**Smart strategies for the transition in coal intensive regions**

**Project No: 836819**

# *Best practice report on environmental protection and post-mining land reclamation*

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# Contents

*1 Preface* 7
*2 Coal mining in Europe* 7
**2.1 From a pillar of industrialisation ...** 7
**2.2 ... into the "post-coal age"** 7
**2.3 A clear political goal, but divergent adaption strategies** 8
*3 Regulatory requirements and planning procedures* 9
**3.1 Legal framework on environmental protection** 9
**3.2 EU Extractive Waste Directive 2006/21/EC** 9
**3.3 BAT Reference Document** 10
**3.4 Environmental Impact Assessment (EIA) / EU Directive 2011/92/EC** 10
**3.5 Transposition in national law - Example: Germany** 10
**3.6 Mine rehabilitation and restoration (definition of terms)** 11
*4 Geomechanical stability: a precondition for land reclamation* 12
**4.1 Dealing with hydraulic failure / liquefaction** 12
**4.2 Managing sinkholes and land subsidence** 12
**4.3 Slope slide prevention** 12
**4.4 Erosion protection** 13
**4.5 Re-establishing soil fertility** 13
*5 Soil preparation - the basic precondition for land reclamation* 14
**5.1 Soil covering** 14
**5.2 Soil treatment / amelioration** 14
**5.3 Soil survey / soil mapping** 15
**5.4 Substrate analysis** 16
**5.5 Soil survey report** 16
*6 Guiding principles of mine site reclamation* 17
**6.1 Land reclamation - the generic term** 17
**6.2 Mine reclamation - leaving room for interpretation** 17
**6.3 Ecological mine site restoration** 18
**6.4 Landscape reset: point zero** 18
*7 Best practice solutions for agriculture reclamation* 19
**7.1 Dumping valuable soil-forming materials** 19
**7.2 Integrating ecological elements** 20
**7.3 Site-adapted biological procedures - restoring full soil functions** 21
**7.4 Soil fertilising crop rotation** 21

**7.5 Low-input energy cropping on reclaimed land 22**

***8 Best practice solutions for forest reclamation 23***

**8.1 Forest reclamation through changing times and frameworks 23**

**8.2 Establishing woodland: legal requirements and self-commitment 24**

**8.3 Integrating natural regeneration into reclamation practice 25**

**8.4 Start-up support- for a proper forest development 26**

**8.5 Criteria for a proper afforestation 27**

***9 Guidelines for Nature Preservation 28***

**9.1 Post-mining landscapes - a chance for wildlife 28**

**9.2 Different strategies: Natural dynamics versus control measures 28**

**9.3 Natural conservation - well justified and no excuse for improper reclamation 29**

***10 Conclusions 30***

***11 Literature 33***

# Abbreviations

| | |
|---|---|
| ABA | acid-base-account |
| AFS | agroforestry system |
| Al | aluminium |
| BAT | Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities |
| BBergG 1980 | German Federal Mining Act |
| BD | soil bulk density |
| BS | base saturation |
| CEC | cation exchange capacity |
| cm | centimetre |
| D | Deliverable (TRACER project) |
| EC | electric conductivity / salinity |
| EEC | European Economic Community |
| EIA | environmental impact assessment |
| EU | European Union |
| FAO | Food and Agriculture Organization of the United Nations |
| GAP | Good Agricultural Practices |
| ha | hectare |
| ISO | International Organization for Standardization |
| kg | kilogram |
| LCA | life cycle assessment |
| LCF | lignocellulosic feedstock |
| m | metre |
| MCDA | multi-criteria decision analysis |
| Mg | mega gram (1,000 kilogram) |
| MU | management unit |
| NPK | nitrogen-phosphorus-potassium (fertiliser) |
| PAWC | soil plant available water storage capacity |
| PC | profit contribution |
| pcs. | Pieces |
| $pH_{KCl}$ | pH value (measured in potassium chloride) |
| SAC | soil air capacity |
| SFM | soil-forming material |
| SOM | soil organic matter |

| | |
|---|---|
| SRC | short rotation coppice |
| UK | United Kingdom |
| USDA | United States Department of Agriculture |
| 2D/3D | two- / three-dimensional |

# 1 Preface

Dealing with lignite and hard coal land reclamation the report provides an overview of legal and planning requirements, overruling ecological standards and best practice procedures as reflected in the relevant academic literature. The focus lies on the re-establishment of soil fertility and basic ecosystem functions for a sustainable and multifunctional agricultural and forestry after use compliant with the complex stakeholder requirements. Also, the usability and availability of reclaimed land for renewable energies becomes more important. Finally, post-mining landscapes offer a unique chance for wildlife in densely populated European mining regions, and there is growing evidence that the ecological approach in land reclamation leads to more biological stable ecosystems in the long-term.

In contrast to the socio-economic concern, a Europe-wide harmonised system and transnational available platform for collecting, assessing and mapping the environmental data concerning coal mining activities is still missing. The same applies to the quality land reclamation and follow-up use of stripped land. Although there is a considerable progress in reclamation practices and technologies, failures are still common, concerning both landform design and post-mining land management. The crucial point seems to be the know-how transfer into reclamation practice - implementing concrete and site-adapted solutions. Also, the exchange of specialist knowledge and practical experience between the mining regions is hardly visible, although the basic environmental challenges are rather similar.

Even more, it is important to exchange information at expert level. Therefore, in other report “Environmental impacts and sustainable reclamation solutions”, the TRACER consortium members get a chance to speak by taking a closer look at their target region using a standardised questionnaire. Readers are encouraged to get more familiar with the specific environmental challenges and results achieved in land reclamation across some typical coal mining regions in Europe.

# 2 Coal mining in Europe

### *2.1 From a pillar of industrialisation ...*

Coal energy and processing industry has a long history starting with the industrial revolution. Since the early 19th century, the European coalfield areas, like the *Ruhr Area*, *Lorraine*, *Donetzk* or *Upper Silesia*, have developed to the largest industrial districts. They are still an economic driving-force of the continent, even if there is nowadays a rapidly increasing restructuring process at different pace and intensity. Currently coal activities are running in 12 EU Member States and 41 NUTS-2 regions with 128 operating coal mines (ALVES et al. 2018). Hard coal and lignite play a key-role for the European energy supply with 24% of the power generation in 2018. According to EURACOAL (2019), the share of coal utilisation in the national electricity balance varies between 27% (Romania) up to 80% (Poland). In fact, there is still a high regional dependency from the mining infrastructure, especially in otherwise structurally weak, less developed European regions, like *Western Macedonia* (EL53) or the *Yugoiztochen (southeast)* region (BG34) in Bulgaria.

Coal industry is still the economic lifeline and driving force of many industrial regions, especially regarding the labour market. Overall coal extraction and processing provides direct employment to about 185,000 people across the EU, alone in Poland 112,500 jobs. Added to this are about 215,000 indirect working places relying on the coal mining sector (EUROCOAL 2019).

### *2.2 ... into the "post-coal age"*

However, coal production and consumption are declining already since decades. Even in the last 5 years, over 30 mines have closed. The main cause is less ecological reasons than economic inefficiency in a globalised world and energy market. Especially cost-intensive hard coal deep mining is under increasing economic pressure. The structural changes and adjustment processes in European coal regions cast their shadows ahead. It is estimated now that two thirds of the mining jobs are endangered in the next decade due to lack of competitiveness in the international market (ALVES et al. 2018, WEHNERT et al. 2018). The transformation process is accelerating and corresponding with the binding EU climate-political targets of reducing greenhouse gas emissions by minimum 40% in 2030 as compared to the reference level of 1990 (*EU Climate & Energy Framework 2030*, HELM 2014).

### *2.3 A clear political goal, but divergent adaption strategies*

Political signals and basic decisions on the national level are sometimes contradictory and leave room for discussion about the energy strategy in Europe. On the one hand, the coal phase-out gathers pace, and most EU countries have announced the national coal phase-out. Meanwhile, the share of electricity from renewable sources in the EU grew again in 2018 now reaching overall 32.3% or 1,051 TWh. Alone in 2018 the hard coal generation fell by 9% from 358 to 324 TWh, it is now 40% below the level of 2012 (AGORA ENERGIEWENDE & SANDBAG - SMARTER CLIMATE POLICY 2019). Austria (2025), France (2021), Sweden (2022), Ireland, Italy, UK (2025), Finland, Netherlands (2029), Denmark, Portugal (2030) go ahead. In Germany, the last hard coal mine closed at the *Ruhr Area* in 2018 after nearly 200 years of deep mining. In the same year, the phase-out of lignite was decided for the year 2038 (option 2035), as set by the so-called *Coal Exit Commission* in compliance with the UN *Climate Agreement* - which is trend setting for the EU energy policy because Germany still accounts for half of the brown coal production in Europe (which has been quite stable in the last years - against all efforts and support programmes for renewable energies).

But on the other side, countries in East and South Europe like Poland, Serbia, the Czech Republic, Greece, Croatia, Romania, Slovenia, Serbia or Bulgaria still depend in their economic development strongly from coal production and an increasing power generation. There is no phase-out under consideration, except for Greece where the coal could be phased out until 2028.Poland for example, is now investing in new more efficient power plants (>40% efficiency) and modernising the outdated mining machinery. According to the Polish energy needs until 2030, there is foreseeable a considerable gap in electricity generation when looking at the installed capacities. The increased demand should be met with a combination of lignite, hard coal, and nuclear power, as well as an increase in natural gas and renewables (AGRORA ENERGIEWENDE 2018). Poland's draft energy plan released in November 2018 will still account for 60% of electricity generation by coal burning in 2030, from actually 77% (AGORA ENERGIEWENDE & SANDBAG - SMARTER CLIMATE POLICY 2019). In addition, Greece has new coal-fired power stations under construction and in the pipeline. However, the Greek Prime Minister, in his speech to the special UN Climate Action Summit (21-23/9/2019), announced that the Greek Government's goal is to close all lignite-fired power plants by 2028 (instead of the initial plans for 2050).

The baseload capacities of Bulgarian power system are 3 TPPs[1] burning local, low quality lignite (~1500 kCal/kg) covering more 50 % of electrical energy balance. The first of the three plants is relatively new – it started operation in 2011. The other two TPPs are subject of systematic renovation of the ageing units.

In Bulgaria, the national policy documents – *2020 Energy Strategy* and *National Renewable Energy Action Plan* – set the **cleaner electricity production from existing coal-fired power plants** as a priority of the TPPs operation. The Bulgarian NECP issued in January 2019 states that *"The coal would provide feedstocks for electricity generation over the next 60 years."*

[1] TPP AES Galabovo – 600 MW, TPP Maritsa East 2 – 1620 MW, ContourGlobal Maritsa East 3 - 908 MW

# 3 Regulatory requirements and planning procedures

### *3.1 Legal framework on environmental protection*

Waste from extraction of mineral resources and subsequent processing of residuals are one of the most serious environmental challenges in the EU. The topic addresses materials that must be removed to gain access to the valuable resource, such as topsoil, overburden and waste rock, as well as tailings remaining after extraction of minerals but also the acid or alkaline drainage. Other likely ecological impacts relate to the loss of fertile land, devastation and disturbance of ecosystems, dust and erosion emissions, water, soil & air pollution.

