht et al. 1988, pp. 198–200.

174 In the case of petrol, for instance, it could, at least "for longer periods and time series […], not be proved that the price has a significant influence on the fuel demand" (Hautzinger/Mayer 2004, p. 177).

3.4 International resource policy

An international resource policy pursues two main objectives:

- to support a country's own raw materials consuming industry in securing raw materials abroad as well as
- to improve the global framework conditions by creating open and transparent markets and establishing consistently high environmental and social standards for the mining and processing of raw materials.

These objectives can be approached at a bilateral, multilateral, or even global level.

3.4.1 Global Approaches

For Germany as a raw materials importer, the decisive point with regard to environmentally and socially acceptable raw material production is the conditions abroad. In the past, many regulatory options have been considered at the multilateral level that might contribute to a better, fairer and more sustainable handling of raw materials. These include:

- **Control by international expert committees:** e.g. the International Resource Panel of the United Nations Environment Programme (2007)
- **Development of global raw materials legislation:** e.g. redesign of the World Trade Organisation (WTO) agreements, the regulation of "Common Pool Resources" (2005), the supraregional regulation of the use of resources (International Institute for Sustainable Development)
- **Sustainability strategies:** e.g. Sustainable Development Roadmap for the WTO (2009)
- **Global resource management:** e.g. in the form of an international metal covenant[175] on "materials stewardship"[176]
- **Global environmental and social standards in the raw materials industry:** e.g. the International Council on Mining and Metals (ICMM) (2001)
- **Control through transparency:** e.g. Extractive Industries Transparency Initiative (EITI) (2002); "Publish What You Pay" (2002)

Given the high economic importance of raw materials for both producing and importing countries, a global agreement on their handling and uniformly high environmental and social standards would certainly be highly desirable. However, the attempts at a global resource policy have so far proved to be more or less impracticable. In view of the various and currently incompatible interests of states and companies and in the absence of a global supranational legislative and supervisory body, there is no chance of a global resource policy in the foreseeable future.

At the EU level, the interests of the member states are likewise too heterogeneous. Since the member states and their respective companies are competitors on the commodity markets, a coordinated policy approach for a common raw materials management is difficult to realise. Although a European raw materials strategy and various initiatives and individual measures were launched in recent years[177], a common European raw materials policy is not to be expected in the near future.

175 Covenants are private contracts concluded between public authorities and the raw materials processing industry. In addition to binding targets negotiated between the parties, they contain sanctioning mechanisms in case objectives fail to be achieved, as well as options for the adaptation of the content should the framework conditions change.

176 Bleischwitz 2009, p. 154.

177 EC 2008; EC 2010; EC 2011; EC 2014-5.

Within the framework of EU trade policy, Germany is committed to removing trade barriers and competitive distortions – both at the bilateral and multilateral level. Via the World Trade Organisation, for instance, legal actions were successfully brought against China for its discriminatory export policy on metallic raw materials.[178] However, the dispute settlement procedures at the WTO are lengthy and, even in the case of success, insufficiently effective as legal safeguards for foreign raw material projects. Nevertheless, as an accompanying framework, multilateral agreements are still important. They epitomise the long-term objective of a fair and sustainable handling of raw materials around the world. In this context, it would be particularly useful to expand the continuous monitoring of global distortions of competition already rudimentarily conducted by the OECD and the EU.

3.4.2 Bilateral approaches

A less comprehensive but more practical approach is **bilateral raw materials agreements and resource partnerships** as an element of national resource policy. Bilateral agreements can ease the access to foreign deposits for industry and help to obtain sufficient quantities of necessary raw materials at affordable prices. Being more quickly implementable than larger multilateral agreements, they tend to be more promising in the short to medium term. In addition to stabilising their raw material supply relations, participating countries can pursue further common objectives, for instance job security, resource and climate protection and raw material efficiency. However, bilateral resource partnerships are, as a rule, only suitable for countries with certain interests in common, as the agreements are otherwise difficult to implement.

178 WTO 2014.

Germany has already concluded three bilateral resource partnerships (Mongolia 2011, Kazakhstan 2012, Peru 2014) and one cooperation agreement (Chile 2013). The resource partnerships endeavour to secure raw materials from the partner countries for the German economy while at the same time strengthening cooperation in the industrial and technology sectors. The establishment of sustainable environmental and social standards in the partner countries is a further objective.

However, such contractual agreements are not always easy to implement, as the 2011 raw materials agreement with Mongolia[179] has proved. So far, German companies have not made any major investments in the Mongolian mining sector – nor is this to be expected in the future: For one thing, the basic political and legal conditions for foreign companies continue to be unfavourable (legal uncertainty, inefficient bureaucracy, special regulations for foreign experts[180]) For another, Mongolia has a poor infrastructure and is situated a great distance from any harbours. All of these are obstacles to the production and trade of raw materials.

Raw materials agreements can only ever be an accompanying offer of support for the industry; the negotiation of specific supply contracts and conditions remains up to the companies. If government measures are to have an effect, they must be accepted by the industry. This requires that the industry is generally prepared to assume an active role in the securing of resources. In addition, the raw materials agreements must be tailored to the needs of the companies.

179 Raw Materials Agreement Mongolia 2011.

180 According to Article 43.1 of the Minerals Law of Mongolia (version from 30 October 2006), a company registered in Mongolia may not employ more than ten percent of foreign workers. If this rate is exceeded, the company is obliged to pay the tenfold monthly minimum wage to the state per month and additional foreign employee (The Minerals Law of Mongolia 2006).

3.4.3 Central contact for raw material issues

The example of Mongolia also shows that the current coordination between the political echelons and industry needs to be improved to ensure that political agreements do not forfeit most of their effectiveness because industry fails to get involved. A **central contact for raw material issues** would be a possibility to focus and coordinate such questions more stringently between politics and the economy. For instance, the **establishment of the post of a state secretary or of a representative for raw material issues at that level** could be considered. This contact person could bring the different political responsibilities together more efficiently than previously and would be in a position to strongly articulate German raw material interests abroad. As a central point of contact, he or she could work towards a closer coordination with both industry and civil society organisations regarding strategic raw material issues as well as environmental and social questions. This could not least strengthen the cooperation between the EU Member States in the field of raw material issues.

3.4.4 Transparency mechanisms

For many resources, the global production and supply chains tend to not be transparent. Especially in the case of raw materials from conflict areas, where armed groups benefit from their production and trade, it is difficult to trace back raw materials to their source and to ascertain under what conditions they were extracted and processed. Companies purchasing their resources from crisis areas thus indirectly support the business dealings of rebels and corrupt governments – at the expense of the local population.

Binding transparency mechanisms are a suitable political instrument to oblige companies to take more responsibility in this question and to uncover trade and production processes. To this end, a number of initiatives[181] have been launched at the international level in the past few years, covering various raw materials and approaching the problem at different levels.

The Dodd-Frank Wall Street Reform and Consumer Protection Act (Dodd-Frank Act), which was adopted in the US in 2010, is currently the most important transparency initiative in the field of metallic raw materials.[182] Article 1502 of the Dodd-Frank Act requires companies listed on the US stock exchange to produce an annual report on whether their products contain "conflict minerals"[183] from the Democratic Republic of the Congo (DRC) and/or the neighbouring countries. The aim is to increase the transparency of the companies' supply chains and to contribute to greater responsibility and diligence in the commodity trade. The risk of damaging their reputation is to induce companies to cease purchasing raw materials from conflict areas in Central Africa. Thus, the financing of armed groups through the illegal minerals trade is to be curbed.

The evaluations of the past results of the Dodd-Frank Act differ. Some consider the law as a positive step, since it has to some degree enhanced the transparency of the global supply chains. Also, the impact of armed groups is said to have been reduced in some mining regions of the DRC, resulting in a partly improved security situ-

181 One of the best known is the *Kimberley process*, launched in 2003 to prevent the trade of so-called "blood diamonds" by means of state-issued certificates of origin. The initiative, which is supported by states, international non-governmental organisations and the diamond industry, claims to cover more than 99 percent of the global rough diamond production (Kimberley Process 2016). However, in recent years, external observers such as the international non-governmental organisation Global Witness have questioned the effectiveness of this system. Besides regulatory gaps, a further problem is that the actual implementation depends too much on participating states, which makes controls by independent bodies difficult (Global Witness 2010; Global Witness 2013).

182 Dodd-Frank Act 2010.

183 According to Article 1502 of the Dodd-Frank Act, the term "conflict minerals" covers columbite, tantalite (niobium tantalum) or coltan, cassiterite (tin), gold, wolframite or their derivatives (Dodd-Frank Act 2010, Article 1502, p. 2218). They are frequently summed up as tantalum, tungsten, tin and gold.

ation in these regions.[184] However, whether this is solely the merit of the Dodd-Frank Act or is, indeed, the consequence of other factors, cannot be said with certainty. Critics, on the other hand, point out that the law has not yet achieved the intended effect and has even been counterproductive, since foreign companies, concerned for their reputations, bought less resources from the DRC, which resulted in many Congolese losing their jobs in the mining industry.[185] They assert, moreover, that the companies' documentation of the origin of the raw materials in their products is still unsatisfactory.[186] Although the Dodd-Frank Act is an important first step, it will take a few more years to gauge and evaluate its effect with more accuracy.

The EU is likewise endeavouring to make the import of certain minerals and metals[187] from so-called "conflict-affected and high-risk areas"[188] more transparent and to subject the transactions to certification. To this end, the EU administration has elaborated a set of standardised rules for the respective European companies. Like the Dodd-Frank Act, this aims at preventing armed groups from conducting illegal raw material business while enforcing more diligence[189] and transparency in the import of raw materials. The regulation requires importers of tantalum, tungsten, tin and gold to exercise due diligence for their supply chains based on the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas.

184 Dranginis 2016.
185 Wolfe 2015.
186 Wipperfürth 2015.

187 EC 2014-4.
188 According to the EU Commission, conflict-affected and high-risk areas are defined as "areas in a state of armed conflict, fragile post-conflict areas, as well as areas witnessing weak or non-existing governance and security". Unlike the Dodd-Frank Act, the geographic scope of which is limited to the DRC and its neighbouring countries, the EU draft applies to all conflict areas worldwide (EC 2014-3, p. 13).
189 The due diligence requirements are based on the Due Diligence Guidance of the Organisation for Economic Cooperation and Development (OECD 2013).

Transparency initiatives	Year	Objectives
International Council of Mining & Metals	2001	Improve sustainability in the mining and metals industries
Extractive Industries Transparency Initiative	2002	Increase the transparency of international financial transactions of countries and companies in the commodity sector*
Kimberley Process	2003	Stop the rough diamond trade by means of state-issued certificates of origin
Conflict-Free Sourcing Initiative/ Conflict-Free Smelter Program	2008	Information for companies on metal smelters processing "conflict-free" raw materials
Dodd-Frank Act, Articel 1502	2010	Reduce the illicit trade with conflict minerals of armed groups by obliging companies to disclose the origin of their resources
Aluminium Stewardship Initiative	2012	Increase transparency and sustainability in the aluminium industry
EU Conflict Minerals Regulation	2017	Increase the transparency of the supply chains of European companies by certifying raw materials imports from high-risk and conflict-affected areas

Table 1: Examples of existing transparency initiatives in the commodity sector[190]
* Germany applied for an EITI membership in December 2015 (BMWi 2015-2).

