ECOMINING AS A PATTERN OF INTEGRATED APPROACH TOWARDS SUSTAINABLE MINING

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This paper briefly describes the Educational Project "EcoMining: Development of Integrated PhD Program for Sustainable Mining & Environmental Activities" (2019–2022), which is being implemented between Dnipro University of Technology (DUT, Ukraine) and Technical University Bergakademie Freiberg (TU BAF, Germany) under support of German Academic Exchange Service (DAAD).

Introduction. Sustainable mining with environmentally friendly approaches of extraction and processing of natural resources erased nowadays as one of the most challenging issues of the XXI century agenda. Mining causes the most powerful impact on environment including water pollution, soil erosion and soil contamination by heavy metals, formation of sink holes, variations of groundwater levels, loss of biodiversity, affecting the surrounding population's health, ecosystem integrity etc. In some countries, mining companies follow strict national environmental standards and implement rehabilitation measures at mining areas that significantly diminish environmental impacts. Otherwise, a range of technogenic consequences related to erosion of exposed tailing dams, overburden dumps, hillsides, mine waters and siltation of creeks, acid mine drainage effects, air pollution emissions etc. will be pertinent to the affected territory even after closure of mining operations.

The severity of environmental impact depends mostly on three factors: availability of mineral resources, the intensity and mode of mining activity in the region, and the effectiveness of environmental protecting measures. The last one is associated with the availability of professional companies and well-educated experts in the sphere of environmentally responsible mining and post-mining territory remediation.

Ukraine is a very attractive country in the Eastern part of Europe in terms of mineral resources. It has 5% of global reserves of iron (Krivbass and Poltava regions) and plays a key role in the field of mining and metallurgy of ferrous and non-ferrous metals possessing the third place in global export of iron and steel with annual production of 5–7 million tons. Lviv-Volyn and Donetsk basins are recognized as the coal base of Ukraine. Except of iron ore and coal, the country has rich reserves of manganese, salt, natural gas, granite, graphite, sulphur, kaolin, titanium, nickel, magnesium, mercury, uranium reserves. The Nikopol basin has one of the world's largest manganese-ore deposits. The country ranks fourth in the production of rutile and fifth in the production of titanium alloys. It is one of the world's top four producers of gallium.

As a result of mining operations the territories suffer from physical destruction of the surrounding lands, establishing technogenic landscapes with open pits and rock dumps. Such disruptions can contribute to the deterioration of the area's ecosystems and their functions for human society. In Ukraine, considerable areas are occupied by overburden dumps and tailing storage reservoirs. The total area of deteriorated mining lands exceeds 2800 km^2, of which approximately 1300 km² are still in operation and 1500 km² are subject to reclamation. The overall amount of mining wastes exceeds 25 billion tons. Annually, 7–8 thousand hectares of rural and agricultural lands are allotted for the needs of mining industry.

Reclamation of mining lands is the most problematic challenge in the range of environmental issues. Traditionally, most of these reclamation technologies consist of two stages: technological and biological. The first one includes formation of the land or dump surface and further soil covering. The second one encompasses diverse phytoremediation techniques with the target of more-the-less sustainable landscape and biodiversity. But the overall result of the site restoration is not always successful.

There are some positive experiences of long-term mine lands reclamation implemented mostly by big mining companies via own specialized subdivisions. One example is the process of restoration of land in the Dnipro brown coal basin (Central Ukraine), including application of a fertile layer of soil and addition of lime and brown coal ash with subsequent cultivation of perennial

herbs. The slopes and upper benches of the Annivskyi open pit (Krivbass) are planted with acacia, poplar and other trees. Ordzhonikidze Mining Plant, the biggest producer of manganese ore in Ukraine, has implemented multi-stage reclamation with subsequent taking-off soil layer and storaging it on the reclamation site with further sowing plants and transferring these lands to agricultural sector. But the examples mentioned above cannot reflect the full scope of problems related to mine land reclamation.