Besides technical measures - starting with the stabilisation of instable and erosive heaps and dumps - special aspects of ecological engineering are discussed. The basic challenge of modern land reclamation is to integrate natural successional processes into reclamation practice, wherever possible, target-oriented and if no other overruling interests are standing against.

### *3.2 EU Extractive Waste Directive 2006/21/EC*

In order to minimise the ecological footprint of mining, the overarching *EU Extractive Waste Directive 2006/21/EC* has been adopted as a complement to applicable horizontal EU general environmental legislation. The safe operation of mining covers the management of waste as defined in Article 1(a) of *Directive 75/442/EEC* resulting from the prospecting, extraction, transport, storage and treatment of mineral resources and the working of quarries. Thereby, the focus lies on the control of major-accident hazardous of land-based ore mining and the processing industry by an integrated approach concerning both the protection of natural resources, but also pollution prevention and control taking into account the principle of sustainable development.

The document lays down general minimum requirements for mining in order to prevent or reduce as far as possible negative effects by hazardous waste materials as defined in Article 1(4) of *Council Directive 91/689/EEC* on the landscape, environment and human health. However, at least the EU Member States have to ensure by national laws that the mining operator takes all necessary measures in context with the raw material extraction and after care. Mining operations have to be in accordance with the objectives of the EU policy on the environment, *inter alia* the *EU Water Framework Directive 2000/60/EC*.

The *Extractive Waste Directive* requires a complete life-cycle assessment and management of any mining operations, in order to minimise and mitigate the environmental impact. It ranges from the exploration over the operation period (active mining) to mine closure and the final end-state defined by the release from mining supervision (FALCK 2018). Several environmental risk management tools (ISO 31000) are widely applied - from mine development, during operation, up to post-closure and reclamation, *inter alia*: *Life Cycle Assessments* (LCA), *Multi-criteria Decision Analysis* (MCDA) and specific risk evaluations as final step (KRZEMIÉN et al. 2016).

In order to reduce the risks of mining activities as far as possible, extractive waste management plans are needed, already as part of the licensing process, involving the local stakeholders and population in the planning and decision finding - right from the beginning of operation until mine closure. Monitoring procedures during the operation and after closure of waste facilities are necessary. It is also of utmost importance that any operator of a waste facility servicing the extractive industries has to provide financial guarantees ensuring that all the obligations flowing from the permit will be fulfilled in good time, including those relating to the closure and after-closure period. The financial provisions earmarked for reclamation activities have to cover the predicted full costs of land rehabilitation.

### 3.3 BAT Reference Document

Based on the information exchange provided in Art. 21(3) of Extractive Waste Directive, the *Best Available Techniques Reference Document for Management of Waste from Extractive Industries* (BAT Reference Document, BREF 2018) offers more than 700 pages of examples for good practice mining operations and best available techniques as defined in Article 3(10) of *Directive 2010/75/EC*. The document is based on an exchange of information between the *EU Member States* and the mining industry with a special focus on the save management of waste rocks, tailings ponds and dams.

However, the BAT Reference Document is not legally binding and the recommendation calls for further specification, especially regarding the untouched land reclamation and reconstruction of ecosystems after coal mining - so it is currently under revision.

### 3.4 Environmental Impact Assessment (EIA) / EU Directive 2011/92/EC

Mine planning has to meet international environmental standards such as ISO 1401 (*Environmental Management Systems*) and other environmental regulations, numerous preventive and mitigation measures as described by national, regional and local laws as well. Therein, the general landscape and reclamation planning gets integrated into process-based *Environmental Impact Assessment* (EIA) and complex management studies (POPA et al. 2013), which have been approved by the licensing authorities (national ministries or regional mining authorities).

The EIA identifies and evaluates all direct and indirect impacts of intended mining activities and other relevant projects on the environment, but also the population (health and living conditions), material goods and the landscape, including the cultural heritage. Moreover, it has to give solutions onhow to prevent and minimise negative impacts on the environment. The individual EU countries transpose the EIA Directive as a methodological and technical routine for environmental planning practice in different forms, be it as separate legal norms (e.g. Bulgaria, Czech Republic, Poland, Germany; WENDE et al. 2012) or, more common, as an incorporation into already existing laws (UK, Ireland, Denmark, France, Greece, etc.), like nature conservation, environmental or special land use planning acts.

### 3.5 Transposition in national law - Example: Germany

The EU Member States have to take the necessary measures for the transposition of the *Extractive Waste Directive 2006/21/EC Directive* into national laws, regulations and administrative provisions. Thereby, the operators responsible for the management of extractive wastes are obliged to implement monitoring and management controls in order to prevent water and soil pollution and to identify any adverse effect that waste facilities may have on the environment or on human health. The implementation into national law and binding administrative provisions is very different within Europe. At this point, we refer to report on the “Environmental impacts and sustainable reclamation solutions” where the TRACER target regions give an overview about the national regulations relevant for mine closure and land rehabilitation.

As an example, in Germany there is one single legislative regime or framework - the national mining law, BBergG (1980) - licensing all mining operations and bringing together the general environmental laws to speed up and simplify the complex planning process. The so-called *general operating plan* defines the framework and describes the key environmental goals and protection measures - it has a legislative character. The subordinated operating plans of the mining companies concretise the general targets and measures. In general, they are assessed and confirmed by the responsible mining authorities. Each indicated and applied plan deviation must be justified. It calls for a new *special operating plan* and the acceptance of the responsible mining authority. And, of course, the mining company tries to avoid any content-related discussion on once confirmed plans - apart from the additional time and efforts.

Thereby, environmental protection and rehabilitation and post-mining redevelopment are linked to the public interest already before and during active mining. However, concerning reclamation in detail the demands of the general legal provisions are relevant, i.e. soil protection, water legislation, waste regulations, nature conservation, forest and other environmental regulations, they "will be applicable insofar the BBergG and derived ordinances do not regulate impacts in detail" - which is actually in most cases. Moreover, mine reclamation planning must fit the overall regional spatial and infrastructure plan.

The release from mining supervision by law relates to the implementation of the final operating plan with its reclamation requirements at all points. According to general experience, the risk of environmental hazards coming from the former mining area can be excluded. To ensure the public safety, for example, the post-mining groundwater is now finished and the structural stability of dumps and embankments must be proved. Moreover, there should be no wind and water erosion or pollution emission affecting the surrounding landscape.

### *3.6 Mine rehabilitation and restoration (definition of terms)*

Following the definition of the leading practice handbooks published by the AUSTRALIAN GOVERNMENT (2016), coal mine rehabilitation (= "reclamation") should return the disturbed land to a stable, productive and self-sustaining condition. It comprises the design and construction of landforms as well as the establishment of ecosystems or alternative vegetation, depending upon the desired post-operational land use. The key objectives are: long-term stability and sustainability of landforms, soil and hydrology, providing habitats for biota and services for people and the prevention of environmental pollution (safeguarding). In other words: mine rehabilitation has to compensate the ecological impact - up to date as possible and depending on the intensity/level of disturbance (JACKSON & HOBBS 2009).

Thereby, it should balance the diverging interests and complex claims on the future utilisation under consideration of the financial possibilities. In this context, the pre-mining landscape provides orientation for rehabilitation. However, in most cases it is simply impossible to restore the historical systems due to the changing environmental situation, habitat conditions, land use claims and societal needs after mining. Thus, the term "restoration" describes the more ambitious aim of re-establishing ecosystem structure and function as before disturbance - replicating the reference ecosystems (BRADSHAW 1987, SEASTEDT et al. 2009, AUSTRALIAN GOVERNMENT 2016, DOLEY & AUDET 2016). However, the definitions open scope for interpretation and may develop over time, depending on the progress of ecosystem development on reclaimed land, e.g. from an artificial afforestation - still needing care and fertilisation - to a nearly natural self-sustaining (restored) ecosystem with a regenerating tree species combination and stand structure comparable to the surrounding landscape.

In terms of licensing aspects land and reclamation - is a multilevel planning and forward-looking process. Approved mining operating and closure plans are essential - implementing the general legal provisions in each case, i.e. soil protection, waste legislation, nature conservation, water protection, forest and other environmental regulations. For providing an environmentally sound and socio-economic fair balance of interests, the intended after use has to be in public concern (so-called *agents of concern*) beyond the scope of the legally binding mining code and other relevant environmental laws.

# 4 Geomechanical stability: a precondition for land reclamation

## 4.1 Dealing with hydraulic failure / liquefaction

Any practical mine site reclamation will fail into the long term, unless the physical stability is not assured under natural extreme events or other disruptive forces. Especially, in the European lignite mining areas quite commonly sandy overburden material is dumped in a loose layering and small scale alternation of substrates. Under this geomechanical pre-setting, raising post-mining groundwater and heavy precipitation events can trigger sudden liquefaction (*quicksand*, NESTLER & STOLL 2001, VOGT et al. 2014). Such unforeseeable hydraulic failures cause a large-scale blocking of reclaimed land - even of areas which have already been released from mining supervision. These hazardous granular spoils need a basic ground improvement by modifying their physical properties: especially for the fast in-situ densification of loose sands the following methods come into question (LERSOW 2001, RUSS 2012, UHLIG 2014): (1) dynamic surface compaction by controlled high-energy tamping, (2) deep vibro-compaction techniques and (3) blasting compression depending on the regional situation. These recommended residue-free technologies provide a most economical and sustainable ground improvement. Besides rearrangement of soil particles into a denser state the (4) large scale regulation of the groundwater table by permanent pumping is a preventive measure.

## 4.2 Managing sinkholes and land subsidence

Concerning the more localised phenomenon of sinkholes and land subsidence as described before, first of all preventive reclamation measures come into question to ensure the structural integrity and public safety. Among them especially backfilling and grouting of mineral materials and residuals can be used to stabilise abandoned underground workings in a large scale. But also the construction of walls and mechanical barriers around an area exposed to sudden collapse or gradual terrain subsidence are promising best practice measures (SINGH & DHAR 1997). Talking about old mining activities, very often little documented, e.g. in the *South Wales*, *Northern France* or the *Upper Silesian Coal Basin*, some mitigating measures are well tried and tested on site, inter alia: surveillance of earthworks, infilling of identified sinkholes or geotextile reinforcement (NICHOL 1998).

Finally, there is a wide range of established methods suitable for locating sinkholes, but also concerning the risk analysis of subsidence and the regular post-closure monitoring as described by ZIĘTEK et al. (2001), SAHU & LOKHANDE (2015) or SALMI et al. (2017) in detail: empirical, semi-empirical, remote sensing, numerical approaches and geophysical 2D and 3D models.