190 A more detailed overview of transparency initiatives can be found in Angerer et al. 2016, Fig. 3.19 and Wellmer et al. 2018.

The obligations covers importers of ore, concentrates and metals with imports above threshold values defined for each category of the respective minerals or metals. The regulation will directly apply to between 600 and 1,000 EU importers. It will indirectly affect about 500 smelters and refiners of tin, tantalum, tungsten and gold, whether they are based inside the EU or not. The EU Conflict Minerals Regulation was adopted in 2017 and will take effect in 2021.[191]

While both the EU regulation and the Dodd-Frank Act aim primarily at limiting the financing of armed groups out of the raw materials trade, the International Council of Mining & Metals endeavours to improve the environmental and social standards in the mining and metals industry. The ICMM is an association of large international mining companies. About 30 to 40 percent of the worldwide production, excluding China, is mined in accordance with its standards.[192]

As the experience with existing initiatives shows, a consistent implementation is of crucial importance. Not until the regulations are legally binding and possible loopholes have been closed and compliance is monitored – with sanctions imposed in the event of non-compliance – can such initiatives have the desired effect in the medium to long term. In the case of voluntary commitments, the standards risk being diluted, undermined or completely disregarded. Sanctions can range from reputational damages to fines or import bans. An effective monitoring can only be ensured by an independent auditor. By including non-governmental organisations and social stakeholders, a broader and socially more legitimised basis can be assured on which to enforce the standards.

However, when introducing transparency mechanisms, the costs and possible side effects must also be taken into account. The implementation costs vary according to the effort involved. Especially for small- and medium-sized mining companies, the realisation of transparency mechanisms often presents a major financial challenge. However, it is precisely the medium-sized or small mining companies accounting for only a small share of global production that frequently cause disproportionately large environmental damage because they do not adhere to standards.[193] Possible negative impacts on the local value creation in mining regions, such as the loss of jobs described in the context of the Dodd-Frank index, should, if possible, be assessed beforehand, in order to find ways to mitigate the consequences.

191 EC 2017.

192 Angerer et al. 2016; Wellmer et al. 2018.

193 Angerer et al. 2016; Wellmer et al. 2018.

4 Policy options: Energy resources

Even if the rapid expansion of power generation from wind and photovoltaics is continued, Germany will, in the short to medium term, require combustion power plants in order to ensure a secure power supply. As long as there are no long-term storage systems for electricity, combustion power plants are the only available technology able to bridge several weeks of little wind and solar radiation. In the future, however, these power plants will run for less hours at full load, viz. consume less fuel. In the heat and mobility sector, the bulk of the energy is likewise currently generated from fuels. In addition to fossil fuels, bioenergy is increasingly being used.

4.1 Biomass as a source of energy

Combustibles and fuels from biomass[194] have a relatively high energy density[195] and are, unlike wind and solar energy, easily storable. They can be used flexibly for all sectors, i.e. electricity, heat and transport. In Germany, they account for about 5 percent of the fuel consumed in the transport sector, for about 10 percent of the heat consumption, and for roughly 7 percent of gross electricity generation.[196] The global energy supply presents a similar picture.[197] Since biomass can be either grown in Germany or imported from a variety of countries, it can contribute to diversifying fuel sources and thus enhance supply security.

In order to reach its long-term climate objectives, Germany continues to include bioenergy in its energy mix. According to the Federal Government's 2010 Energy Concept, bioenergy will play an important role for the future energy supply; its use is hence to be expanded in the heat, electricity and fuels sectors. This point of view is reflected in practically all current energy scenarios: It is generally assumed that bioenergy will play a similar role for power generation in 2050 as it does today.[198] In the transport sector, the exclusion of bioenergy would hamper the transition to renewable energy sources even more than it would in power generation[199] – at least if we fail to reduce the greenhouse gas (GHG) emissions in transportation by other measures (such as the expansion of the public transport system). However, it should be borne in mind that biofuels tend to have a less favourable greenhouse gas balance than other biogenic energy sources.[200]

194 These include gaseous and liquid fuels such as biogas, biodiesel and bioethanol from maize or rape seed as well as solid combustibles (e.g. wood).

195 In other words, they have a high energy content per kilogramme or cubic meter, thus providing "compact" energy.

196 AEE 2014-2.

197 IEA 2014.

198 In 62 scenarios analysed, the share of bioenergy assumed for the German power supply in 2050 ranges between twelve and eighty terawatt hours (equating to between 2 and 14 percent of the power consumption). In 2013, the share amounted to 48 terawatt hours (8 percent) (Elsner et al 2015).

199 Cf. e.g. Henning/Palzer 2015; Gerhardt et al. 2015.

200 Creutzig et al. 2015; WBGU 2009.

However, there are a number of disadvantages to the energetic use of biomass to be considered:

- Biomass is also required as food and feed, as well as for material uses, i.e. the production of plastics, building materials and chemicals. However, the potential of biomass is limited, since it requires available cropland, a certain soil quality and sufficient water and nutrients. Consequently, there are frequently competing uses.[201]

- Only under certain circumstances is biomass a carbon neutral energy source: Either the biomass is obtained from additional and sustainably managed plant growth, or the biomass in question would otherwise (i.e. if not burned for energy production) be biodegraded.[202] In addition, intensive agriculture[203] produces greenhouse gas emissions (mainly nitrous oxide) and is responsible for biodiversity losses, increased water consumption and water contamination by excess nutrients from fertilisers.[204] The soil quality can likewise deteriorate.[205] A growing demand for bioenergy can further result in the clearing of forests which will inevitably ensure GHG emissions.[206] Figure 4 gives a schematic overview of the flows of carbon and greenhouse gas emission occurring in the life cycle of bioenergy.

- As a rule, bioenergy contributes less to the reduction of greenhouse gases than wind and solar energy.[207] In addition, it usually comes with higher abatement costs[208] per tonne of CO_2.

- Bioenergy has a lower space efficiency rate. The energy yield per hectare of land area is smaller for biomass than for wind and solar energy.[209] As often as not, the energy efficiency is likewise lower.[210]

201 For instance, Lambin/Meyfroidt 2011.

202 Plevin et al. 2010.

203 In intensive agriculture, the harvest yield per land area is maximised, for instance by means of irrigation and the use of mineral fertilisers and plant protection products. Extensive agriculture, on the other hand, affects the ecosystem much less, but implies lower harvest yields per area.

204 Newbold et al. 2015 (biodiversity); Kraxner et al. 2013 (emissions, water, fertilisers and biodiversity); BMUB 2014; UBA 2011; UBA 2014-1.

205 UBA 2011.

206 Searchinger et al. 2008; Fargione et al. 2008; Havlík et al. 2011.

207 Strictly speaking, no type of renewable energy is completely carbon-free as long as the energy required to produce the respective plants is generated from fossil fuels. Power from wind turbines thus accounts for four to eleven grammes of carbon equivalent per kilowatt hour (g/kWh), power from photovoltaics for 55 to 63 g/kWh, electricity and heat from wood from about 15 to 25 g/kWh. In the case of bioenergy from agricultural sources, however, the values are usually substantially higher, for example 202 to 472 g/kWh for power from a biogas cogeneration plant fuelled with maize silage (values from Fritsche 2013, UBA 2014-2 and Ökoinstitut 2010). To put these values in perspective: A modern natural gas-fired power plant produces 350 g carbon emissions/kWh, a lignite power plant about 1000 g/kWh (Schäuble et al., 2014). For the calculation of greenhouse gas emissions, all greenhouse gases are converted into Carbon Equivalent Values. Nitrous oxide (N2O), for instance, has a carbon equivalent of 265. In other words, the greenhouse effect of one kilogramme of nitrous oxide equates to that of 265 kilogrammes of carbon. The nitrous oxide emissions caused by nitrogen fertilisers are one of the reasons for the partly rather poor greenhouse gas balance of agricultural bioenergy.

208 GHG abatement costs are the expenses necessary to save a tonne of CO_2 compared to the existing system or a reference system.

209 Leopoldina 2013, p. 23.

210 The "Energy Return on Investments" (EROI) serves as an indicator for the energy efficiency of energy conversion technologies. It is obtained by dividing the energy generated over the entire service life of a plant by the energy required to build, erect and operate that plant. In other words, the EROI indicates by what factor the energy output exceeds the energy input. In Germany, the EROIs for photovoltaics (EROI = 7) and, above all, for wind power (EROI = 18) and hydroelectric power (EROI = 100) are far superior to that of bioenergy (EROI <5). However, it should be borne in mind that a full power supply from wind and photovoltaics would imply storing some of the electricity in long-term storage systems. Due to the efficiency losses occasioned by the storage, the EROI would drop significantly.