First, existing positive experience in mining land reclamation refers to big Ukrainian companies that have subdivisions dealing with remediation techniques. The mining company is not interested in attracting external companies specialized in the sphere of reclamation. So, there is no market place for such companies. As a result, there is no need for training experts and professionals for land reclamation.

Second, the personnel engaged in mine land reclamation have different educational background and experience. Professionals with technological education usually do not deeply understand the processes pertinent to ecological approaches in mining, physical and chemical conditions occurring in the soils, plant physiology, biodiversity issues etc. On the other part, professionals with biological background deal with phenomena and processes related to biocoenoses and their components neglecting features of mining technologies like rock physical properties, dump slopes inclination, porosity and water filtration, sulfur content etc.

Third, there is no specialized Department or curriculum at the Ukrainian technical universities focused on land reclamation, particularly of mine lands. Most of technological Universities offer separate academic courses concerning diverse aspects of reclamation in Bachelor or Master degree programs. But one course does not provide a comprehensive understanding of and effective approach to above mentioned problems.

Thereby, there is a gap between existing wide-scale problems of mine lands and absence of well-experienced professionals in the field of environmentally friendly mining and land reclamation with profound knowledge of both technological and biological approaches.

Aim. Transfer of knowledge from TU BAF to DUT via common courses, workshops, lab research internships, a Summer School and an International Conference will be an essential strategy to qualify both teaching staff and PhD students from DUT, training experts both with a technological-engineering and environmental and resource management background and thus to bridge the gap between individual disciplines in the fields of mining, mineral processing, environment and related sectors.

The main purpose of the paper is to present the achievements of former DAAD project oriented to Biomining and new project focused on development of PhD program “Ecomining” in Dnipro University of Technology.

Ecomining Project and Sustainable Development Approach. Ukrainian higher education is currently in the process of deep multilateral reforms in the course of European standards. Training qualified scientists and specialists of the PhD level in Ukrainian universities and research institutes started in the fall of 2016. The new Law of Ukraine “About Higher Education” identified the need for the development of new standards of higher education for all levels, including the PhD level.

Since 2018, Ukrainian universities have been developing educational components of PhD programs designed for 30–60 ECTS credits.

The Ministry of Education and Science of Ukraine has identified the main directions of scientific research as a priority for the development of higher education and implementation of PhD programs. In the range of these priorities are: research on the most important problems of the development of scientific, technical, socio-economic, socio-political potential for ensuring Ukraine’s sustainable development; rational nature use, environmentally safe technologies and biotechnologies etc.

Nowadays, the most successful and developing eco- and biotechnologies in Ukraine are: biodegradation and waste utilization, phytoextraction and phytoremediation, technologies of biofuel production etc. Therefore, it requires development and implementation of appropriate scientific and PhD programs.

Design, implementation, execution and evaluation of the PhD program “EcoMining” are performed in close cooperation between TU Bergakademie Freiberg (TU BAF) and National Technical University “Dnipro Polytechnic” (DUT). Modules with lectures, seminars and practical courses, Workshops and Summer Schools will be developed by staff from both universities and

associated partners from academia and industry in such a way that they will serve educational and scientific needs of DUT as well as other regional Universities. During the timeframe of the project annual round table discussions with staff from both universities will evaluate activities including training success of modules and common supervision of PhD theses.

The courses developed will be integrated into DUT curricula of PhD Programs at the Department of Ecology and Technologies of Environmental Protection, and at the Department of Open Cast Mining and Department of Mineral Processing.

Transfer of knowledge in basic and applied technologies for sustainable mining and related environmental activities, and technologies e.g. for mine water treatment, phytoremediation and phytomining applicable in the Ukraine will be a central issue both in lectures/practical trainings and in PhD theses to be supervised in common by all partner Universities. A common program for PhD theses based on an agreement on long-term cooperation in education and science between DUT and TU BAF will be one of the instruments of sustainable cooperation between both universities after termination of the project.

A PhD committee with members from both universities will be established to design concepts for long-term cooperation between both universities in research on sustainable mining. Common education activities to be implemented, organized and evaluated by this committee will include exchange of PhD students e.g. via DAAD or other programs.