## 4.3 Slope slide prevention

Another hot topic of hard coal mining and not only in the public eye, are slopes of heaps and embankments susceptible to translational failure (NICOLAU IBARRA 2002, STEIAKAKIS et al. 2009, etc.). For the practicing geotechnical engineers, it is most important to have reliable methods to estimate the two and three-dimensional factors of safety for slopes for both preventive risk assessments but also controlling reclamation. There are many different methods to evaluate the slope stability which is defined as the potential of soil covered slopes to withstand and undergo movement - a comprehensive overview is given by HAWLEY & CUNNING (2017), but the most applicable is still the general static limit equilibrium method (so-called *method of slices*), dividing the slip mass into separate blocks with a parallel surface and gravity force (BISHOP 1955, SPENCER 1967, etc.). But also more simplified methods make sense, like validated stability charts based on parametric studies under field conditions and with respect to configurations of the sliding mass, unit weight and shear strength of the involved materials (EID et al. 2011). However, as the case study of the *South Field* lignite mine in *Western Macedonia* shows, limit equilibrium analyses by different methods cannot always rule out unpredictable events (STEIAKAKIS et al. 2009). Nowadays, there are complex material related stability calculations and dynamic 3D slope models simulating field conditions (REYES & PARRA 2014, TRIANTAFYLLIDIS 2015, *infinite slope analysis*).

### *4.4 Erosion protection*

Structure-poor dumped coverage materials are highly sensitive to accelerated water erosion per se. Namely before a soil-conserving plant cover gets established, water run-off and the susceptibility to erosion corresponds to the slope inclination and length, topography (linear, concave) but also exposition (CULLING 1965, KNOCHE et al. 2006). That is always calling for an integrated management of topography, soil coverage and vegetation (NICOLAU IBARRA 2003). Especially, a plant-friendly, moderately compacted soil and other similar materials is stimulating plant colonisation. In general, the best results are achieved with topsoil rich in humus (POWER et al. 1981, HAIGH 2000). But also the concave slope design promotes reclamation (MARTIN-MORENO et al. 2013, 2018). Moreover, it is essential to structure slopes by terraces or horizontal and vertical dams in a checkerboard pattern, so that rainfall can infiltrate to a large extent, even after maximum rainfall events (SAWATSKY et al. 2000). Depending on the inclination angle, spacing should be 100 to 20 m horizontally and 20 m vertically. Other constructional features are water collection channels and basins, nearby access-roads and berms inside the slope system, which are leading the remaining surface runoff into the heap.

After remodelling the final slope design should fit into the natural topography of the surrounding landscape. For a mechanised agricultural after-use, inclination angels must be less than 35% from the technical point of view, in case of all-year trafficability of skid roads in forestry not exceeding 70%. However, with respect to soil protection and cropping efficiency the desirable slope gradient is much lower, e.g. for arable cropland <7.0%.

### *4.5 Re-establishing soil fertility*

Surface mining leads to irreversible environmental changes, but on the other (dump) side a new anthropogenic, landscape type is born - transformed in its geological features: the post-mining landscape. Thereby, a core issue especially in lignite and hard coal reclamation is to re-establish quite fertile soils as essential for a diverse food, fodder or feedstock production. Basic soil functions are essential for a sustainable ecosystem development. In most cases the basic challenge is to transfer quite infertile, sometimes polluted, mostly sandy to stony and sorption-poor geological raw substrates into developing technogenic soils (*Technosols*) for regular farmland or sustainable forestry. In a common way mine site reclamation ends, when revegetation is achieved and ecosystems come into a regular post-mining after-use. However, from the ecological point of view restoring fully sustainable and healthy ecosystems is a long-term process - for example, the soil humus accumulation to a steady-state level is taking several decades (JORDAN et al. 1987, KNOCHE 2001). According to the ecological definition by PIETRZYKOWSKI & KRZAKLEWSKI (2007) mine site reclamation needs stable nutrient cycles from plant growth and microbial processes. It gets finished when a self-sustaining, integrated biological system (ecosystem) is formed, in which a certain exchange of matter and energy takes place.

# 5 Soil preparation - the basic precondition for land reclamation

## *5.1 Soil covering*

Restoring soil fertility and establishing basic soil functions is at the core of land rehabilitation and essential for a sustainable land use after mining - regardless of the location and mine type. Thereby, reclamation success depends on the substrate quality but also the efficiency and environmental compatibility of reclamation methods. Soil preparation aims at a basic improving of the physical, chemical and biological properties to promote revegetation.

Against increasing environmental standards in the current mining directives of the EU countries, nowadays heaps and dumps should be covered with pre-selected overburden material - insofar available, technologically and economically feasible. However, the local availability of biological active topsoil material or other fertile mineral substrates in mine closure situations is very often limited. Moreover, the highly mechanised extraction and dumping of overburden material with heavy mining equipment causes a considerable small-scale heterogeneity of the final land/soil cover. Contrasting soil properties make the land preparation more demanding.

Regarding the summer-dry climatic conditions in Europe and requirements of agriculture and forestry there should be a minimum soil cover of barren soils and infertile geological substrates from 1.0 to 2.0 meters. Insofar the thickness of the applied stripped soil or crop-friendly overburden material is sufficient to provide enough nutrients and water to maintain a proper biomass growth and self-sustaining ecosystem development (HAUBOLD-ROSAR 2018). In general, cohesive covering substrates with a high soil water and nutrient storage capacity are preferred. However, their pressure sensitivity is rather high. Therefore, it is essential to avoid structural damages by dumping and harmful soil compaction, e.g. by using low-weight bulldozers in few crossings. The spoil air capacity should not fall below 10%-vol. in order to allow a good deep rooting of the soil and optimal soil development. Otherwise compacted soils have to be ameliorated by deep loosening machines with a working depth of 60-80 cm quite costly afterwards.

To improve humus- and nutrient-poor covering materials they can be mixed with green-waste compost, pre-treated digestates, uncontaminated sewage sludge or other organic materials. Residues like fly ash, slag or rubble or street sweeping are suitable for stabilising subsoil layers in specific cases, especially in coverage systems for heaps. However, in each individual case their application has to meet the minimum requirements laid down by EU regulations and in the national environmental legislation and implementation rules, in particular: waste and soil conservation legislation, water law. Taking into account all aspects, waste materials shall only be used in reclamation, if they add value to the soil development and if environmental risks are not higher than without using these specific materials.

## *5.2 Soil treatment / amelioration*

In many cases, especially regarding abandoned mines there is no adequate substrate available or the covering is simply too expensive, disproportionate to the environmental benefit. For example, in the *Lusatian Lignite Mining District*, lignite surface mining left behind large areas with sandy to loamy *Tertiary* sediments containing high amounts of iron sulphide and dispersed coal. Because of strong acidification ($pH_{KCl}$ <2.5) by pyrite or marcasite ($FeS_2$) oxidation and intensive clay mineral weathering, these substrates remain barren of vegetation - sometimes even for decades forming a *lunar landscape* (PIETSCH 1996). Therefore, any revegetation and cultivation of acid-sulphurous mine substrates needs a considerable and durable upgrading of the pH value by soil liming. Unfortunately, the acidification potential varies considerably, and it is necessary to calculate the lime requirement exactly for each mapped substrate unit considering the intended after-use with different demands of the plants grown on the soil chemical properties.

As a predictive tool for the suitability of sulphide-containing overburden materials for mine soils different *Acid-Base-Accounts* (ABA) come in question. They all need to quantify the substrate-specific buffer capacity and the acidification potential from complete iron sulphide weathering (*A/B Account = Neutralisation Potential - Potential Total Acidity*) under consideration of the intended pH value for the regular follow-up use (KATZUR & HAUBOLD-ROSAR 1996, HOSSNER & BRANDT 1997). Negative ABA values for overburden materials indicate the probability of acidification and an appropriate lime requirement to stabilise a crop-friendly pH and to minimise the bioavailability of phytotoxic aluminium and iron cations but also water soluble Al/Fe sulphate and hydrogen complexes.

### *5.3 Soil survey / soil mapping*

Juvenile mine substrates are anthropogenic raw soils with unique properties and a set of growth limiting factors. For the most part, they are free of recent organic matter (humus) and have a negligible soil biological activity at the beginning. A lack of plant-available macronutrients is linked to the missing biological nutrient turnover. Especially the lack of nitrogen and phosphorous inhibits early plant growth. Moreover, in the case of strong acidification, heavy metal contamination or high soil compaction mine sites remain barren of vegetation, sometimes even for decades (PIETSCH 1996, HÜTTL & GERWIN 2005). Nevertheless, driven by the successive process of natural revegetation or initial cropping mine substrates underlie high soil dynamics and pedogenic processes over time. Reclamation has to restore the ecological integrity and fertility of the disturbed land including a management of physical, chemical and biological features (SHEORAN et al. 2010). From the ecological point of view, restoring fully sustainable and productive soils and ecosystems is a long-term, quite challenging task taking several decades (PIETRZYKOWSKI 2015).

It is common consent, that mine site survey takes a key position in the complex and challenging process of biological driven reclamation and soil restoration. The evaluation of basic soil properties and fertility is essential for the determination of soil (function) target values and land use expectation values, which have to be reached by a proper land management. However, since mine soil dynamics are quite high in the initial stage, it turns out rather difficult to predict the long-term ecosystem behaviour and thus the final success of reclamation. That's why each mine site investigation should include a detailed substrate evaluation with special respect to plant growth-limiting and -controlling (key) soil properties, special soil functional values and the site-related growth potential. Moreover, it has to be feasible under field conditions and the intensity of soil survey as well as investigated properties have to meet the available technical and personal capacities. Finally, any mine soil survey should be compatible to national and international reference (EN ISO) methods and general guidelines for agriculture and forest site mapping.

For the routine mine soil mapping and the upscaling of point information to spatial average we recommended a geo-referenced raster scanning with soil core samplers, e.g. the so-called *Pürckhauer* boring rod with 1.5 cm in diameter and 100 cm length. The field mapping grid depends on the expected soil heterogeneity and should be 50 m x 50 m to 100 m x 100 m, in case of quite homogenous coverage material 200 m x 200 m is sufficient. For each drill point, basic morphological and other diagnostic soil criteria are recorded following the proposed soil classification scheme according to FAO (2015). The following set of soil-related parameters can be assessed quite easily: layer / horizon boundaries, soil colour, parent soil material (bedrock), geological stratum, particle size distribution, texture of fine earth, humus and calcium carbonate ($CaCO_3$) content, soil pH ($CaCl_2$), degree of soil compaction and cementation and hydromorphism.