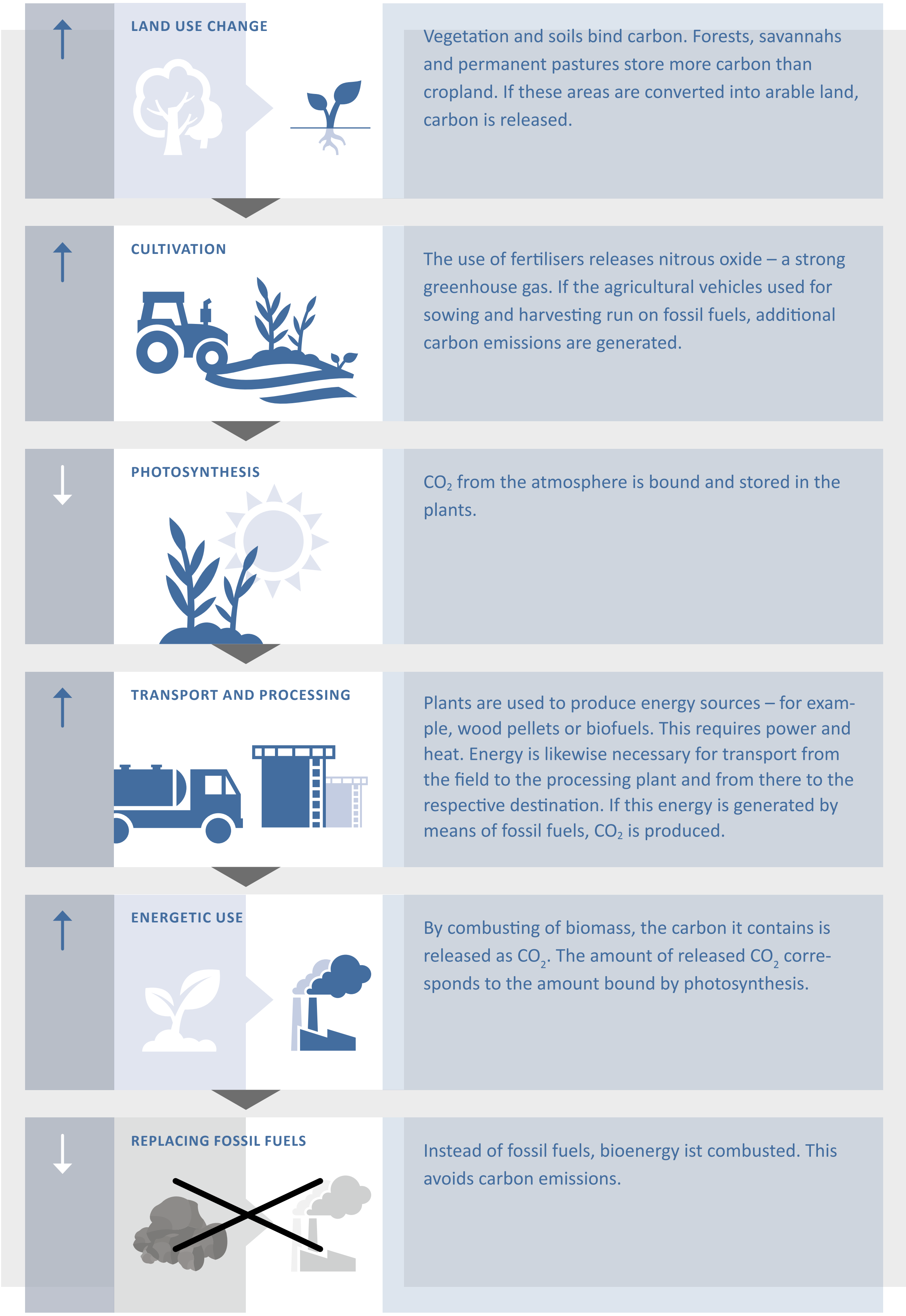

Figure 4: The greenhouse gas balance of bioenergy must take the entire lifecycle into account. Greenhouse gas emissions vary widely and are difficult to gauge. The white arrows indicate that CO_2 is bound, the blue arrows that CO_2 is released.

The estimates as to the global bioenergy potential which can actually be sustainably used differ widely. For 2050, they range from 50 (current bioenergy consumption) to 500 exajoules per annum.[211] The large deviations are due to different assumption regarding, for instance, the increase in crop yields, the land available for agriculture, future technologies and management systems, or the agricultural and animal products required to feed the growing world population.

Agricultural productivity also depends on the availability of plant nutrients and can be considerably increased by fertilisation. Of the fertilisers required, only phosphate is not indefinitely available. If the current consumption level remains constant, the known reserves would suffice for the next three hundred years[212] – although there are also less optimistic estimates.[213]

Due to its high population density and high standard of living, Germany is currently dependant on considerable biomass imports, since its biomass requirements for nutrition, materials use and energy purposes exceed the domestic production by 30 to 40 percent. In other words, Germany is availing itself of large areas of land outside its own borders. It must be noted that importing biomass also means exporting the potential problems associated with its use for energy purposes. About ten percent of the total biomass annually consumed in Germany is used to produce energy. About half of it is wood, the other fifty percent consist of biogas, biodiesel and bioethanol.[214]

In the overall view, we must therefore weigh the positive effects of bioenergy – i. e. replacing fossil resources[215] and contributing to supply security – against possible negative ecological and social consequences. In this context, the public acceptance of bioenergy is of importance. At the local level, for instance, there is less support for biogas plants than for wind and solar power plants.[216] The energetic use of wood from sustainably managed forests or of excess agricultural waste, on the other hand, is generally accepted, since it is usually environmentally- and climate-friendly and does not compete with food production.[217] Nevertheless, using forest wood for energy purposes may to some extent clash with the requirements of nature conservation, such as increasing the share of dead wood and establishing wilderness areas.

In the following section, we will present options for a sustainable provision and use of bioenergy for the energy transition.

4.1.1 Reducing environmental impacts and competition with food crops

Intensive agriculture has made it possible for over seven billion people to live on Earth today. Although there is enough land to feed them all, almost one billion people are currently undernourished. Due to a growing world population and the increasing consumption of meat in developing countries, an adequate food supply for all will not become easier in the future. Globally, the production of agricultural biomass and food production competes for land area. Cultivating energy crops can therefore further aggravate the food situation. Locally, on the other hand, it may likewise be a source of greater prosperity.

211 Smith et al. 2014.

212 Angerer et al. 2016; Wellmer et al. 2018; BGR 2013; USGS 2015; Scholz et al. 2014.

213 Vgl. Leopoldina 2013.

214 Leopoldina 2013.

215 Even if land-use changes and the cultivation (especially fertilisation), harvest and transport of biomass generate GHG emissions, these can be lower than those produced by the combustion of fossil energy sources (Sterner/Fritsche 2011).

216 AEE 2014-1.

217 Forest: Leopoldina 2013; Waste: UBA 2010, p. 56

Intensive agriculture generates considerable greenhouse gas emissions in the form of nitrous oxide and/or methane. In Germany, it accounts for eight percent of all greenhouse gas emissions, worldwide even twenty percent. Forests, on the other hand, will usually reduce emissions. With continued global deforestation, therefore, an annual three gigatons of CO_2 is released into the atmosphere.[218] In addition, intensive agriculture diminishes biodiversity, contaminates water and uses up great quantities of drinking water, draws important carbon from the soils and increases their erosion. Regarding biodiversity losses, our interventions in the nitrogen cycle and the anthropogenic climate change, we have probably already exceeded the limits of the Earth's ecological resilience.[219]

The ecological consequences of intensive agriculture are the same for food and feed production (82 percent of the agricultural land in Germany) as for the cultivation of energy crops (15 percent) such as rape seed or maize. Some of the approaches discussed below explicitly address only the cultivation of energy plants, while others aim at the agricultural sector as a whole. The courses of action presented constitute elements of a more sustainable agriculture, which can be implemented individually and in combination.

Limit state subsidies to bioenergy from waste and sustainably cultivated wood

The easiest option is to subsidise only bioenergy generated from wood from sustainably managed forests, agricultural and animal waste (such as liquid manure[220], manure or food residues) and residues (lignocellulose fractions of plants). Without state subsidies – such as the feed-in tariffs granted by the German Renewable Energy Act (EEG) or legal requirements such as a minimum share of biofuels in the total fuel sales[221], bioenergy from plants such as maize and rapeseed would then no longer be competitive. This would free land for organic farming and would resolve the competition with food crops.

However, what requirements a forest needs to fulfil to be categorised as sustainably managed and what exactly the terms residual and waste materials imply would have to be defined. It should also be taken into account that wood from sustainably managed forests is not necessarily carbon-neutral.[222] Nevertheless, the implementation and monitoring of this course of action would probably be more straightforward than including the agricultural sector in the emissions trading system (cf. below). A limitation of the subsidies would probably be rather easy to incorporate into current German regulations.[223] In the 2014 EEG, this has already been implemented: In contrast to the 2012 EEG, the compensation for the use of the basic material has been abolished for maize, sugar beets and corn. This essentially limits the expansion of bioenergy to plants operated with slurry and waste materials. The EU's sustainability criteria for biofuels likewise stipulate that beyond 2020, only second and third generation biofuels are to be granted state subsidies. These are fuels derived from the cellulose/hemicellulose fractions of plants, agricultural waste or algae.[224]

218 Smith et al. 2014, pp. 819–828.

219 Rockström et al. 2009, p. 32.

220 A stable production of biomethane from slurry and manure requires the addition of a certain amount of plant biomass. An additional advantage of fermenting slurry and manure in a biogas plant is that the use of the fermentation residues as fertiliser produces less GHG emissions than the spreading of non-fermented manure (UBA 2013, Biogasrat 2012).

221 Biofuels Quota Act 2006; 2009 Act amending the subsidy of biofuels.

222 Silviculturally, a forest is sustainably managed when the wood volume does not decrease. However, whether this implies a neutral carbon footprint is currently controversially discussed amongst experts (cf., for example, Bright et al. 2012, Cherubini et al. 2012, Haberl et al., 2013-1, Holtsmark 2013, Schulze et al. 2012).

223 However, an amendment of the German regulations needs to observe the respective EU provisions, including Directive 2009/28/EC (Renewable Energies Directive). It stipulates that Germany cover 10 percent of the energy consumption in transportation and 18 percent of its total energy consumption by renewable energies.

224 EC 2016-2.

However, this measure would severely limit the bioenergy potential. Unless this is compensated for by other renewable energies or a reduction in energy consumption, the use of fossil fuels will be increased. In addition, this course of action offers no incentives to avoid waste along the value chain. On the contrary, the selective subsidisation of bioenergy generated from waste would have the disincentive effect of putting a premium on an inefficient processing of biomass and the ensuing larger amount of waste.

Including the agricultural sector in the emissions trading system

So far, Germany has not included GHG emissions from the agricultural sector in the emissions trading system. This means that, contrary to the intentions of the Kyoto Protocol, agricultural energy crops also remain excluded. Including the agricultural sector would probably be the most effective way to limit greenhouse gas emissions from intensive agriculture. However, according to a study by the Federal Environmental Agency, this would entail "significant challenges in terms of implementation and monitoring"[225] and is therefore not likely to be realised in the short term. The implementation of market-based instruments in agriculture is altogether difficult.[226] If negative repercussions of indirect land use changes are to be avoided, and in the case of a market failure (for instance regarding the financing of innovations), additional instruments will probably be required.

Compared to the existing emissions trading system, which includes large point sources such as power plants and cement factories, the recording of GHG emissions is way more complex in the agricultural sector. It is, for instance, very difficult to quantify emissions from land-use changes and from soils and assign them to a causer, since they tend to occur over a large area and, in some cases, are delayed. Also, the methods used to calculate agricultural emissions differ both in their accuracy and complexity. Whereas, for instance, emissions from livestock farming are estimated on the basis of the number and type of livestock kept, emissions from crop cultivation are gauged according to the amounts of nitrogen fertiliser used and the fertiliser management. Depending on the method, the high accuracy requirements of the existing European emissions trading system are hardly achieved in the agricultural sector.[227] Since the 2013 reform of the EU's Common Agricultural Policy, at least some parameters have been recorded that could be used.[228]

From a macroeconomic point of view, a well-functioning emissions trading system is a dynamic and efficient climate protection measure – in other words, it can achieve the specified emissions targets at minimal costs.[229] This, however, tends to be counteracted by high transaction costs. Since a great number of farms would have to be registered, and monitoring is complex, the transaction costs would be a comparatively greater burden for the farms than for the energy sector and the industry, with smaller farms being, in proportion, more heavily affected than large ones.[230] On the other hand, the largest ten percent of farms alone account for one-third of all agricultural emissions.[231] The bulk of these emissions could hence be saved simply by focussing emissions trading on farms of a certain size.[232]

225 UBA 2013.

226 Grosjean et al. 2016.

227 UBA 2013.

228 EC 2015.

229 acatech 2015, p. 6.