The data set contributes to a definition of substrate types that are verified at site representative soil profiles that for their part ensure the soil description from the drilling points. In fact, the quality of the data obtained is highly depending on the sampling strategy and intensity (AUSTRALIAN GOVERNMENT 2016), *inter alia* DOLLHOPF (2000), YATES&WARRICK (2002) and MCKENZIE et al. (2008) give some practical guidance. In minimum and depending on the observed substrate heterogeneity one reference soil profile (in minimum 100 cm depth covering the major rooting zone) per 3 to 5 hectares geo-referenced mapping section or observation plot should be characterised in more detail. Therefore, the soil profile description and coding of key attributes should follow the internationally accepted *FAO Guidelines for Soil Description* (FAO 2006) or comparable mapping instructions on national level, providing basic soil and cropping information. The soil profile investigation gives a description of the soil structure and it leads to the effective rooting depth. Furthermore, it allows a more accurate assessing of soil compaction, stone content and salt precipitations. But also growth relevant soil admixtures like lumps of clay or coal can be identified.

However, to achieve more reliable recommendations on an ecological sounding revegetation or the commercial agricultural and forest land use, the pedological description and interpretation should be underpinned by specific soil chemical and physical analysis following the identified substrate layers. From the point of land reclamation practice it is important to focus on integrating, directly growth relevant soil parameters (SHEORAN et al. 2010). By this the soil evaluation should allow an estimation of limiting properties (e.g., nutrient availability, water storage, soil compaction) of raw soils in the early stage of ecosystem development but also the long-term growth potential following the stepwise ecosystem development, e.g. when assessing the potential root-space for mature forests.

### *5.4 Substrate analysis*

Substrate analysis coming from site-representative soil profiles or boreholes with mixed but layer related samples (e.g., 0-30 cm. 30-60 cm and 60-100 cm soil depth) should be done with international established methods in applied soil analytics (FAO 2006, MCKENZIE et al. 2008, COOLS & DE VOS 2010, SHEORAN et al. 2010). Ideally, the analytical procedure is also synchronised to pedological parameters in international soil survey, national standards or data collected already in the mining region. All environmental laboratories involved, have to use the same standard methods to make results comparable, mainly following EN ISO:

- The soil chemical analysis includes: soil reaction (pH($CaCl_2$)), electric conductivity/salinity (EC), cation exchange capacity (CEC), buffering properties/base saturation (BS, percentage of CEC occupied by bases: Ca, Mg, K, Na), carbon content, soil organic matter (SOM) and macronutrient availability (N, P, K, Mg, Ca). When looking at coal and sulphide bearing substrates, it is always necessary to assess the soil acidification potential by ABA. In suspected case of hazards, special soil contaminants (heavy metal, organic pollutants) expand the spectrum of analysis.
- Relevant mandatory soil physical parameters characterising the growth conditions are: soil skeleton (mineral particles >2.0 mm, gravel, stones, blocks), texture (7 classes, from clay over silt to coarse sand, <2.0 mm), soil bulk density (BD), soil water storage capacity (SWSC), plant available water storage capacity (PAWC), air capacity (SAC) and porosity (pore size distribution). Additional and deeper going analyses refer to the hydraulic and air conductivity.

However, the measurement of soil water parameters is quite time-consuming and requires profound laboratory expertise. Optionally, both soil water retention curve and hydraulic properties can be derived from surrogate data, such as soil texture and compaction using *Pedotransfer Function Models* like *Rosetta-NRCS* or *USDA*.

### *5.5 Soil survey report*

Mine soil substrate mapping is essential for any land use planning and the implementation of reclamation measures. The results of the soil survey and evaluation are essential for the deduction of site-adapted land use options, soil improving measures (liming, subsoiling, upgrading by composts, etc.) and reclamation technologies (choice of suitable plant species, tillage, fertilisation, planting schemes, tending strategies, crop rotation and management, etc.). A consistent mine soil classification scheme has to consider both, soil quality requirements for a sustainable post-mining land use but also engineering or reclamation procedures.

In principle for each soil mapping plot and planning unit the results of soil evaluation are reported in a *Soil Survey & Mapping Report*, summarising and visualising the investigated site and analysed soil profiles. Thus, the account lists the main results of the soil survey providing site specific information (location, orientation, slope angle, etc.) and analytical data of soil profiles. Taken together that information leads to a soil classification and fertility appraisal. Furthermore, there should be recommendations on a sustainable post-mining land management with special respect to the reestablishment of basic soil functions.

# 6 Guiding principles of mine site reclamation

## *6.1 Land reclamation - the generic term*

Land reclamation is a quite complex concept, usually known as reclamation of ground or land fill. In a number of other jurisdictions for example in the United States, the term *reclamation* refers to returning disturbed lands to an improved state, in other words: to make them suitable for a more intensive use. Another definition relates to reconverting disturbed land to its or other productive uses. Land reclamation in the context with mining and mine closure means the smoothing and revegetation of strip-mine spoil areas on schedule (ENCYKLOPAEDIA BRITANNICA 2019, https://www. britannica.com/ science/land-reclamation), including (guided) plant succession and crop growing.

Looking at the relevant technical literature but also international legislation frameworks and implementation rules as well, the common denominator is to restore the terrestrial landscape by different technical and biological measures. The rehabilitation of artificial residual lakes, land drainage (swampy lands), rainfall-deficient areas by irrigation, salt-affected soils, the reclamation of coastal areas and eroded land or the removal of hazardous wastes are special cases, not further discussed in this report.

## *6.2 Mine reclamation - leaving room for interpretation*

The term mine reclamation refers to the process restoring land that has been mined making it suitable for a proper after-use. “Key objectives in reclamation activities are to reduce potential damage and prevent negative impacts to the natural environment in and near mined areas…” (Hayes 2015). In a holistic approach, the overall target of land reclamation is creating useful landscapes but also *improving lands* to make them suitable for a more intensive use in many respects going beyond a simple revegetation by accident. According to SER (2004) there are several ecological process attributes for measuring/monitoring the final restoration success, notably similar ecosystem diversity and structure as compared to unmined reference sites, self-sustainability of ecosystem development, presence of self-regenerating indigenous species and functional groups necessary for long-term stability, integration into the surrounding landscape, resilience to natural disturbances and the elimination of potential threats.

By this way abandoned mine reclamation plays a key role to minimise the environmental footprint of ongoing and closed mining and to attain a sustainable land use (BRADSHAW & CHADWICK 1980). When the pre-existing land quality was quite unfavourable, for example in the case of contaminated ground, *re-landscaping* can even lead to a substantial enhancement in land use (HARRISON 2000) - however, the used terms *improvement* and *landscape value* leave room for interpretation and discussion and need further regional specification.

For example, in the Czech Republic mining companies are required to return land to a more natural state. By evaluating the costs and benefits from mining, the value of the reclaimed landscape should be increased by 80% as compared to the pre-mining baseline, e.g. by a higher portion of vegetation types and habitats with a high ecological classification value (HENDRYCHOVÁ 2008). By contrast in Germany, reclamation in the sense of re-utilisation of the land as defined by the *Federal Mining Act* (BBergG 1980) highlights soil productivity, usage requirements and economic claims rather than ecological aspects, notably in agriculture and forestry. Moreover, this approach leads to a strict separation of different land use categories with purpose optimised soil conditions.

In Bulgaria the reclamation is an obligation of the mining company “Mines Maritsa East EAD”. A special commission appointed by the Minister of Agriculture and Forestry systematically defines the areas for subsequent reclamation and accepts the already reclaimed lands available for agricultural and forestry use. The humus collected and stored before the commencement of mining operations is used for the reclamation.

In fact, mine reclamation addresses many specific goals ranging from the restoration of productive ecosystems to the creation of industrial and municipal areas. Rehabilitation of land and ecosystems intends not only the recovery of the disturbed landscape and a save access to the land but also the long-term safe-guarding of the mining residues. This means to eliminate all risks for the environment and human health caused by the former mining area, e.g. negative impacts on groundwater resources, emission of pollutants, wind and water erosion. Below the line, there should be always a well-balanced compromise between ecological aspects, socio-economic demands based on the landscape features and historical context - to improve the public acceptance of landscape restoration.

### *6.3 Ecological mine site restoration*

The stated goal of mine site reclamation is to establish useful and stable ecosystems connecting technical to biological methods on a scientific base - using natural processes (BRADSHAW 1983, 1997 HÜTTL & BRADSHAW 2000) for the development of sustainable, and multifunctional post-mining landscapes (GHOSE 1989, 2005, PIETRZYKOWSKI 2015). Thereby, modern mine site reclamation is a basic precondition, not only for the ecological and but also a socio-economical recovery of the affected region - essential to the way of life and well-being of people (FROUZ 2014). From the ecological point of view, mine site reclamation is a quite demanding ecosystem reconstruction - from an unrestored to desired state of recovery. Thus it targets at ecological functions and is going far beyond than only improving the soil quality on unfertile, barren ground as left behind from mining activities (SHEORAN et al 2010). Nevertheless, restoring biologically active soils is essential for the rehabilitation of disturbed ecosystems and post-mining landscapes (BRADSHAW & CHADWICK 1980, WHISENANT et al. 1995).

In a holistic approach, restoration means the process of assisting the recovery of degraded, damaged or destroyed ecosystem to a previous, more natural or any other desired condition (SER 2004, RUIZ-JAEN & AIDE 2005, HENDRYCHOVÁ 2008). It starts with a profound reclamation planning and goes ahead with the stepwise re-establishment of basic ecosystem functions like providing living space, water and matter turnover, etc. Under these conditions, the revitalisation of post-mining landscapes with the embedded ecosystems calls for special reclamation procedures / technologies and provides strategies for a sustainable development (PRASAD et al. 2018).

### *6.4 Landscape reset: point zero*

Mine reclamation stands for a redesign of the landscape with it's very specific anthropogenic site conditions. It can achieve structures and functions close to native ecosystems (PARKER 1997). However, a reconstruction of the original, quasi natural pre-mining landscape inventory is impossible. In fact, reclamation targets at a new, technogenic ground mosaic, with its own, very specific soil-forming substrates, habitats, ecological potentials and cropping properties (BRADSHAW 1997, HÜTTL & GERWIN 2005). The revegetation of stripped land is quite complex due to a bundle of growth limiting factors at the beginning of reclamation. Besides the infertile character of many spoil and overburden materials, especially if acid sulphurous, and the lack of soil life, additional abiotic features complicate the task, like the irregular, frequently steep topography of the spoil-bank area, substrate instabilities, rough microclimatic conditions, or the high substrate heterogeneity. That's why reclamation of post-mining land is cost-intensive and frequently limited to low-demanding, and self-organising ecosystems, in the first place unassuming pioneer forests and meadows or open land. Usually such areas are turned into recreational or nature protection areas.

Mining is a temporary phenomenon, although after mine closure there are many long-term ecological impacts on the landscape. Ideally, the basic decisions for the future landscape are already made before starting excavation and material extraction - notably under survey of the geological substrates as expected to be available for the later surface cover and reclamation. But the multiple demands on post-mining land are competing, changing during mining operation and finally, very often conflicting, e.g. biomass production/exploitation vs. nature conservation or recreational after use, calling for a landscape compartmentalisation that prevents later land use conflicts. In addition, landscape zoning already on the early planning level offers a good chance for a target-oriented reclamation - right by dumping of a land use adapted substrate quality. At last, specific reclamation standards and measures tailored for each land use type minimise the risk of unfilled and unrealisable expectations. Are the reclamation outcomes realistic and achievable? Indeed, land reclamation is costly, needs specific site information and has to be carefully planned and implemented. A poor land reclamation - without or insufficient considering of defined reclamation success criteria / target values - leads to reputational damage, additional restrictions, higher costs and may call in question future mining activities among regulators and other stakeholders (see stages of rehabilitation planning and implementation and rehabilitation success criteria by AUSTRALIAN GOVERNMENT 2016). On the other hand, a proper, forward-looking (progressive) rehabilitation under involvement of stakeholders can even improve the pre-mining conditions, e.g. by depositing high-quality geological substrates and fertile topsoil material to the heap surface - thus increasing the long-term livestock carrying and ecological capacity of the land.

As a general rule, the intended after-use is laid down in the landscape and mining operation plans and needs special methods and technologies adapted to the site-specific situation. However, from the historical perspective, reclamation practices very often have only created site conditions poorly suited for the intended after-use - with a low productivity and a lack of ecosystem services (*inter alia* RADEMACHER & HAUBOLD-ROSAR 2012, ZIPPER et al. 2011). Moreover, it is still unclear which kind of reclamation has the most favourable effects regarding the intended targets. In the following, the best practice solutions and recommendations from experience and scientific research are presented. Therein, we give a brief overview about the fields of geotechnical safety, agricultural and forest reclamation and rehabilitation of nature protection areas.

# 7 Best practice solutions for agriculture reclamation

## *7.1 Dumping valuable soil-forming materials*

Large-scale surface coal mining causes in many European regions a considerable loss of fertile soils and arable farmland. In the individual case, the land consumption can endanger and even withdraw the production base of farmers, while other options of land compensation in mining areas are limited. Even more the time lag between taking land by mining operation and preparing land for a regular post-mining land use should be as short as possible, ideally less than 20 years (progressively reclaim).

Beyond an adequate and fast area compensation there is a vested interest of both the responsible mining company and the later land user in high-yielding soil substrates and a proper land restoration (HOSSNER 1988). The term *soil-forming material* (SFM) relates to earth material (typically *spoil*, *overburden*, *backfill*) which evolves over a period of some years to a semi-natural soil which is essential for revegetation (YOUNGER 2004). On the fact, that all pedogenetic processes are driven by the substrate properties, reclamation relates on a stepwise and sustainable development of soil fertility (HAUBOLD-ROSAR 2018). At least, restored cropping sites should have the same or even a higher yielding potential.

To achieve satisfactory agronomic results, it makes sense to reserve the most valuable mine spoils or soil substrates such as calcareous boulder clays or sandy loams for agricultural reclamation (KENNEDY 2002, KRÜMMELBEIN & RAAB 2012, SCHLENSTEDT et al. 2014). For proper, cost-effective field management, good homogeneous physical and chemical qualities of the soils are beneficial, without growth restrictions such as harmful compaction. Silviculture can adapt to small scale fragmented mine soils in a better way. Forest tree species are less demanding and more adaptable as compared to agricultural crops. Finally, nature preservation areas benefit from or even rely on oligotrophic site conditions as they are rare in the intensively managed surrounding landscape.

- In the case of agricultural land specific areas are designed in particular according to the agronomical and operational and needs of the farmers. Therein, substrate homogeneity plays a key role, especially regarding the better rooted, more organic topsoil. Ideally, over 80% of a single management area should be covered with one substrate type of similar cropping properties and reclamation demands.
- The final surface layer, which is the rooting zone, should be only lightly graded. To minimise soil compaction dumping and levelling should be done in separate operations. Especially, for levelling the lightest equipment available comes into question using the fewest paths as possible, which goes beyond standard engineering practices. In general, all soil-preparing operations should be carried out during dry weather conditions.
- Agricultural reclamation calls for $pH_{KCL}$ target values in the topsoil between 6.0 to 7.0 (7.5). In any case, the dumping of crop-friendly, selectively stripped overburden material from the mining forefield is preferable. The thickness of the coverage layer should be minimum 2.0 meters to maintain root growth and a sufficient plant water availability - even in summer-dry regions. Looking at acid-sulphurous and fine textured substrates the cultivable soil layer can require up to 500 Mg CaO $ha^{-1}$ referring to a liming depth of 1.0 meters.
- Uniform growth conditions and soil properties allow the aggregation of so-called *Management Units* (MU) with specific soil target values considering the most important, yield-relevant soil properties, like pH, organic carbon (0.5 to 2.0 mass-% in the topsoil, indicating a good soil fertility), mineralisable nitrogen (N) stock, macronutrient availability (P, Mg, K). In general, the organic carbon content is positively correlated with plant available nutrients, namely N, P and K. Such MU make much easier the tuning of soil developing measures, but also all agricultural work steps within the regular cropping, i.e. soil tillage, seedbed preparation liming, fertilisation, crop protection, harvest.
- In case of arable land, most cropping systems need a regular soil tillage. Therefore, the ploughing depth / topsoil of 30 to 40 cm should be free of stones and stone blocks, to ensure a trouble-free workflow. Notably, considering non-uniform substrates, soil tillage plays an important role for the homogenisation of the topsoil and an even distribution of fertilisers and soil improving agents.
- Beneath soil quality and homogeneity the surface shape is another economical important factor, considering the location of the field within the farmland, it’s size, form and relief. Suited for a highly mechanised agricultural, single fields or management units wherever possible should take 20 to 30 hectares in minimum, with a length to width ratio of 2 to 1.
- In general, the flat wavy arable cropland should have a moderate slope of usually less than 4.0 to 7.0% depending on the soil texture. The gentle inclination ensures a sufficient water infiltration and drainage, reduces surface ponding, prevents serious erosion problems and meets the requirements of general farm tillage equipment.
- Finally, the designated farmland in itself should be set without use competition and legal use restrictions (e.g. EU protected habitat types, *Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora*).

### *7.2 Integrating ecological elements*

Regional landscape planning opens the way to create a *man-made bio-productive (agro)-landscape* and offers quite favourable agronomical preconditions for a profitable feedstock production. Nevertheless, reclamation should not lead to species-poor *agricultural steppes* and monocultures. Moreover, ecological aspects, can gain relevance without reducing the crop potential - in the sense of an integrated land management.

In this light and in good agreement with the *EU 2020 Biodiversity Strategy*, post-mining landscape forming should care about integrating small-scaled and contrasting ecological elements, like hedges, copses, wetlands and tree rows within the field blocks and along roads or field borders, especially in smooth transition to other land use forms. Special habitats / biotopes being unused or managed extensively, contribute to biodiversity with a compensatory or balancing function for intensive agriculture on the other hand (SCHLENSTEDT et al. 2014). Even more, ecological compensation structures are decreasing the wind erosion and unproductive evaporation of the cropland, thus having positive microclimatic and yield effects to the end. Beyond their outstanding ecological value, they provide an attractive post-mining landscape image.

But also perennial soil conserving feedstock is not only a backdrop and *environmental upgrading*. Low-input farming systems that are promoting the self-regulation within the biocoenosis, can improve the agricultural productivity and crop safety - in particular, by positive phytosanitary effects but also a more efficient use of water and nutrients.

### *7.3 Site-adapted biological procedures - restoring full soil functions*

The main objective of agricultural reclamation is to re-establish quite fertile soils as essential for a diverse food, forage or feedstock production - that means: productive cropland, pasture and rangeland. At the beginning, post-mining agriculture deals with initial ecosystems on humus poor raw soils with developing soil functions and an instable structure. Not really surprising, the first yields are quite low due to nutrient deficiency and low biological activity and do not reflect the real cropping potential. A major concern of *biological restoration* is to restore the soil fertility by a proper, conserving management. Within the first crop rotation specific topsoil target values must be achieved (cross compliance).

In principle, both soil protection and economical reasons speak for a more extensive, soil conserving farming. Essential elements are the integration of atmospheric nitrogen binding fodder plants and a conserving tillage with stimulating the humus formation. However, the initial *Syrosem* and *Regosol* mine soils are highly dynamic and complex systems in transition, regarding the interrelations between land management and humus accumulation, nutrient turnover and the development of a proper soil structure.

However, the young ecosystems and soils are also quite sensitive to improper management, e.g. compaction by heavy machines, humus degradation through cultivation of hums-draining crops, a nutrient leaching or immobilisation depending on the quality of plant residuals and the fertilising practice (animal, green manure, mineral fertilisers, organic residuals). Moreover, as proofed by numerous field experiments the appropriate land management for soil-building, results in additional expenses. In particular, the mineral fertiliser application rate as derived for the main crops and crop rotations is exceeding the nutrient removal with harvest products and higher as compared to nearby native farmland, for example +30-50 kg $ha^{-1}$ $yr^{-1}$ (N) and +50-70 kg $ha^{-1}$ $yr^{-1}$ (K) depending on the cultivated crop (HAUBOLD-ROSAR 2018). Finely distributed coal admixtures in carboniferous mine spoils cause wide C/N-ratios, thus impeding the microbial N-mineralisation. The fossil organic substance acts as a considerable sink for applied nitrogen and requires a strong nitrogen fertilisation.

Even this example shows that a proper, soil humus accumulating land management within the *Good Agricultural Practices* (GAP) speed up early soil and ecosystem development. Under these very special circumstances, all available farm manure can be used for agricultural reclamation in order to promote the formation of soil organic matter. Thereby, the type of organic material applied seems to be less important than the application rate (DELSCHEN 1999). Moreover, organic soil improvers like compost, biochar compost, mulches, certified sewage sludge or other humus fertilisers come into question. But in each case, the application must be based upon local soil assessment and conform to legal regulations / precautionary values and thresholds (ZIER et al. 1999).

### *7.4 Soil fertilising crop rotation*

The typical initial crop rotation on poorly structured raw soils involves the cultivation of quite stress-tolerant, deep rooting and fast growing perennial plants, with legumes in a key position. This kind of well-balanced *phyto-amelioration* of at the beginning unfertile raw soils - *point zero of ecosystem development* - has to comply with the establishment of soil functions at first.

On the other side there is only little flexibility for the cultivation of other soil improving energy crops in the first years of management. Only from the date that the ownership is formally transferred the later land users have common cropping options, quite similar to *normal* arable land. Within the *Good Agricultural Practices* (GAP) farmers can position for the permanent cultivation of LCF feedstock and other renewable raw materials depending on the individual operational requirements and market situation.