230 UBA 2013.

231 Grosjean et al. 2016.

232 A study by the Federal Environment Agency examines differents methods to include significant agricultural sources of GHG emissions into the emissions trading system, considering their effectiveness, their compatibility with the EU Emissions trading system (ETS) and the respective transaction costs. The study comes to the conclusion that recording the emissions from intensive livestock farming in large farms in detail and assessing the nitrous oxide emissions on the basis of the amounts of fertiliser used are appropriate methods (UBA 2013).

Emissions trading would presumably bring a competitive advantage for, and increase the use of, bioenergy from sustainably managed forests, plant and animal waste and residues vis-à-vis bioenergy from specially cultivated field crops (such as soybeans, maize and rapeseed). It could also trigger a change in farming practices towards cultivation methods with lower greenhouse gas emissions, such as organic farming or precision agriculture.[233] Due to the reduced use of nitrogen fertilisers and pesticides, such production methods would not only contribute to climate protection, but could also help to prevent water pollution and preserve biodiversity. However, these positive side effects will only be achieved if the agricultural sector incentivises other production methods. If, on the other hand, the emissions allowances are purchased from other sectors (e.g. the industrial or energy sector), no such effect will occur. Therefore, it must not be assumed that emissions trading will automatically solve other environmental problems in the agricultural sector.

Less intensive agriculture usually has much lower yields per area.[234] This would mean that, initially, more land area is required for food production, leaving less for the cultivation of bioenergy. However, this is countered by the fact that food of animal origin, the production of which requires significantly more land per calorie[235], is likely to become more expensive due to emissions levies. As a result, the demand could shift towards plant-based foods, which would, in turn, reduce the land requirements for food production altogether. How these opposing effects would altogether affect the availability of land area for bioenergy and the environmental implications of agriculture, is, however, difficult to quantify.

Whether the emissions trading system will ultimately lead to an eco-friendlier agricultural practice, or whether emissions allowances are merely purchased from other sectors, depends on the price of the emissions certificates.[236] In the relevant literature, the estimates as to the costs and potential of greenhouse gas reductions in the agricultural sector differ widely.[237]

Other studies propose to begin with a **separate emissions trading system** for the agricultural sector.[238] From an economic point of view, this would be somewhat less efficient than a combined emissions trading system for all sectors, but it would ensure that the agricultural sector really implements emissions reduction measures (instead of purchasing certificates from other sectors). This would not least entail the above-described positive effects of a less intensive agriculture in terms of biodiversity and water protection. The extra costs would hence come with an additional environmental benefit. However, a separate emissions trading system could also be useful with a view to the “less accurate” recording of emissions. Trade between the two emissions trading systems could be permitted within certain limits and be successively extended until the two systems could finally be merged.[239]

233 Targeted land management, where differences in soil and productivity within a field are considered in sowing, fertilising and the use of plant protection products.

234 In a network of test farms representative for Germany, the yield for wheat from organic farming amounted, for instance, to 3.72 tonnes per hectare in the marketing year 2014/15, while conventional farms harvested an average of 8.38 tonnes per hectare (BMEL 2015, p. 24).

235 For example, the production of protein from meat requires 6 to 17 times as much land as the production of the same amount of soybean protein (Joyce et al 2012). The ratio per food calorie is similar.

236 Since the emissions rate from the agricultural sector is low compared to that of the energy sector, the latter will have more influence on the certificate price. If the GHG reduction costs are higher in agriculture than in other sectors, the tendency would be to buy emissions allowances rather than reduce emissions.

237 Vermont/De Cara 2010.

238 UBA 2013.

239 UBA 2013.

In order to avoid risks of carbon leakage and distortions of competition between domestic (or European) and imported biomass, agricultural emissions should be priced worldwide. Until an emissions trading scheme for agricultural emissions is globally implemented, a suitable mechanism must be devised to take the emissions occasioned by imported biomass in upstream processes into account. This could, for instance, be achieved by certifying imported biomass according to sustainability criteria.

The introduction of an emissions trading system would affect the heavily subsidised agricultural sector in the EU by changes in the income distribution. The farmers' resistance could impede or altogether prevent an implementation. This, of course, depends not least on how the emissions allowances are allocated. A transparent redistribution of the revenues from emissions trading ("revenue recycling") could also serve to counteract unwanted distribution effects.

Sustainability requirements for the cultivation and import of energy plants

A further option to reduce the negative environmental impacts of bioenergy production would be to lay down sustainability criteria. These could include minimum savings in net greenhouse gas emissions compared to fossil fuels, as well as requirements for the conservation of biodiversity or for soil and water protection. Food competition aspects are often omitted in practice.

In the EU, for instance, standards for the sustainability of biofuels and liquid bioenergy sources are already being implemented. State subsidies are subject to a minimum savings of fifty percent of greenhouse gases compared to fossil fuels as of 2017, as well as to requirements for the protection of biodiversity.[240] An unsatisfactory aspect is that greenhouse gas emissions resulting from the indirect effects of land-use changes are not considered.

A comprehensive certification system could cover all biomass products irrespective of their intended use, making both domestic products and imports conditional on specific sustainability criteria. Such a system could also be expedient should a first emissions trading scheme for the agricultural sector be limited to Europe. Alternatively, certification could be confined to biomass and biomass products (bioethanol, biodiesel and biogas) imported for energy purposes.

However, limiting sustainability criteria to Europe involves the risk that biomass produced outside Europe but meeting the sustainability criteria is merely "redirected": If it was previously intended for food and feed production, it would then preferably be used to provide bioenergy for Europe. As a consequence, there would be altogether less biomass available from sustainable crops for food and feed purposes – which would impede the development towards more sustainable global agriculture. A draft amending the EU Directive provides for the prospective inclusion of such "indirect land-use changes" in the sustainability criteria.[241]

As in the case of emissions trading, the principle is: The more countries join the system and the more agricultural products are included, the better carbon leakage can be prevented and the more effective the measure will be – and also the more complex and difficult to implement.

Complementary measures for sustainable agriculture

Besides significant climate impacts due to nitrous oxide emissions, the extensive use of nitrogen fertiliser has numerous other negative environmental consequences (e.g. increased algal growth in waters,

240 Directive 2009/28/EG.

241 EC 2016-2.

pollution of drinking water and hazards to biodiversity).[242] Against this background, further measures (in addition to emissions trading) could be considered to reduce the nitrogen input into the ecosystem. For example, a tax could be imposed on nitrogen surpluses[243] or the nitrogen fertiliser itself. In Sweden and Denmark, a tax on the mineral fertiliser price led to a significant reduction in the use of mineral fertiliser.

In the Netherlands, on the other hand, the **taxation of nitrogen surpluses** proved problematic due to quantification difficulties. This made an extensive monitoring necessary, which involved high administrative costs.[244] Another option would be a **trading system for nitrogen** along the lines of the emissions trading scheme. Such a system has already been applied in New Zealand, where experience has shown the introduction phase to be the most cost-intensive – requiring, for instance, the installation of the monitoring software – with costs subsequently falling to a reasonable level.[245]

In addition to nitrous oxide, agricultural soils can emit considerable amounts of CO_2.[246] This occurs, for example, when grassland is converted into arable land and, above all, when marshland is drained. During these processes, soil carbon is converted into carbon dioxide (and partly also methane). These emissions being very difficult to register, supplementary regulatory measures may be indicated as an additional provision to preserve the function of **soils as carbon sinks**. Such measures could include prohibiting the conversion of marshlands and permanent pastures, or requirements for a climate-friendly cultivation.

4.1.2 Development of additional potential

The options presented until now are aimed at reducing the environmental impacts of biomass production, but tend to reduce the usable potential for bioenergy. In the following section, we present options apt to develop additional bioenergy potential.

Fallow and degraded land for the cultivation of energy crops

Various grasses can also be used as energy crops (for instance chinagras [miscanthus], switchgrass, reed canary grass, sorghum), along with woods such as willow, poplar or eucalyptus, or, indeed, oil plants (e. g. jatropha). If these are cultivated on fallow and degraded[247] land, there is no competition for land for the production of food. However, here too, high yields can only be obtained at the price of intensive fertilisation, with all of the ensuing ecological consequences. Regarding the potential of unused land areas like these, opinions differ widely. Some studies surmise a global potential of up to a hundred exajoules[248], while others consider such estimates to be overrated and perceive a much lower potential.[249]

Degraded areas can also be reforested. Whether the negative GHG balance coming with reforestation contributes more to climate protection than the replacement of fossil fuels with bioenergy must be carefully weighed in each individual case. Often, the two purposes can be combined, for instance when using biomass from sustainable forestry.[250]

242 SRU 2015.

243 The nitrogen surpluses of a farm equate to the difference between the nitrogen brought to the farm by the purchase of fertilisers, feed and livestock and the nitrogen leaving the farm in agricultural products.

244 UBA 2013, p. 32–33.

245 Duhon et al. 2014.

246 In 2010, the global emissions of greenhouse gases other than CO_2 from cropland amounted to at least 1.5 Gt of carbon equivalent. This corresponds to about one third of the overall emissions from the agricultural sector and to three percent of all anthropogenic emissions (Smith et al. 2014).

247 Degraded land is no longer suitable for the cultivation of field crops, the function of the soil being impaired, for example, by erosion, salinisation (as a result of irrigation), machine-induced compaction or pollution. It may, however, still be fit to grow grasses and shrubs.

248 Smith et al. 2014; Nijsen et al. 2012.

249 Baka/Bailis 2014; Baka 2013; Baka 2014; Haberl et al. 2013-2; Haberl 2013.

250 This was, for instance, examined by a Task Force of the International Energy Agency (IEA Bioenergy Task Force 31 2009).

As yet, grasses and woods are used primarily as solid fuels for the generation of power and heat. The currently applied methods do not yet allow for an economical conversion into biofuels and biogas. This also applies to the production of biofuels from algae.[251]

Extending energy generation from waste

In Germany, it is legally prohibited to dump organic waste, which is why we already have specific uses for most biomass waste (e. g. biogas plants, composting). Partly, however, additional bioenergy could be obtained with a cascade utilisation system. For example, after fermenting biowaste in a biogas plant, the fermentation residue can be composted. Thus, a better greenhouse gas balance would be obtained compared to direct composting.[252]

Partly, more straw is left on the fields in Germany than is required to conserve the carbon content of the soils. This could be used energetically.[253] However, straw has a relatively low energy density and unfavourable combustion properties.[254] In most cases, therefore, the production of heat, electricity and fuels such as bioethanol from straw is more complex and expensive than from other biogenic or fossil sources.[255]

Outside Germany, organic waste is still being dumped on a large scale, partly producing significant emissions of the strong greenhouse gas methane.[256] Using this waste for energy could probably increase the potential for bioenergy without negative environmental consequences while also contributing to climate protection by avoiding methane emissions.

Freeing agricultural areas for the cultivation of bioenergy

How much agricultural land is available for energy purposes is mainly determined by the land requirements for food and feed production. This, in turn, depends on agricultural productivity, the losses incurred in the chain from producer to consumer[257], the waste of food in private households[258] and not least on the proportion of food from animal products[259], for which a great deal more land is used than for plant-based products. Measures reducing losses in the food production chain and inducing changes in eating habits (towards less waste and less animal products) can therefore free land areas for organic farming and the cultivation of biomass.

The currently most comprehensive study on food waste estimates that about eleven million tonnes of food are thrown away in Germany every year, about sixty percent of which comes from private households.[260] The Federal Government is determined to halve this amount by 2020.[261] Measures starting at the consumer level[262] can significantly reduce the agricultural land requirements. More robust data and studies, as well as a more effective networking between the relevant stakeholders, would make it easier to assess the success of such measures and to introduce them. For this, the EU initiative Fusions is to lay the foundation.[263]

251 Turkenburg 2012, p. 787.

252 Austrian Environment Agency 2011.

253 The amount of straw that could be sustainably used for energy purposes in Germany is estimated to be between 30 and 50 TWh per annum (Weiser et al. 2014).

254 Kaltschmitt et al. 2009.

255 DBFZ 2011.

256 For instance, in palm oil production (cf. Stichnothe/ Schuchardt 2010).

257 The figures in the relevant literature range from one third (Gustavsson et al., 2011, p. 4) to sixty percent (Lundqvist et al. 2008). This includes all foods that are discarded in storage units, during transportation, by retailers and consumers. Harvest losses and losses occuring in the supply of animal feed are taken into account to varying degrees in the studies.

258 Kranert et al. 2012, p. 204.

259 In Germany, this amounts to about 38 percent (Leopoldina 2013, p. 33).

260 Kranert et al. 2012, p. 204.

261 Federal Government 2016.

262 Campaigns to inform consumers are a common steering mechanism. They are intended to increase the knowledge and appreciation of foodstuffs and thus mitigate their waste. While there are indications as to the effectiveness of such campaigns, we have, as yet, no results from robust empirical studies (Federal Government 2014-2, p. 6).

263 The members include public institutions, research institutions, non-governmental organisations and companies (EU Fusions 2016).

In Germany, about 38 percent of food calories are derived from animal products. Various measures are envisioned to reduce the consumption of animal products. The easiest way would be to include the agricultural sector in the emissions trading system: Owing to the higher rates of carbon emitted in the production of animal-based foods compared to plant-based foods[264], the price of the former would increase. Additionally or alternatively, animal-based foods could be taxed more heavily than plant-based foods.[265] However, taxes have so far not proved a very successful means of influencing eating habits. The rapidly abolished Danish fat tax is a case in point.[266] Information campaigns can likewise contribute to shaping consumer behaviour.[267] The most promising approach to convince consumers to reduce their meat consumption is to present it as a healthier, rather than a more ethical or environmentally friendly lifestyle.[268] So-called "nudges", i.e. measures that change the decision-making structures, can likewise be employed to influence consumer behaviour.[269] Such measures, however, are prone to attract criticism if they are perceived or represented as paternalistic.[270]

Further potential lies in the safety standards for food.[271] Options could include better information on food shelf life and the abolishment of the feed ban on food wastes. National production quotas are likewise considered a promising tool to reduce the production of animal-based food.[272]

4.1.3 Making a more targeted use of the benefits of bioenergy

As discussed above, bioenergy is basically versatile in the three sectors electricity, heat and transport. However, since it can only cover a small portion of the total energy requirement, it should be specifically used where it is most beneficial to the overall system.

A common method for evaluating different utilisation paths consists of ascertaining the amount of GHG-savings compared to the use of fossil energy sources. Various studies have come to the conclusion that the cultivation of wood for power and heat generation avoids the most greenhouse gases per hectare of land, while biofuels have the poorest balance.[273] Bioenergy achieves the greatest emissions reductions in utilisation paths where it replaces very carbon-intensive coal-fired power generation. Such studies, however, usually use the current energy system as a reference, and therefore have a rather short-term perspective.

In the long term, however, the crucial question is how bioenergy can be most effectively used in an energy system dominated by wind and solar energy.[274] The advantage of biomass and biomass-based fuels over power generated from photovoltaics and wind turbines is that they can be stored relatively easily, in large quantities

264 WWF 2012 provides an overview of the carbon emissions in the context of food production.

265 For example, it was recommended to abolish the reduced VAT on meat, eggs and dairy products (SRU 2015).

266 Reisch et al. 2013, p. 20.

267 Chatham House 2014.

268 Joyce et al. 2012, p. 5.

269 Placing vegetables or salad prominently in canteens measurably increases their consumption (Reisch et al. 2013, p. 16), while a simple means, such as smaller plates at buffets, reduces the food residues (in a project in Denmark by 26 percent, cf. iNudgeyou 2016). Another effective measure is for public institutions to set a good example, for instance by large-scale purchases of groceries with a lower share of animal-based products (Reisch et al., 2013, p. 21).

270 For example, the call for a weekly "Veggie Day" was strongly criticised during the 2013 Federal election campaign in Germany, although a study in six EU countries shows the majority of people to be supportive of a meat-free day (Reisch/Sunstein 2016).

271 Reisch et al. 2013, p. 21.

272 Reisch et al. 2013, p. 20.

273 Osterburg et al. 2009, p. 95; Sterner/Fritsche 2011.

274 Most current energy scenarios assume that wind and photovoltaics will be covering the bulk of power generation in Germany, since they are the most cost-effective and technically advanced renewable energies (Elsner et al., 2015).

and with a high energy density for later use. Storable energy sources with a high energy density are required, for instance, as fuel for aeroplanes, lorries and freight ships, which will hardly be operable with electricity in the near future. However, they are also required to generate electricity during periods when the sun does not shine (power from photovoltaics) or the wind does not blow (power from wind turbines) – if no conventional power plants are to be kept at readiness. Against this background, it would be advisable to prospectively put a stop to the continuous power-generation from biogas currently practised in most of the over 8,000 plants in Germany.[275]

Bioenergy has another advantage over other renewable energies: In combination with carbon capture and storage technology (CCS) it can remove emissions from the atmosphere. Plants absorb CO_2 and convert it into energy-rich carbon compounds. When these are combusted in the power plant, the resulting carbon is separated and stored underground. Since the carbon concentration in the atmosphere has already risen significantly, ambitious climate protection targets will not be achieved unless the carbon concentration is lowered again.[276] Here, **bioenergy with CCS** (BECCS) could make a contribution.[277]

Carbon could likewise be removed from the atmosphere by means of large-scale reforestation, which, under current conditions, is more cost-effective than BECCS.[278] However, the available land area is limited and opposing biophysical effects (such as changes in the albedo[279]) must also be taken into account. In the long term, therefore, a climate protection strategy resorting both to reforestation and BECCS could achieve a higher carbon savings rate than reforestation alone.[280] There are other ways to remove carbon from the atmosphere besides BECCS and afforestation, but they are, for the most part, still inadequately researched or have significantly lower potential.[281]

4.1.4 Recycling of phosphates as fertilisers and feed additives

Of the three essential main fertilisers nitrogen, potassium and phosphorus, only phosphate deposits are limited in the long term.[282] Still, until 2050 and beyond, no bottlenecks are expected for the raw material phosphorus – provided all sources are used.[283] However, Germany has no phosphate deposits of its own. About half of the phosphate currently used as agricultural fertiliser comes in the form of slurry and manure, and the other half needs to be imported. Phosphate is not only used as fertiliser; larger quantities are also required as an additive to animal feed. Since there are hardly any phosphate deposits in the rest of Europe either, phosphorus is classified as one of the twenty critical raw materials for the EU[284] – albeit only for the future.

In order to enable an early detection of bottlenecks in the phosphate supply from deposits, a **monitoring procedure** could be established. To this end, a standing committee could be set up at the international level.[285]

275 Leopoldina 2013, p. 25 sq.

276 Fuss et al. 2014.

277 Smith et al. 2014.

278 Humpenöder et al. 2014.

279 The albedo is a measuring unit for the reflective power of diffusely reflective, i.e. non-luminescent surfaces.

280 If large amounts of carbon need to be removed from the atmosphere over a long period of time, it should also be considered that avoiding the equal amount of carbon emissions by means of afforestation would require larger land areas than BECCS (Smith et al. 2015).

281 An overview is given by Smith et al. 2015.

282 Basically, nitrogen and potassium are available indefinitely, since bio-available nitrogen compounds can be produced from atmospheric nitrogen via the Haber-Bosch process, and potassium can be extracted not only from extensive geological deposits but also from seawater.

283 Angerer et al. 2016; Wellmer et al. 2018; BGR 2013; USGS 2015; Scholz et al. 2014.

284 Cf. section 2.6.2.

285 Wellmer/Scholz 2015.

The development of recycling structures for phosphate could reduce the dependency on imports and ease the pressure on the limited deposits. There are already promising approaches, for instance the recovery of phosphate from sewage sludge. Both the methods for removal of contaminants and yields have already been improved in recent years, but there is still a need for further research and development.[286] In addition to **technical recovery processes**, the introduction of efficient phosphate cycles also requires better knowledge of the use plants make of phosphorus.[287]

4.2 Fossil energy resources

At present, more than 80 percent of primary energy consumption is covered by the fossil energy sources oil, natural gas and coal.[288] This is also the case in Germany.[289] According to estimates by the International Energy Agency (IEA), energy consumption will increase until 2040, although the growth will not take place in Western Europe, but mainly in China and various emerging countries.

The bulk of global greenhouse gas emissions is due to the combustion of fossil fuels. In 2014, the energy sector was responsible for around forty percent of all German greenhouse gas emissions, while the transport sector accounted for 18 percent.[290] In order to meet climate protection targets, the use of fossil fuels must be significantly reduced in the coming decades. By 2050, Germany intends to reduce its carbon emissions by 80 to 95 percent compared with 1990.[291] At the EU level, a reduction of 40 percent compared to 1990 is to be achieved by 2030.[292] If these goals are implemented, we can expect the demand for fossil fuels to decrease significantly in the long term.

Coal is available in the long term and is relatively inexpensive. However, it generates more carbon emissions than other fossil fuels. A lignite power plant produces almost three times as much carbon per kilowatt hour of electricity than a natural gas power plant.[293, 294] Gas power plants have the further advantage of being more flexible than coal power plants and are therefore well suited to compensate for the fluctuating feed-in from wind power and photovoltaics. Also, compared to coal, the combustion of natural gas and biogas is much cleaner, but more expensive.

In the case of hard coal, lignite and uranium, the resources and reserves are large enough to guarantee their long-term availability – even should consumption increase.[295] However, owing to the decision to phase out nuclear energy, uranium is no longer important for the German energy supply. While the lignite used in Germany originates from domestic production, the share of domestic hard coal has drastically declined over the last ten years, amounting to less than 13 percent in 2014.[296] With the phasing out of subsidies in 2018, production will be discontinued in Germany.