- In general, crops should be cultivated, that largely use the yield potential of the dumped substrates, which means: having low demands on soil structure as well as on nutrient and water supply. Further criteria are the ability of deep and intense rooting, fixing and accumulation of atmospheric nitrogen and generation of big amounts of crop residues to stimulate the desired humus development.
- Thereby, in European coal mining region lucerne (*Medicago sativa*) or lucerne and grass mixtures, other legumes (*Vicia faba*, *Pisum sativum*, *Melilotus officinalis*) play a key-role in the first crop rotation, to a lesser extent winter cereal, rape (*Brassica napus*) or maize (*Zea mays*).
- At the beginning of biological reclamation, the proportion of perennial lucerne or lucerne-grass-mixture cultivation should be almost 40 to 50% within the crop rotation and the proportion of grain 25 to 35%. With ongoing initial soil development, the proportion of grain growing can be increased to 40 to 45% step-by-step.
- Because of the difficult growing conditions at the beginning - including unfavourable soil structure, unbalanced nutrient supply - the growing should be improved by higher seed rates. The recommended initial sowing rate is about 10 to 20% higher as compared to common recommendations for common farmland of the region.

## *7.5 Low-input energy cropping on reclaimed land*

Very often the cropping potential of well-developed mine soils is insufficient for the cultivation of more profitable and demanding root crops (potatoes, sugar beet). Even considering *EU Single Farm Payments*, the profit contribution (PC) is low or remains negative at the moment due to the high volatility of the agricultural markets. That’s why alternative options for a more predictable production awaken the farmer’s interest, like non-food feedstock, extensive farming but also new, higher priced value-added chains like bio-refining. Moreover, especially on young sorption-poor and water limited mine soils the ecological aspects favour perennial feedstock systems with a low nutrient removal and high, humus-forming carbon sequestration rate.

As recently shown in a feasibility study by KNOCHE et al. (2019), growing energy crops for biomethane production with lucerne and *Sorghum* in a top position makes economic sense when considering the whole production chain. However, under the current market situation with rather low fossil fuel prices, investment in energy cropping for biomethane on the selected reclamation sites is not fully viable yet. The high cultivation costs dominate the financial result. But it turns out as a borderline situation: A higher payment for the feed-in of biomethane into the natural gas grid by only 10% would turn the whole investment into the profit zone. On the exploitation side, upgrading and purification of raw biogas to natural gas standards makes sense, even more as the additional costs for biogas up-grading account for only around 2% of the total investment.

It is obvious, that rapidly changing market conditions as well as variable and unforeseeable national subsidies for renewable energies in the future are serious barriers for such initiatives. Although first small-scale growing trials speak for a further diversification of the plant spectrum, there is up to now no noticeable implementation of perennial feedstock crops into the reclamation practice. Moreover, it is proven that some high-performing energy and platform annual crops like *Sorghum*, *Sudan* grass or *Miscanthus* can be more embedded on disturbed land without impairing the soil development. Anyway, it seems really difficult to animate the farmers for an overall production conversion, given the incalculable and unknown financial risks.

Possibly, a more extensive reclamation is not only cost efficient, but can also speed up the desired soil development, especially early humus formation. As it is well known, short-rotation coppices (SRC, agricultural wood) and agroforestry systems (AFS) make a substantial contribution to enhance the ecological and aesthetic value of post-mining landscapes (QUINKENSTEIN et al. 2009, 2012). However, at the moment such innovative land use systems are hardly profitable (BÖHM et al. 2011). And there are strong psychological barriers regarding the cultivation of woody biomass or perennial energy and LCF crops on reclaimed land.

Nevertheless, energy crops grown on post-mining land are providing feedstock opportunities for future innovative value chains integrating the production of bioenergy, materials and higher value chemicals. Such innovative green technologies can be the initial spark for a new bio-based industry in the regions after the phase-out of coal mining. In order to deal with these planning uncertainties the focus should be on smart, demand-driven processing systems beyond the already established production systems (KNOCHE et al.2019). The idea is to process energy crops locally in a short distance from the field - and if possible, in cascades, including all unused potentials from agriculture and landscape maintenance. Also the necessary crop rotation in agriculture calls for a diversified biomass utilisation combining material and energy use.

# 8 Best practice solutions for forest reclamation

## *8.1 Forest reclamation through changing times and frameworks*

Especially in the North American and European temperate climate zone, afforestation of lignite sites and hard coal waste dumps plays a key-role for reclaiming mine lands and is commonly applied (KATZUR & HAUBOLD-ROSAR 1996, FLICHEVA et al. 2000, HÜTTL & WEBER 2001, HOLL 2002, KNOCHE 2005, ZIPPER et al. 2011, PIETRZYKOWSKI 2015, McDONALD et al., 2015, KNOCHE 2018, etc.). In fact, it has a long tradition, the first scheduled and quite successful reforestation, for example in the Czech and German lignite areas as well as the *Upper Silesian* hard coal district, date back to the early 20th century.

Forest restoration faces many challenges such as the need to re-create the landform complexity that underlies variation in ecosystem structure, composition and function and to redevelop soil types that in natural systems develop slowly over long time periods. On the other hand, forest restoration in post mining sites bring numerous opportunities such as possibility to restore relatively fast ecosystem functioning of the landscape. For example, forest restoration of post mining sites allow facts sequestration of carbon in ecosystem in rates that are several fold higher than in reforested former agricultural land (FROUZ AND VINDUŠKOVÁ, 2018).

Over time the guiding principles have changed due to the developing experiences on reclamation and general forest understanding as a mirror image of the social demands to forests and forestry (KNOCHE & SCHLENSTEDT 2018). At the beginning, those responsible for reforestation favoured more robust, less nutrient and water demanding pioneer trees like common birch (*Betula pendula*), Scots pine (*Pinus sylvestris*) or aspen (*Populus tremula*) and some elsewhere proved species like the North American black locust (*Robinia pseudoacacia*) and red oak (*Quercus rubra*). Although both survival rate and initial growth of these species are sufficient to ensure forest development, they very often undervalue the site-related growth potential. Planting poorly site-adapted, even-structured or quite instable coniferous tree monocultures should be avoided - although they lead to a fast revegetation and show a good productivity in the first decades (KNOCHE 2005). One sobering example for a misleading forest reclamation is the strong infestation of Scots pine plantations by *Annosum* root rot, causing an alarming dieback in first thinning stands (KNOCHE & ERTLE 2010). Therefore, modern forest reclamation tends to site-adapted forest systems - in good agreement with the potential natural vegetation of the region thus avoiding not site adapted hybrid woods and instable monocultures.

### *8.2 Establishing woodland: legal requirements and self-commitment*

Thereby, in some European coal mining regions, like the *Lusatian Lignite District*, forest reclamation efforts of the mining companies exceed the minimum legal requirements of revegetation and establishing woodland in a formal sense (KNOCHE & SCHLENSTEDT 2018). The justified goal is to establish useful and stable, near-nature mixed (native) forest ecosystems, following consequently the ecological approach of reclamation (PIETRZYKOWSKI 2015, KNOCHE 2018, VACEK et al. 2018). In this way up-growing trees modify the habitat and stand conditions in direction to a sustainable ecosystem development driving the revitalisation of the whole post-mining landscape (BYERS et al. 2006, PRAUSOVÁ et al. 2017) - especially by carbon sequestration in soil and plant, forest ecosystems act as *natural ecosystem engineers* (VINDUŠKOVÁ & FROUZ 2013). Thereby, up-growing forests on new ground act as a considerable carbon and nutrient sink in the first decades of stand development before reaching an equilibrium in the long term (BARTUSKA & FROUZ 2015, KÖHLER & KNOCHE 2019).

New woodlands have to meet the increasing demands on multifunctional forests concerning productivity and protection of natural resources but also recreational and aesthetical claims of the population - right from the very beginning. Moreover, the implied sustainability of non-market services and goods leads necessarily to low-input and low-risk systems with a high biodiversity - in terms of biological self-regulation a basic condition for long-term profitable forest management. Thereby, site-suitable tree species on *new ground* should also generate value and income for their owners. In most cases afforested stands show a higher biomass growth and better economic benefit as compared to more diverse stockings from natural succession (VACEK et al. 2018):

- For a profitable timber production, surface design has to meet the requirements of a fully mechanised harvesting and tending. To ensure the full forest technical trafficability of unpaved logging paths the slope angle should not exceed 1:4 (25%). Small-scale terrain differences in height of 0.5 metres can be tolerated. As previously mentioned, substrate preparation and amelioration depend on the quality of the dumped soil substrates.
- Long-term planting trials confirm that an optimal forest ecosystem development on reclaimed land can be achieved at $pH_{KCl}$ >5.0 in the silicate buffer range - alkaline macronutrients (Ca, Mg) are dominating the soil solution without exchangeable aluminium at the clay surface. Regarding pyrite containing acid-sulphurous substrates the pH stabilising lime incorporation should be up to 1.0 metre soil depth to assure a good deep rooting.
- The species configuration has to meet both the adverse growth conditions of humus-free dumped raw soils but also the long-term habitat conditions under consideration of soil and ecosystem development. That speaks for trees tolerating a wide range of soil conditions and a high soil heterogeneity. Moreover, target stocks should represent tree species combinations as they appear most likely by free succession in the terminal stage of ecosystem development. As commonly known, native species and ecosystems offer the best chances of self-sustainability. In continental-minted Central and East Europe, for example, common stand-forming species for nutrient poor and dry sandy substrates are sessile oak (*Quercus petraea*), common oak (*Quercus robur*), lime tree (*Tilia cordata*) and Scots pine (*Pinus sylvestris*).
- Such robust climax tree species have a broad ecological amplitude and can even tolerate equilibrium pH values below 4.0, which makes them suitable even when the soil preparation is insufficient regarding the targets. In contrast, other more pH sensitive valuable broad-leaved trees, like ash (*Fraxinus excelsior*) or maple trees (*Acer spec*.), are reserved for the most valuable substrates with growth optimal conditions of the silicate and alkaline buffer range.
- All the more mine spoils show a very high small-scale heterogeneity. The formation of mixed stands is reasonable from the ecological point of view. The natural seeding of gap-filling pioneer trees like common birch (*Betula pendula*), European aspen (*Populus tremula*), goat willow (*Salix caprea*) or mountain ash (*Sorbus aucuparia*) is welcome, insofar they do not counteract the higher-level development goal towards the terminal forest type.
- Furthermore, rare tree species and local provenances worthy of conservation but also autochthonous bushes should be considered. Added in small groups, they contribute to

biodiversity and serve landscape aesthetics, especially along stand edges, forest roads and in transition to the surrounding land.

- Modern forest reclamation takes up consequently the common trend towards a near-natural forest management. Consequently, to the ecological approach, non-native, invasive and poorly site-adapted trees and bushes - how they are still frequently used in gardening or small-scale landscaping - are refused.