286 The 2012 Federal Government/Länder working group on waste, for instance, has published an overview of secondary phosphorus sources and their use. For the recovery of phosphorus from sewage sludge, various processes are under development. They are presented in BAM 2014, Doetsch et al. 2010 and Pinnekamp et al. 2011.

287 The phosphorus cycles in forest ecosystems are examined e. g. in the DFG priority programme SPP 1685 – *Ecosystem nutrition: forest strategies for limited phosphorus resources* (University of Freiburg 2016).

288 IEA 2015, p. 6.

289 BMWI 2016-1.

290 BMUB 2015.

291 Federal Government 2010, p. 4.

292 EC 2014-2, p. 5.

293 BMUB 2015, p. 29.

294 To compare electricity generation, also CO_2 from transport of natural gas from the production side to the electricity plant and possible losses have to be taken into account. Lignite is burned close to the mine side.

295 BGR 2015-1.

296 BMWi 2016-2.

In 2014, natural gas from domestic sources covered around ten percent of German consumption, while the rate was only two percent for domestic oil. Oil was mainly imported from Russia, Norway, Great Britain and from politically unstable regions in the Middle East and North Africa. Not only is oil the most expensive energy resource, but it is also subject to strong price fluctuations: Between 2000 and 2008 the price increased more than tenfold. As a rule, such price surges are, however, induced not so much by the costs of exploitation as by political developments; past examples include the Organisation of Petroleum Exporting Countries (OPEC) cutting the supply, the Kuwait crisis or the Iraq war. As regards natural gas, Germany is also dependent on a small number of supplier countries. While today some gas is still purchased from the Netherlands, this source will be lost in the future as reserves are waning. This will increase dependence on imports from Russia.

The current low world market prices for oil and natural gas are largely attributed to the increased production of so-called shale oil and gas in the USA. This is an eloquent example of the radical impact that technical innovations – in this case hydraulic fracturing (fracking) – can have on the raw material supply. However, even if the exploitation of these deposits were to increase significantly, natural gas and petroleum are still scarce raw materials compared to coal.[297] Despite the current price decline, we must therefore expect the prices of oil and natural gas to remain at a high level and even to rise in the long term.

In principle, many of the measures proposed for metals (cf. Chapter 3) can be applied to natural gas, petroleum and coal: In each case, an intimate knowledge of the deposits, market observation, the diversification of supply sources, the mitigation of import dependencies, stockpiling and a more sparing use of the respective resource can contribute to a secure supply. Unlike metals, however, energy resources, once used, cannot be recycled.

The following policy options focus on natural gas, since this raw material has the lowest emissions rate of all fossil energy sources and is hence of particular importance for climate protection and the transition[298] to a sustainable energy system.[299]

4.2.1 Natural gas storage

The easiest way to temporally cushion limited supply bottlenecks and price fluctuations in natural gas is to provide for additional storage facilities. In 2014, Germany's storage capacity for natural gas amounted to some 24 billion cubic meters in 51 underground storage units (each stocking about 50 percent of its contents to cover daily fluctuations, and the other half for seasonal fluctuations).[300] This corresponds to about a quarter of the natural gas consumed in Germany in 2013. According to the planning in 2014, the storage volume could be further expanded, so that around 32 billion cubic meters would be available in the long term.[301]

In 2015, an investigation commission appointed by the Federal Ministry for Economic Affairs came to the conclusion that Germany's supply of natural gas is

297 The total natural gas and oil resources amount to 32,603 exajoules and 18,594 exajoules, respectively (some sixty percent in each case being unconventional), while the coal resources equate to 490,716 exajoules (BGR 2015-1).

298 By switching from coal to natural gas, carbon emissions could be reduced by about 50 percent. To avoid them completely, however, we must resort to renewable energies or the capture and permanent storage (CCS) of the carbon generated during the combustion of fossil fuels. In the long term, therefore, the use of natural gas must also be reduced (unless it is combined with CCS) in order to reach the climate goals.

299 An analysis of possible energy supply systems for 2050 with a carbon reduction of at least 80 percent compared to 1990 shows that in some scenarios, the use of natural gas for power generation could be twice as high as today (acatech/Leopoldina/Akademienunion 2015).

300 LBEG Niedersachsen 2015.

301 BMWi 2014.

generally safe. Should, however, a political conflict with supplier countries coincide with an extreme or permanent cold period, a supply shortage could arise.[302] A government-controlled strategic gas reserve[303] would be an option to avoid bottlenecks even in such critical situations. This could be modelled along the lines of the German National Petroleum Stockpiling Agency[304], which ensures an oil supply for 90 days. Gas traders and domestic natural gas producers would be obliged to maintain appropriate stocks. The Federal Government would only release the reserve if the emergency level were established.[305] However, the increase in supply security would have to be weighed against the cost of introducing such a reserve.

4.2.2 Diversifying the supplier countries for natural gas

One way to diversify the supply sources would be to expand the **pipeline infrastructure** to enable supply relationships with further suppliers in the Middle East and Central Asia. Alternatively, liquefied natural gas (LNG) can be purchased on the world market. Being transported in tankers, it can also be imported from regions without pipeline connections. However, the liquefaction and reconversion processes require a lot of energy. Currently, Germany does not have any LNG terminals to return liquefied gas to a gaseous state. The closest terminals are located in Belgium, the Netherlands and Poland from where the gas would have to be transported by pipeline.[306]

4.2.3 Exploiting unconventional deposits

The extraction of natural gas (as well as oil) from unconventional domestic deposits would likewise increase Germany's independence. "Unconventional" refers to deposits in very dense rock formations (such as shale gas and shale oil), the exploitation of which frequently requires additional technical measures. The best-known case is the hydraulic creation of cracks by means of the **hydraulic fracturing technology** (fracking), which is subject of a controversial public debate. Many citizens oppose fracking as they fear environmental hazards, in particular a possible contamination of the groundwater by the chemicals involved. However, a 2015 position paper by acatech – National Academy of Science and Engineering concludes that scientific and technical facts do not justify a general prohibition of the technology. The procedure must, however, follow strict safety standards, be clearly regulated and comprehensively monitored.[307] Whereas Germany's conventional natural gas reserves are expected to run out in about ten years' time, the production of natural gas could be continued at the current level for decades if shale gas were exploited.[308]

Even with a political decision against the inclusion of shale gas as a regular feature of the energy mix, it could be resorted to as an "emergency reserve" in the event of imminent natural gas shortages. This, however, would require preparatory measures: The deposits would need to be explored and developed to the point that exploitation could be started within a few weeks. Also, the respective legal requirements would have to be created.

There is also the potential for **natural gas from coal seams**, especially in northern North Rhine-Westphalia. However, these deposits require further exploration. In other countries such as Australia and the US, such deposits are already being commercially exploited. The disadvantages include

302 Becker Büttner Held partnership 2015.

303 The gas storage facilities in Germany are operated privately.

304 Further information available at: http://www.ebv-oil.org.

305 Becker Büttner Held partnership 2015, p. 157–173. Alternative options, such as allocating the reserve to the transmission system operator, or storage obligations for market participants, are also discussed in this report.

306 Becker Büttner Held partnership 2015, p. 78.

307 acatech 2015.

308 acatech 2015; BGR 2016.

high water consumption and the generation of large amounts of wastewater.[309]

In the long term, the **methane hydrates**[310] in the deep sea could also gain a growing significance. These deposits are estimated to be very large, even though the exact scope nor the production costs can be quantified. In any case, a profitable exploitation is not yet possible. Onshore, on the other hand, where the gas hydrates occur in permafrost regions with permafrost soils, they are already being exploited. The situation for methane hydrates from the deep sea is comparable to that of marine metallic raw materials (cf. section 3.2.3): The exploration and extraction of raw materials from the deep sea is technically very complex and hence very cost intensive. Economically therefore, the exploitation of methane hydrates would only be viable if the future market price for natural gas is significantly and permanently higher than today. In addition to the development of suitable technologies and the clarification of the economic benefits, there is also a considerable need for research regarding possible environmental impacts. Whether gas from methane hydrates will play any role at all for the energy supply until 2050 is doubtful.

4.2.4 Alternative gaseous energy sources

Another possibility for reducing the dependence on natural gas imports is the production of gaseous energy sources from wind and solar energy surpluses (synthetic gas). The so-called **power-to-gas technology** uses electrolysis to split water into hydrogen and oxygen. The hydrogen can be stored in long-term storage systems to be used for power generation in times of low feed-in rates from wind and solar power plants. Alternatively, it can be employed for heat generation or as fuel in the transport sector.

Small amounts of hydrogen can simply be fed into the natural gas grid. At present, an admixture of five percent is legally permitted. From a technical point of view, the current gas-powered facilities in the industry, small businesses and households could possibly cope with an increase to ten or twenty percent.[311]

If large amounts of synthetic gas are to be used, there are two possibilities: Either the pipelines, storage systems and combustion units are technically adapted so as to allow for the processing of high hydrogen contents or even pure hydrogen, or the hydrogen is further processed into methane (for instance by way of a reaction with carbon dioxide). The latter solution, while coming with a higher energy consumption and increased manufacturing costs, has the advantage that the existing infrastructure for natural gas can be used without restrictions.[312] In order to decide which option is the most suitable, the expenses the necessary infrastructure would incur should be weighed against the costs of processing hydrogen to methane.

The great advantage of synthetic gas from wind and solar power is that it does not generate any carbon emissions. Hence, unlike natural gas, it is not merely a transitional solution on the way towards a carbon-neutral energy supply, but may be expected to constitute an important long-term component of future energy systems.

Biomethane, i. e. biogas refined to natural gas quality, is another possible gaseous energy source. However, the quantity of sustainably usable biomass is limited (cf. section 4.1).

309 IASS 2014.

310 In the case of methane hydrates, methane is embedded in a cage of solidified water. They form under high pressure at low temperature.

311 DVGW 2013; Hüttenrauch/Müller-Syring 2010.

312 Natural gas mainly consists of methane.

5 Conclusion

From a geological point of view, there are sufficient metals and energy resources to implement the energy transition by 2050 – even with global demand increasing. In the case of many economically strategic raw materials, however, we are highly dependent on a very few suppliers on the world market. It is therefore by no means assured that all of the required raw materials will be permanently available on the market at affordable prices. Here, both the political echelons and industry can resort to a variety of measures to increase supply security. A sustainable energy transition likewise requires that the raw materials used for its implementation are produced in an environmentally and socially acceptable manner. The following tables summarise the policy options for a sustainable, secure and affordable raw material supply that are presented in this paper.

The time horizons indicated with regard to the feasibility and effectiveness of the measures are defined as follows: "short-term" refers to a period of one to three years, "medium-term" to a period of three to ten years, and "long-term" to a period of more than ten years.

5.1 Overview of the policy options for metallic raw materials

For the construction of renewable energy plants, smart grids and storage facilities for the future energy system, a wide range of metals is required. Amongst these, the so-called technology and special metals such as copper, cobalt and lithium, the platinum group elements, indium, tellurium, gallium and germanium and the rare earths play an important role. The bulk of these metals has to be imported, since they are not mined in Germany and their recycling rates often remain low. The following policy options are aimed at reducing dependency on imports or securing the supply from abroad in the long term.

Policy option	Aim	Feasibility, opportunities and risks
3.1 Expertise and knowledge transfer		
Development of legislation on raw material deposits obliging companies to disclose certain data	Efficient use of geoscientific data; avoid double work and costs	Infringement of the companies' ownership rights. While the law can be amended in the short term, the effect of data availability on resource availability will only be perceptible in the long term. Can be combined with measures promoting exploration and mining in Germany.
Promote a European knowledge network for raw materials (e.g. EU Minerals Intelligence Network)	Provide an information base for political decision makers and the industry	Competitiveness and inconsistent data standards can impede implementation. Short to medium term. Can be combined with EuroGeoSurveys. Coordination at EU level necessary.
Stronger EU-support of EuroGeoSurveys, the Association of European Geological Surveys and an update of the EU Raw Materials Initiative	Improve an information base for political decision makers and the industry	Competitiveness and inconsistent data standards can impede implementation. Short to medium term. Can be combined with a European knowledge network. Coordination at EU level necessary.
Merger of those geological databases of the Geological Surveys of the German Länder with relevance for raw material issues	Increases the availability and efficient use of data in case of cross-border deposit issues	Federal thinking can impede implementation. Possible in the short term. Coordination required at the Länder level.
Establish an International Study Group for economically strategic high-tech metals	Provide an information base for political decision makers and the industry	Possible lack of cooperation of key stakeholders, especially industry (protection of business secrets). Can be established in the short term, but will only show effects in the medium term.
Strengthen university education and university and non-university research	Develop raw materials expertise in Germany	Cooperation between the Federal government and the Länder is desirable. Effectiveness only in the very long term.
Reinforce the raw materials expertise of the Geological Surveys of the Länder	Explore new raw material potential in Germany	Staff shortage – more personnel required in the field of international commodity questions. Effectiveness only in the medium term. Funding by the Länder governments.
Continue the raw materials monitoring implemented in the coalition agreement for the 18th legislative period	Continuous counselling for stakeholders from politics and the industry regarding price and supply risks on the commodity markets	The Raw Material Monitoring Programme of the DERA is already being expanded and continued.
NOTE short term: 3 – 6 years, medium term: 3 – 10 years, long term: > 10 years		

Policy option	Aim	Feasibility, opportunities and risks
3.2 Supply security		
Development of efficient technical recycling standards for product groups with a particular relevance in terms of resources	High-quality recycling, recovery of high-tech metals	Compulsory technical standards, the registration of all recycling and trading companies as well as certified processing plants is required. Can be implemented in the medium term. If possible, a consistent EU-wide regulation should be the long-term aim. Most effective if high-quality recycling is stipulated and promoted at all process stages (collection, disassembly, preprocessing and metallurgical processing).
Provide the respective authorities with special recycling expertise, by analogy with the expertise held on primary production by the mining authorities	Monitor compliance with recycling standards; define indices for the recyclability of products	The additional bureaucratic effort could imply higher costs. Possible in the medium term. Prerequisite: Development of appropriate standards.
Create consumer-friendly collection systems	Increase the return rates of electronic products in order to recycle more high-tech metals	Not profitable at low commodity prices. A legal framework, comprehensive monitoring and acceptance by manufacturers required. Although regulations can be introduced in the short to medium term, a comprehensive monitoring system and a change in manufacturers' and consumers' basic attitude is more likely to be realised in the medium term. Most effective if high-quality recycling is stipulated and promoted at all process stages (collection, disassembly, preprocessing and metallurgical processing).
Develop leasing- and innovative business models for electronic products	Increase the return rates of electronic products in order to recycle more high-tech metals	A legal framework, comprehensive monitoring and acceptance by manufacturers required. While pilot projects can be introduced in the short term, a widespread use contributing substantially to resource availability is only to be expected in the medium term. Most effective if high-quality recycling is stipulated and promoted at all process stages (collection, disassembly, preprocessing and metallurgical processing).
Reinforce port controls across Europe	Prevent illegal exports of electronic scrap and end-of-life vehicles	EU-wide cooperation and adaptation of the legal framework required. Possible in the short to medium term. Most effective in combination with other measures to prevent illegal exports of electronics scrap and with the introduction and monitoring of technical recycling standards.
Modification of the system of customs tariff numbers so as to allow for the distinction between new and used export goods	Prevent illegal exports of electronic scrap	EU-wide cooperation and adaptation of the legal framework required. Possible in the short to medium term. Most effective in combination with other measures to prevent illegal exports of electronics scrap and with the introduction and monitoring of technical recycling standards.
NOTE short term: 3 – 6 years, medium term: 3 – 10 years, long term: > 10 years		

Policy option	Aim	Feasibility, opportunities and risks
Electronic waste exports only to certified repairers and recycling companies	Prevention of illegal exports of electronic waste	EU-wide cooperation and adaptation of the legal framework required. Possible in the short to medium term. Most effective in combination with other measures to prevent illegal exports of electronics scrap. Prerequisite: introduction of appropriate technical recycling standards.
Improve processes for the processing and metallurgical recovery of complex products and high-tech metals	More comprehensive recovery of high-tech metals	Research funding is already being provided and can be continued without problems. An effect will only be visible in the medium to long term, once investors have been found.
Develop product standards/ labels for a recyclable product design	A more comprehensive recovery of high-tech metals	Acceptance by industry and consumers is questionable. Legal frameworks must be created for a variety of different products and raw material components. A change in manufacturers' and consumers' basic attitude is to be expected in the medium term; also, depending on the life cycle of the products, the raw materials will not be available until after a certain time. Most effective if high-quality recycling is stipulated and promoted at all process stages (collection, disassembly, preparation and metallurgical processing). Leasing and other service-oriented business models ("use instead of own") can contribute decisively to repairable and recyclable products.
Establishment of a state-subsidised German raw materials company, which acts anticyclically and operates internationally	Increase the raw materials base and reduce import dependency; strategically secure a reliable, long-term supply of raw materials for German industry. Model mining companies with high environmental and social standards	The government would have to enter a longer-term financial commitment, irrespective of current commodity prices and the economic situation; high financial risk for the taxpayer; disparity in the interests of government and industry. State companies are often less efficient than private enterprises; high risk that the measure will be economically inefficient.
Maintain the operability of mines by means of state aid (care and maintenance)	Expansion of the domestic raw materials base or – in the case of mines abroad – prevention of oligopolies and monopolies	This constitutes state intervention in the market, which can lead to distortions of competition. Has been successfully used in Austria. High risk that the measure will be economically inefficient.
Research efforts in the field of exploration and processing (for non-ferrous metals, the elements obtained as their by-products, as well as for precious metals), adjusted to the characteristics of deposits in Germany and Europe.	Discovery and exploitation of raw material deposits in Germany and Europe	Relatively easy to implement. In the long term, contribution to supply security. Can be combined with: enhancement of German raw materials expertise; modernisation of the German Raw Material Deposits Act. Raw material mining in Germany risks provoking the resistance of environmental associations and local residents (e. g. citizens' initiatives). Communication and participation possibilities in the planning process can increase acceptance.

NOTE short term: 3 – 6 years, medium term: 3 – 10 years, long term: > 10 years

Policy option	Aim	Feasibility, opportunities and risks
Establishment of a European fund for critical raw materials	Strategically securing a reliable, long-term supply of raw materials for European industry	Heterogeneous interests and unclear responsibilities between EU Member States, European politics and the industry. Realisable in the medium to long term. A concept would have to be developed at the European level.
Intensify research in the field of marine raw materials	Provide information and technical know-how for the subsequent mining and processing, understand environmental consequences	So far, the production costs of marine raw materials are too high compared to the current market prices of the raw materials. Commercial mining would require considerable progress in the exploitation and processing technologies. Very long-term effectiveness. Marine mining would entail high and not exactly predictable costs. Raw materials mining in the deep sea would provoke the resistance of environmental associations.
Creation of financial incentives for the production of marine raw materials	Increase the raw materials base and reduce the import dependency	Due to current commodity prices and the lack of adequate technologies, industry is currently not interested. The government would have to enter a longer-term financial commitment, irrespective of current commodity prices and the economic situation. High financial risk. Raw materials mining in the deep sea would provoke the resistance of environmental associations.
Secure raw material projects abroad against political and economic default risks	Increased supply security for Germany with regard to critical raw materials	Is already being successfully applied. Can be used in the short term.
Exploration funding	Realisation of measures for the production of raw materials	The exploration funding programme, launched in 2013, was discontinued in 2015 due to the lack of interest in industry. The necessary interest from the raw materials consuming industry will happen during high-price phases when it is very expensive to start exploration activities with a high probability of success. Medium to long term effects. Can be combined with: Enhancing raw materials expertise
Create incentives for industry to stockpile critical high-tech metals	Cushion supply bottlenecks	The industry's willingness depends on commodity prices and the level of government funding; high costs. High risk that the measure will be economically inefficient.
Establishment of a public stockpiling system for critical high-tech metals	Cushion supply bottlenecks	High costs. High risk that the measure will be economically inefficient. If raw materials processing companies are compelled to bear a share of the expenses, e. g. by means of insurance premiums or supply options for times of crises, this risk is reduced, as the quantity and type of stored raw materials is determined according to demand.

NOTE short term: 3 – 6 years, medium term: 3 – 10 years, long term: > 10 years

Policy option	Aim	Feasibility, opportunities and risks
3.3 Resource efficiency		
Research and development for the further development of exploration, production and processing	Efficient, environmentally friendly and cost-effective production of raw materials	Realisability depends on the individual technologies. Effectiveness only in the long term once investors have been found.
Foster bilateral technical development cooperation	Establish environmental and social standards, increase administrative efficiency in the management of raw material projects	A long-term implementation of the standards and measures and their practical enforcement are difficult to ensure.
Introduction of a resource tax	More economical use of raw materials	The effectiveness of this measure is doubtful. In order to be neutral in terms of competitiveness, the tax would have to be levied internationally, which is difficult to implement.
3.4 International resource policy		
Implement a global resource governance system	Consistent global environmental and social standards, fairer resource management	Diverging interests between the different nations, unclear responsibilities, intervention in the global commodity markets. There are approaches such as the Extractive Industries Transparency Initiative as well as further approaches for individual raw materials, but their comprehensive international enforcement will only be possible in the long term.
Conclude bilateral raw materials agreements	Ensure access to raw materials, establish environmental and social standards	Depends on the conditions in the respective country. Effectiveness depends on the industry's willingness to invest.
Establishment of a central contact for the German raw materials policy, for example creation of the post of a state secretary or of a representative for raw material issues at that level	Coordination between politics, industry and civil society; better coordination of the raw materials activities in Germany and the EU, higher visibility of German raw materials policies abroad	Fairly easy to implement at short notice. Effects on the availability of raw materials are difficult to assess.
Establish and promote transparency mechanisms in raw materials supply chains	Establish environmental and social standards, prevent the financing of armed conflicts through raw materials	Negative, unintended effects on the local economy are possible, lack of control. Establishing systems without loopholes is difficult. Can be implemented in the medium term.
NOTE short term: 3 – 6 years, medium term: 3 – 10 years, long term: > 10 years		

Table 2: Policy options for metallic raw materials

5.2 Overview of the policy options for energy resources

As a storable renewable energy source, bioenergy can be used flexibly for power and heat generation and as fuel in transportation. However, the cultivation of biomass generates greenhouse gas emissions and other harmful environmental impacts. The primary aim of the policy options presented in this paper is to reduce these undesirable effects.