Risk-spreading mixed stands are always reasonable, because of the small-scale substrate heterogeneity quite typical for mine spoils and against prognostic uncertainties pretaining to soil development and climate change effects on tree growth. Also the various multiple uses and environmental benefits of forests call for a plant combination of ecological complementary native timber species in small habitat adapted groups (KNOCHE & SCHLENSTEDT 2018). However, the establishment of mixed stands is no end in itself or done in a haphazard and random way:

- Selecting trees should always consider the special site conditions, growth potential, competitive relationships, ecological issues and the timber production following the principles of a sustainable and multifunctional forestry on reclaimed land.
- As a general rule, the growth dominant and forest-forming tree species take 50 to 75% of the total plant number, ancillary fillers or complementary and economically important understory 30 to 50%. Additional, particularly biodiversity increasing intermediate trees cover between 10 and 20%.
- At least, rare provenances worthy of conservation and autochthonous bushes should be considered as well, e.g. for the ecological shaping of forest edges. In any application, only regional or proofed, well site-adapted propagation material is suitable.

### *8.3 Integrating natural regeneration into reclamation practice*

The new situation allows an implementation of spontaneous succession into forest ecosystem reconstruction (KNOCHE 2001, MACDONALD et al. 2015, PIETRZYKOWSKI 2015, FROUZ et al., 2015, PRACH et al. 2016) - as far as possible from the biological point and not counteracting the desired post-mining landscape development and the specific forest objectives associated with a multifunctional silviculture. Therefore, it is essential to have a regulatory framework that is opening scope for trees with pioneering growth strategies to achieve the defined objectives of forest establishment in a reasonable time, especially on very low-yielding and heterogeneous sites. From a point of legal view, it is finally irrelevant if a forest stand - defined as a definable area stocked with forest plants - results from afforestation or natural (managed or unmanaged) succession.

As compared to artificial forests, succession processes without human interference lead to a higher small-scale habitat and biodiversity which also meets the substrate heterogeneity of geological overburden materials (VACEK et al. 2018). Thereby, soil-preparing pioneer trees are driving the ecological restoration (PRACH et al. 2016), even more as they can have a surprising high aboveground biomass in the early stage of development (KUZNETSOVA et al. 2011). As proofed in many field studies the soil development of sites under spontaneous forest succession and afforestation is quite similar, for example when looking at the microbiological activity (FROUZ et al. 2006). Nevertheless, it is fundamental to have or create an adequate rooting medium before, because otherwise in more extreme site conditions, especially very acid sulphurous substrates, less-demanding grasses and herbs may block wood succession (PRACH et al. 2001b). It is also important to have enough seed trees in the vicinity (<1,000 metres) - a crucial point for natural revegetation of post-mining land (HENDRYCHOVÁ 2008):

- Spontaneous succession and promoting natural selection processes do reduce the direct costs (labour, materials. maintenance) and intensity of intervention at the beginning - a contribution from nature herself in the sense of *biological automation*. In fact, the expenses for soil preparation are much lower as compared to the demands of intensively managed ecosystems.

- Replacement of fertile overburden material, for example, selectively excavated forest floor and topsoil of the cleared opencast working face (forefield) or other biological active organic materials, contributes to the establishment of native species. The management of rootstocks and seeds already present in the soil is also speeding up the soil development processes, especially, the desired humus accumulation.
- However, in reality the highly mechanised mining technologies are very often fail to extract and transform such ecological valuable substrate cover or structural elements. Besides basic operational constraints the costs and other limiting factors are making it impractical.
- Both spontaneous and assisted regeneration take a longer time for a full-surface covering revegetation as compared to more homogeneous yield-optimised forest monocultures or plantations using only a few species. Moreover, in most cases the production value, namely timber growth and quality, is lower. Very often low-priced timber assortments fail to generate a short-term net income for landowners in the first rotation period.
- Self-seeding pioneer trees have a high ecological value but they clearly undervalue the site-related growth potential as it can be achieved by final plant communities. Aspen, alder or common birch have a great potential for regeneration, they are good adapted to extreme site conditions, but unfortunately they are aging early destabilising forest stands.
- Notably from the production point of view but also considering soil conversion, it is calling for an early stand conversion (already in immature pole forests). Such measures maintain basic ecological forest functions and ensure the long term soil development.

Spontaneous natural regeneration and managed succession in forestry are sometimes considered as poor reclamation practice, also it has numerous ecological benefits, notably looking at biodiversity, habitat conservation and saving endangered species. The challenge for reclamation planning is to find a fair trade-off between the diverse, sometimes conflicting stakeholder interests - in specific site conditions and to socially acceptable terms - for example: biomass production vs. biodiversity, early net income vs. long-term ecosystem stability - taking into a count the small-scale substrate heterogeneity and different yielding properties of mine sites (VACEK et al. 2018). But especially for dense populated industrial and urban regions, extensification of forest management by recourse to natural succession, should be no turning away from a multifunctional forestry - including the climate friendly timber production. For the population it is important to get free access to the land (enjoying nature, field observation, recreational activities, collecting berries and mushrooms, etc.) according to the legal provisions unless there are no higher ranking provisions or spatial planning aspects are standing against, e.g. nature protection areas without or only regulated public access. That implies the opening-up of forests by forest road construction and trials - not only for purposes of forest management and protection against hazards. From this results the responsibility of the land owner to ensure and maintain public safety on woodland.

### *8.4 Start-up support- for a proper forest development*

In general, juvenile coal mine substrates are structure-poor geological substrates, free of humus. Ecosystem development starts at point zero: the choice of proper tree species is a trend-setting decision, determining the long-term ecosystem development, and so the final success of reclamation. Therefore, all technical and biological restructuring measures taken should be derived on the basis of a detailed pre-analysis of the site conditions, i.e. soil mapping and evaluation for each management unit (SCHLENSTEDT et al. 2014).

The bio-productivity of virgin mine soils is mostly limited in by a very low nutrient availability. Notably, freshly exposed mine soil has no or only low reserves of plant available nitrogen, phosphorus and sometimes potassium (BRADSHAW & CHADWICK 1980). Such macronutrients relating very much to the biological nutrient cycling, are plant growth limiting in the early stage, even for quite unassuming pioneer tree species (HEINSDORF 1996, KNOCHE et al. 2000). Therefore, a growth-supporting and soil life triggering basic mineral NP(K)-fertilisation before planting is essential. In addition to enriching substrates with basic nutrients, there are needs-based top-dressings spread over the first decade

(SCHLENSTEDT et al. 2014). The tree species-specific fertilisation sequence does not only enhance survival rate and stimulate early plant growth but also accelerates the desired soil building humus accumulation which stimulates the biological nutrient turnover and thus biomass growth - a kind of self-enforcing process (KNOCHE et al. 2002).

The intention is to supply a continuous supply of growth-limiting macronutrients to force ecosystem development until an ecological equilibrium is achieved (PALMER & CHADWICK 1983, 1985). And, in fact litterfall is the dominant ecosystem flux on reclaimed coal mine spoils and thus the major nutrient source, especially considering NPK (KNOCHE 2005, SEVER & MAKINECI 2009). In addition, there are other flanking management improvements to support planting success and early ecosystem development, like consequent weeding / pest control or mixture regulating to reduce the competition for limited resources - if necessary (SCHLENSTEDT et al. 2014).

### *8.5 Criteria for a proper afforestation*

From a formal point of view, forest reclamation means to restore woodland which is - in narrow interpretation - just a surface stocked with woody species according to the national forest legislation. Thereby, it is regardless of whether a forest stand gets established by planting, sowing or natural succession. In order to assess the reclamation success by the forest or other approval authorities involved, it makes sense to define quality criteria for proper plantings and their final acceptance as wood or commercial timberland in a legal sense. However, the features for assessment depend on the needs and goals of reclamation as defined in the regions, and it is really difficult to determine clearly when such a complex biological processes get efficient and self-sufficient (BELL 2001, PIETRZYKOWSKI 2015).

One best practice example with respect to operating plans and legal requirements for that, offers a public law agreement in the *Lusatian Lignite District* negotiated between the involved forest authority and the mining company: over there the early sapling stage (10-20 years after planting is relevant for the quality check) is relevant for completing the administrative process of reforestation, which means that forest in a material/formal sense gets established, following the common legal definition: any surface stocked with forest plants having a minimum size and the ecological character of woodland. At that time the basic structural and functional features are existing: canopy closure has already taken place, a balanced forest microclimate and ecosystem nutrient cycling are established and the mineral nutrition is sufficient (KNOCHE et al. 2002). So it can be expected that the up-growing ecosystems are self-sustaining and self-regenerating in the long term. Very concretely, at this growth stage plant failure should not exceed 10% of the initial stem number - and no single gaps larger than 1,000 square meters are tolerated. Moreover, there are tree species-specific minimum plant numbers per hectare that have to be achieved, for example: scots pine / 8,000 pcs., sessile and common oak / 6,000 pcs., other hardwood species / 2,500 to 4,000 pcs.

After overcoming some initial growth limiting factors, like the lack of plant-available nitrogen and soil humus, there is a quite promising ecosystem development. Already in the sapling stage, ecosystem nutrient turnover by crown leaching, litterfall and humus mineralisation is similar to comparable forest stands growing on undisturbed soils (KNOCHE et al. 2002). Below the line, after 20 to 30 years' forests on the mine sites show a growth performance and biological-ecological diversity which is comparable to the surrounding countryside (HÜTTL & WEBER 2001, KNOCHE 2001, KNOCHE & SCHLENSTEDT 2018).

# 9 Guidelines for Nature Preservation

## *9.1 Post-mining landscapes - a chance for wildlife*

Large scale surface mining causes a complete and irreversible destruction of the original landscape and ground cover, in Europe corresponding with revegetation after the last ice age (HENDRYCHOVÁ & KABRNA 2016). Not only at the first impression, mining leads to a loss of biological elements and leaving behind a *lunar landscape*. But taking a closer look, a new post-mining landscape is organised, with an unexpected high species richness due to contrasting soil and extreme abiotic site factors (BARANOVÁ et al. 2015, LORENZ & LANDECK 2017, etc.). Hence, this anthropogenic landscape type shows a high development dynamic getting more diverse over the time (ANTWI et al. 2016). And it offers valuable analogues of natural biotopes a unique chance to preserve and develop important habitat structures for nature conservation - a *new wilderness* (*rewildering*) by accident (KRZYSZTOFIK et al. 2012, GREMLICA 2014).