In the case of the fossil energy sources, the suggested policy options focus on natural gas, since it has the lowest emissions rate of all fossil energy sources and is hence of particular importance for the energy transition.

Many of the options discussed for metallic raw materials – market observation, diversification of supply sources, mitigating the dependency on imports, stockpiling and a more economical use – can also be applied to the fossil energy sources natural gas, petroleum and coal. These options are not repeated in the following table.

Policy option	Aim	Feasibility
4.1 Biomass		
Limit tax incentives to biofuels produced from waste and timber from sustainably managed forests	Avoid food competition and environmental damage caused by the cultivation of energy crops	Can be implemented fairly easily and in the short term. Compliance with EU law must be ensured.
Include the agricultural sector in the emissions trading system	Reduce the greenhouse gas emissions from agriculture	Would involve great efforts, since gauging the emissions from agriculture is complex and opposition from the farmers is to be expected. Possibly, some parameters collected under the EU's Common Agricultural Policy could be used. The optimal solution would be a global system, the implementation of which would, however, be still more complex than a national or EU-wide system. An incremental extension of the emissions trading system would allow for large and easily recordable emissions to be included in the European emissions trading scheme in the medium term. The inclusion of the entire agricultural sector on a global scale would only be possible in the long term. This approach must be coordinated at the EU as well as the global level. Further supplementary measures (e.g. sustainability requirements) can be expedient.
Establishment of sustainability requirements for the cultivation and import of energy plants	Avoid food competition and environmental damage caused by the cultivation of energy crops	The more countries and farm products are involved, the more effective the measures will be – but also the more complex and difficult to implement. Can be started in the medium term and expanded step by step. Directive 2009/28 / EC (Renewable Energy Sources Directive) provides a possible basis for further measures.
NOTE short term: 3 – 6 years, medium term: 3 – 10 years, long term: > 10 years		

Policy option	Aim	Feasibility
Taxation of nitrogen fertilisers or nitrogen surpluses	Reduce greenhouse gas emissions and other environmental consequences of nitrogen fertilisation	Can be implemented fairly easily and in the short term; has already been introduced in other EU countries.
Regulatory measures to preserve carbon-rich soils	Reduce greenhouse gas emissions by preserving the function of soils as carbon sinks.	Can be implemented fairly easily and in the short term
Use of fallow land and degraded land for the cultivation of energy crops	Develop additional potential for sustainable bioenergy that does not compete with other goals such as securing food production	Commercially viable technical processes to produce biogas and biofuels from these plants still need to be developed. The potential of suitable land areas is very controversial. Implementable in the medium to long term. Sustainability criteria (including a clear definition of fallow land) and a corresponding monitoring system should ensure that no greenhouse gas emissions are caused by land-use changes and that existing ecosystems on fallow land sites are not affected.
Expand the energetic use of waste	Develop additional potential for sustainable bioenergy	Depending on the type of waste, there are technical and economic obstacles. Technically realisable in the medium term.
Reduce food waste and the consumption of animal-based foods	Free agricultural areas for bioenergy and reduce the environmental impacts of agriculture	The necessary changes in consumer behaviour will probably only be achieved on a large scale in the long term.
More targeted use of bioenergy	Use the limited bioenergy potential where it is most beneficial to the energy system	Needs-based power generation from biogas can be realised fairly easily and in the short to medium term. The more complex part, however, is the optimal allocation to the electricity, heat and transport sectors. The time horizon for implementation depends on investment cycles and on the infrastructure requirements coming with the respective technologies. Cross-sectoral market-based, technology-neutral instruments such as emissions trading could implicitly lead to an economically reasonable allocation of the existing bioenergy potential. Individual measures in the electricity, heat and transport sectors, on the other hand, should be explicitly coordinated so as to allow for an economically sensible allocation of the potential.
Use of bioenergy in combination with Carbon Capture and Storage	Remove CO_2 from the atmosphere ("negative emissions")	In the long term, this can become an important measure for global climate protection: In view of the steady emissions level, we need to consider options for the removal of CO_2 from the atmosphere. A larger-scale use before 2050 is unlikely, but the necessary technologies and infrastructures would have to be developed in time. In order for the option to be available in the second half of the century, tests would have to be launched in the medium term to check bioenergy technologies with regard to their combinability with CCS, their potential contribution to climate protection and the impact on food security and the environment. Should be combined with measures ensuring that bioenergy is sustainably cultivated, and that food security is not in jeopardy.
NOTE short term: 3 – 6 years, medium term: 3 – 10 years, long term: > 10 years		

Policy option	Aim	Feasibility
Large-scale reforestation measures	Remove CO_2 from the atmosphere ("negative emissions")	Can gain importance as a measure for global climate protection in the medium to long term. In principle, the same considerations and limitations apply as for bioenergy with CCS.
Establishment of an inter-national committee for the monitoring of phosphorus	Continuous control of the development of reserves, resources and geopo-tential	Can be implemented fairly easily in the short to medium term.
Development of technical processes for the recovery of phosphorus	Establish a recycling system for phosphate	Cost-effective technologies must be developed and industrially implemented. Effectiveness only in the medium to long term.
4.2 Fossil energy resources		
Expand natural gas storage facilities	Bridge bottlenecks in the natural gas supply	High costs. Can be implemented in the medium term.
Expand the pipeline and LNG infrastructure for natural gas	Access to additional supplier countries	High costs, possible resistance of environmental associations and residents against infrastructure projects. Realisable in the medium to long term.
Use shale gas	Reduce import depend-ency	Since a majority of the public rejects fracking tech-nology, strong opposition is to be expected. Technically, it could be implemented in the short term.
Increased use of natural gas from coal seams (coal bed methane)	Reduce import depen-dency	Is already being employed. As an extended use would require fracking-technology, resistance is to be expected. A legal framework remains to be created. Technically, it can be implemented in the short term.
Use methane hydrates	Reduce import depen-dency	At present, the production costs for methane hydrates are still too high compared to the current market price for natural gas. For commercial ex-ploitation, significant progress will have to be made in extraction technology. As regards marine methane hydrates, a technology must first to be developed. It is doubtful whether this is realistically achievable before 2050.
Generate gaseous energy sources from wind and solar power (power-to-gas)	Protect the climate; com-pensate for the volatile generation of wind and solar energy	Cost-effective technologies still need to be devel-oped. Can be implemented on a large scale in the medium to long term.
NOTE short term: 3 – 6 years, medium term: 3 – 10 years, long term: > 10 years		

Table 3: Policy options for energy resources

Glossary

By-products
Occurrences of by-product elements are associated with another primary commodity. The ore mineral phases of the primary commodity and the by-product may be closely intergrown, or the by-product element is integrated into the crystal lattice of the primary commodity. The different commodities can often only be separated with significant use of energy. The recovery of the by-product elements is therefore unavoidably coupled with the recovery of the primary commodity, and the by-products are therefore distinguished from commodities that form their own mineral deposits.

Care and Maintenance
A mine maintained on a care-and-maintenance basis is kept in "stand-by mode". Care and maintenance includes the continuous maintenance of the infrastructure of a mine, e. g. pumping systems, water retention, backup and safety operations, as well as exploration works. Thus, the mine could be quickly reopened at a later stage.

Critical elements
In the context of the availability of raw materials, the terms "critical" and "raw materials of strategic economic importance" frequently appear. "Critical" does not refer to the respective raw material itself or to the amount of the existing reserves or resources, but to the availability of the raw material and its importance for the economy. Important factors include the source countries and their political stability as well as possible supply concentrations. The environmental impacts of the extraction of raw materials are likewise often included in the assessment.

Exploration
The term "exploration" covers the prospecting and exploration of raw material deposits onshore or offshore by means of various scientific methods. These include, for instance, geophysical measuring methods on the ground or the analysis of the geologic layers of the underground by means of airborne methods. The collected data can be used to create three-dimensional models of deposits (ore bodies), the correctness of which is verified by means of drillings. For the deep sea, further exploration technologies are required, for example, seismic measuring methods and diving robots.

Platinum group elements
The metals of the platinum group elements include platinum, palladium, rhodium, ruthenium, iridium and osmium. They play an important role in fuel cells and hydrogen electrolysis and are consequently significant in several possible key technologies for the energy transition – e. g. hydrogen-based electric mobility (fuel cell vehicles operated with electrolytically produced hydrogen), long-term storage and power-to-gas. Platinum group metals are classified as critical elements. More than 68 percent of the platinum supply is controlled by South Africa, and about 75 percent of the palladium is produced by Russia and South Africa.

Primary raw material production
The term refers to the extraction of raw materials from ores, mining or marine deposits. It differs from secondary production (recycling).

Rare earths
Rare earths, or more precisely rare earth metals, comprise a total of 17 elements in the periodic system, including yttrium, neodymium, dysprosium, praseodymium, terbium, europium, cerium and lanthanum. They are required for a number of key technologies, including batteries, photovoltaic systems, wind turbines, motors and generators. In the case of rare earths, the country concentration is

particularly high: More than 86 percent of the global production is located in Inner Mongolia, China, and the second largest producer is Australia. On the other hand, there are known deposits in many other countries, such as Brazil, the US, Canada or Greenland, that are not being exploited. Rare earths count among the critical elements.

Reserves, resources, geopotentials

Reserves are known mineral occurrences that can be mined economically in the prevailing circumstances. Reserves can be increased by new discoveries or decreased as a result of, for example, a decline in the commodity prices. Resources are known mineral occurrences that cannot be mined economically in the prevailing circumstances. Geopotential includes occurrences that have not yet, or have only partly been discovered, and it is therefore not possible to make any statement on the possibilities for economic exploitation. The geopotential is therefore the big unknown factor. All three classes are dynamic, and are permanently changing. Their movements depend on, for example, the prevailing economic situation (including prices), technical advances or environmental requirements.

Secondary raw material production

The secondary production of resources is the recovery of raw materials from discarded materials, such as products (vehicles, computers) and infrastructure (roads, transmission lines) that are deposited as waste and scrap in the technosphere.

Special metals

Special metals is not a sharply defined group of metals; in general, it includes rare earth elements and electronic metals or semiconductors such as indium or germanium.

Technology metals

Technology metals are also referred to as "high-tech metals". They are not a sharply defined group of metals, but generally include elements such as copper, cobalt, platinum group elements and the special metals.

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