Thereby, spontaneously developed sites have a high proportion of species worthy of protection than technically reclaimed land according to human usage and design requirements (TROPEK et al. 2012). For example, ŠÁLEK (2012) highlight the importance of complete succession series and especially early revegetation stages for developing valuable bird communities, which are one of the most studied indicator groups for large scale ecosystem restoration. Proceeding from this viewpoint, costly technical reclamation of post-mining sites is in a conflict situation with biodiversity conservation. But other findings suggest, that a combination of reclaimed and un-reclaimed sites is the best practice for species protection (HENDRYCHOVÁ & BOGUSCH 2016, MORADI et al., 2018). In any case nature conservation should always focus on integrating his prioritised goals into reclamation plans already at an early landscape planning stage. For the consistence of restoration planning it is helpful to have prognostic tools predicting the probable successional series depending on the controlling factors, i.e. substrate quality, topography, microclimate and the surrounding vegetation as a source for diasporas (PRACH et al. 2001a).

The conditions that made post mining landscape particularly valuable for restoration of close to natural habitat that harbour many species of high value for nature conservation (threaten and endangered species) can be summarized as follows: presence of substrates with low nutrient content (many rare species are oligotrophic nut most of recent landscape is heavily leaded by nutrients), high variability in substrate quality and spatial heterogeneity, presence of base soil with rough and loose soil (most of bare soil in our landscape is compacted by agriculture machinery or other means) (FROUZ 2014). Avoiding extensive site eutrophication and compaction is an important precondition for successful application of close to natural regeneration (FROUZ et al. 2018).

A good example offers the *Lusatian Lignite District*, over there natural succession is a landscape planning option since the 1990s (SCHULZ & WIEGLEB 2000, WIEGLEB & FELINKS 2001). In this specific areas biotopes and species protection have priority over commercial targets of forestry or agriculture. Actually, about 25% of the post-mining area is now reserved for nature conservation purposes: *Natura 2000 / EU Habitats Directive*, *Specially Protected Areas* / *EU Birds Directive* and protected areas according to national legislation. But still the official statistics about post-mining land use in Germany do not count the land for nature conservation - indicating that restoration aims remain controversial. The same situation is in Czech Republic and many other European countries, where restoring post mining landscape for nature (wildlife) has been experimentally tested sometimes with good reasons but still cope with many legal and administrative obstacles.

## *9.2 Different strategies: Natural dynamics versus control measures*

As demonstrated exemplary by BRÄNDLE et al. (2000), KENNEDY (2002), NOVÁK & KONVIČKA (2006), FROUZ (2014) or HILDMANN & SCHLENSTEDT (2018) for a broad spectrum of species groups and biocoenosis, the post-mining landscape as whole can be an unexpected counterbalance for lost habitats in agricultural landscapes untouched by mining. Notably, in landscape zones with intensively managed farmland dominating, the environmental path may play a key role for conserving biodiversity in the region and beyond (BRADSHAW 1989, KENDLE 1995, PFLUG 1998, TISCHEW & KIRMER 2007, LANDECK et al. 2017). And HENDRCHOVA (2008) referring to Tajovský & Voženílková (2002) concludes that "a combination of technical afforestation - in a broader sense *reclamation* - with spontaneous succession seems to be the most acceptable general management strategy in post-mining landscapes, both from the ecological and from the economic point of view."

According to SCHULZ & WIEGLEB (2000) and HENDRYCHOVÁ (2008) there are three complementary and sometimes competing restoration concepts of nature conservation in post-mining landscapes leading to different approaches and later management options: (1) allowing natural dynamics to take place without human interference (*close to nature approach*) and (2) implementing selective species and (3) habitat protection measures in the sense of a managed or guided succession.

Sometimes the mining company has an obligation to restore surrogate habitats close to the pre-mining situation as an equivalent compensation for destroyed biotopes. Another quite complementary nature conservation strategy is focused on the intentional reintroduction of special key species, such as rare or otherwise endangered plants by sowing.

### *9.3 Natural conservation - well justified and no excuse for improper reclamation*

Many ecological arguments speak for a systematic implementation of successional sites into land reclamation and nature conservation practice, even more as in European agricultural landscapes extinction of species is a pressing issue. Besides leaving disturbed sites completely untouched is the lowest-cost option. However, in no case low-input natural greening should preclude the mining operators from their responsibility for a proper reclamation which satisfies the permit requirements and land user's claims (HODAČOVÁ & PRACH 2003, HENDRYCHOVÁ 2008): regardless of the designated follow-up land use as set in mine and reclamation planning they have to ensure sufficient preconditions for plants. Such non-negotiable land preparation includes: safeguarding of the geomechanical stability, levelling and profiling of heaps and dumps if needed, soil amelioration and basic fertilisation in the case of unfertile spoil material and the sowing of a protective plant cover to prevent water erosion of barren land.

Thereby, it should be noted, that the expenses for land reclamation in lignite or hard coal extraction are only a small part of the total costs of mining operation. For example, in the *Lusatian Lignite District* ecosystem reconstruction in the narrow sense amounts only 2 to 4% of the production costs.

# 10 Conclusions

When summing up, there are some key principles to consider when planning mine closure and implementing post-mining reclamation. First of all, any concrete guidelines for ecological restoration should be an integrated part of the mine resource management through the life of a mine, always regional specific, situative and considering the available scientific information on both substrate quality and usability best as possible. However, and besides key milestones that have to be achieved (like soil target values, growth and vitality criteria), there remains still a degree of uncertainty when looking at the long-term ecosystem development on new ground - even more as nowadays the climatic conditions are changing rapidly thus overlapping endogenous soil and ecosystem forming processes. In addition, the economic framework conditions and production targets in agriculture and forestry continue to develop, one example are innovative biomass processing chains.

Therefore, it makes sense to apply the risk-spreading precautionary principle when conclusive information on long-term ecosystem development is missing in detail. For reclamation performance and quality control there must be detailed conceptual descriptions and assessments of all reclamation activities including target criteria that have to be achieved in definite time, like soil target values in agriculture or biomass growth and biodiversity indicators for afforestation. It must be ensured that the reclamation objectives have been met once operations cease. Otherwise, additional maintenance measures are necessary.

However, the land management itself should be adaptive to react reasonably if the cropping situation changes, e.g. by integrating natural succession processes in restoration or site adapted native species and special cultivation methods developed for reclaimed land. Below the line, a mosaic of different land use categories is promising the highest economic and ecological value but also stakeholder acceptance in entirety.

*Agricultural reclamation*

- Agricultural reclamation of suitable arable mine spoils may contribute significantly to assure the continued existence of agricultural enterprises affected by mining activities, especially in times of an increasing shortage of fertile agricultural land worldwide.
- As compensation for the minus of production area a somehow agronomic upgrade should de intended - in particular, through the provision of high-yielding substrates and a proper topsoil preparation.
- The application of organic materials (composts, solid and liquid manure, digestates, etc.) with a balanced ratio between carbon and plant available macronutrients is stimulating soil development. But equally important is a soil fertilising and structuring crop rotation with nitrogen-fixing legumes in a key position.
- Scientific preliminary studies and a monitoring of the soil and yield development are necessary for the elaboration and adaption of all restoration procedures and land management activities under the special site conditions on dumps and tips.
- Guideline (target) values for soil properties and a monitoring of the yield development provide an evaluation or control of the reclamation progress and success. The key criteria for the topsoil evaluation are: pH-value, humus and carbon content, plant available macronutrients, water storage capacity and bulk density.
- On humus- and nutrient-poor raw soils the first yields do not reflect the real cropping potential. Improving soil fertility is a long-term, biological driven process taking 60 to 80 years until the site-adapted and sustainable yield production potential is achieved.

*Forest reclamation*

- In the temperate climate zone afforestation and natural reforestation of stripped land are the most obvious and promising solution for revegetation. Forests are the climax vegetation form providing basic ecosystem functions and services in the long term.
- In principle, the biological self-organisation of forests can follow technical reclamation and natural succession, depending on the landscape planning objectives, i.e. the requirements of the society and subsequent users of the reclaimed land. Leaving behind or creating a suitable rooting medium is an essential precondition for ecosystem development - in particular, if forest management orientates primarily at economic targets.
- The overall challenge is to establish diverse, low-risk, forward-looking and sustainable forest ecosystems for multifunctional use options. Scheduled afforestation by planting or seeding and natural succession should complement each other, with different nuances and emphases in detail.
- Implementing natural succession can expedite the artificial establishment of forest habitats. Even though successional tree species cannot replace commercially valuable crop trees in an economic sense, they are most important for wildlife and early soil revitalisation.
- The of artificial forest ecosystems with productive functions but close to nature is promoting a self-supporting development. On the other hand, natural forest succession can be accelerated by introducing late and final successional, heavy-seeded species such as oak trees or beech.
- It is well known that deciduous trees support humus quality, soil life, soil forming processes, ecosystem nutrient turnover and mineral nutrition - all aspects considered having positive effects on timber growth a reclamation progress.
- As for all long-living and complex ecosystems it makes sense to assess the reclamation quality by a combined growth evaluation and biodiversity check. In contrast to agriculture, soil target values which have to be achieved in a short management period are questionable, since after initial revegetation there is no more regular soil cultivation.
- Forest ecosystem and soil development are long-term processes, although mature forests on reclaimed land show quite similar functional features as forest stands of the surrounding area regarding biomass growth, mineral nutrition, water turnover, nutrient cycling.

*Nature Conservation*

- Technical agriculture and forest reclamation implies a landscape design and soil preparation adequate to the management demands of the land users. By this the structural diversity and small scale patchwork of the ground surface resulting from spoil heaping gets levelled out to some extent.
- Moreover, strictly reclaimed land is developing much faster from the starting point. Notably basic soil amelioration and regular fertilisation speeds up ecosystem development in the early stage.
- A dilemma from the ecological point of view: Intensification of mining operation and standardised good reclamation practice are in general leading to a more productive but also uniform, artificially smoothed post-mining landscape.
- Especially, when looking at a higher landscape scale, better-yielding cropping systems correspond with a loss of biodiversity as compared to human-undisturbed sites. In contrast, many comprehensive studies reveal, that both natural self-development and guided succession lead to better ecological values as compared to one-way technical reclaimed areas.
- As a counterpoint to production targets the different plans in the active mining and mine closure should always take into account the management requirements to ensure biodiversity values and ecological variety in the developing post-mining landscapes. In particular, habitats with extreme substrate and specific microclimatic conditions are a good refuge for endangered species.
- Various management strategies are available and exercised to support the formation and conservation of scarce habitats in post-mining landscapes suitable for the re-colonisation of indigenous and threatened species.

- Therefore, the establishment and conservation of sparsely vegetated, nutrient poor and dry bare substrates, dunes and wetlands plays a key role. Another option relates to agro-environmental measures for conserving the open landscape and early successional stages, e.g. by extensive grazing and cutting regimes.
- Summing up, nature conservation measures should contribute to improve biodiversity upon the pre-mining conditions, even if there is no concrete legal obligation. However, even in designed nature reserves landscaping cannot stand against overruling and legally-binding reclamation targets, notably considering long-term erosion control and safeguarding of ground stability.

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