An advisory board from companies and administration will assist the PhD committee in assessing the program's achievements, adjusting the program aims to recent needs from industry and legal developments, integration of issues from industry and authorities on practical issues into PhD topics and support graduate students during their PhD thesis with relevant information and access to sites, facilities etc.

EcoMining-Centre at the DUT will be created in order to provide a scientific, research and educational platform for master students and young researchers on the basis of association of highly skilled professionals as training experts from partner universities and industry specializing in the area of environmentally friendly and sustainable mining.

Biomining Project (2015–2018) and development of innovative biotechnologies. In 2015, the four-year educational project "Biotechnology in mining – integration of new technologies into educational practice" at Dnipro University of Technology (former name – the State Higher Educational Institution "National Mining University", NMU) jointly with Technical University Bergakademie Freiberg (TU BAF, Germany) had been started. The project was supported by German Academic Exchange Service (DAAD) in the framework of program "Professionally related partnership with universities of developing countries". The purpose of the educational project was introducing new modules entitled "Biomining" for students in the area of speciality "Ecology and Environmental Protection", "Mining" and "Geology" into DUT curriculum.

The term "*Biomining*" is relatively new for both experts in the field of mining and specialists in the area of ecology. It covers the use of a wide range of environmentally friendly "green" technologies in the mining industry, based on the processes of bioleaching, biological treatment of mine water, bacterial coal desulphurization, phytoremediation of contaminated areas, phytoextraction of commercially valuable elements, and other technologies. Certainly, this subject became as the object of interest from the side of students, lecturers and researchers of DUT.

Main results achieved in the frame of the DAAD educational project had impressive outcomes not only for partner Universities curriculum but also for development of new trend in Ukrainian engineering education:

1) *Development and implementation of new Bachelor and Master educational modules in the field of* ***Phytomining & Phytoremediation*** *and* ***Microbial Technology in Mining.*** Two Bachelor disciplines into DUT curriculum: "Fundamentals of Microbiology for Mining" and "Fundamentals of Phytoremediation"; and two disciplines for Master students: "Biomining: Part I. Microbiological Technologies in Mining" and "Biomining: Part II. Phytomining" (Fig. 1.).

2) *Lecture courses "Biotechnology in Mining" presented by German professors at DUT.* Professors of TU BAF provided the courses "Phytoremediation Technologies in Mining" and "Fundamentals of Microbiology for Mining" in 2015 and "Phytomining" and "Microbial Technology in Mining" 72 hours each (2 ECTS credit) for DUT students involved in the Programs

"Ecology and Environmental Protection", "Underground Mining", "Open Cast Mining", "Hydrogeology" and "Ore Processing" (Fig. 2.).

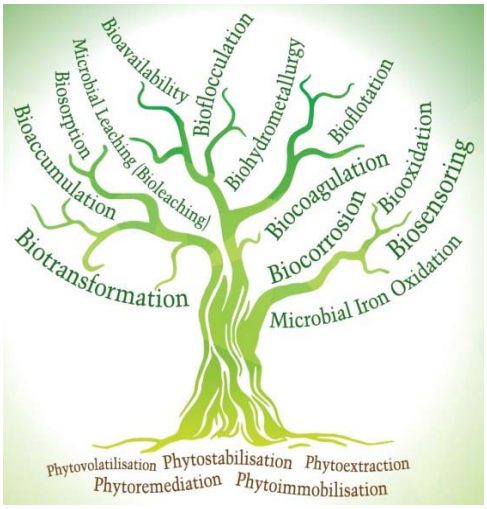

Fig. 1. Biomining technologies

Fig. 2. Lecture of Prof. H. Heilmeier on Phytomining

3) *Five weeks practical lab training for DUT students at TU BAF*. In 2015 and 2016 TU BAF professors provided intensive lab courses for DUT students related to the Phytomining and Bioleaching area of research (Fig. 3-4.). Students studied the research technics for:

- investigating the ability of different species of plants to accumulate rare-earth elements in their tissues or in soils near the root system (rhizosphere) under different conditions. Students prepared the plant material and soil samples for chemical analysis using ICP-MS. Besides, they measured pH and conductivity of soil samples, and concentration of plant nutrients (via spectrophotometry);
- working with microbiological material, microscopy, staining and technology of inactivation of microorganisms (nitrogen-fixing bacteria enrichment; cultivation of *Ralstonia eutropha* bacteria to dispose of aromatic compounds and produce a biodegradable biopolymer polyhydroxybutyrate; anaerobic cultivation of *Rhodopseudomonas palustris* bacteria to investigate spectral absorption curves of bacterial photosynthetic pigments);
- conducting experiments with chemolithoautotrophic bacteria for microbial leaching of elemental sulfur and copper sulfide.

4) *Monthly fellowship for DUT students to carry out research in the frame of Master Theses.*

Students used the following techniques:

- Treatment of soil and plant material for physical and chemical analysis;
- Determination of ammonium, nitrate and phosphate in soil samples via spectrophotometry;
- Bioleaching of industrial waste samples under oxidative and reductive conditions;
- PicoGreen fluorescence staining of bacterial cells by multi-plate reader for biomass analysis;
- Sample preparation for ICP-MS and IC analysis.

5) *Double supervising of Master Theses.* In January 2018 two Master students of DUT defended their theses under double supervising. The topics of the Master Theses: "Study of the environmental hazard level of soil pollution by vehicles and developing methods for its decreasing" and "Study of the Possibility of Using Brown-Red Clay for Reclamation of Waste Rock of Coal Pits of Western Donbas".

6) *Field trips*. The topical excursions on the following industrial objects:

- Thematic excursions on reclamation site of lands disturbed by mining operations of PJSC "DTEK Pavlogradugol";
- Field trip to industrial plant DTEK "Prydniprovsk Thermal Power Station" and dumps material after coal burning (ash and slag wastes);
- Field trip to the reclaimed dumps of the iron open cast mining in Kryvy Rih and Botanical Garden of the National Academy of Sciences of Ukraine (city of Kryvy Rih);
- Professional excursions to the industrial plant Ferrexpo Poltava Mining (Poltava Ore Dressing and Metallurgical Plant).

Fig. 3. Ukrainian students in Phytomining lab

Fig. 3. Working in Microbiological lab

7) *Establishment of the biomining laboratory.* In 2017, the biotechnological lab at the Department of Ecology and Environmental Technologies of DUT was launched. It allowed students to carry out basic experiments related to bioindication and environmental risk assessment.

The outcomes of the project were discussed at the final International Scientific Conference "Applied Biotechnology in Mining" held at DUT on April 25–27, 2018. In total about 40 oral and poster presentations were delivered for more than 100 participants from Ukraine, Germany, Chile, Pakistan, Algeria and Nigeria.

EcoMining Project (2019–2022) and new PhD program. The new PhD program "EcoMining" is designed, implemented, executed and evaluated in close cooperation between DUT and TU BAF as a further step towards development of ecologically responsible mining. TU BAF already has comprehensive and profound knowledge and expertise in the field of sustainable mining and environmental activities. Associated universities and companies from the mining industry are also involved in developing and executing the program. Courses, workshops, lab research internships and a Summer School will be offered in the following fields:

- "Environmental Technologies in Mining"
- "Innovative Technologies in Mining and Technical Reclamation"
- "Biotechnology in Mining"
- "Advanced Topics from Biomining"
- "Responsible Mining Approach".

Direct and indirect target groups. The PhD program is focused on graduate students from various fields in the disciplines of mining (surface and underground), mineral processing, geology (engineering geology, hydrogeology etc.), ecology, environmental sciences, technologies and engineering, biotechnology, agronomy, resource management and related subjects, both from the Ukraine and Germany. The summer school is open to participants from any country. Indirect target groups who can register as guest students are practitioners from industry and administration in the mining and environmental sectors.

Aims of the project. The aim of the project is to develop a PhD program for the Dnipro University of Technology and associated partner universities that allows to bridge the gap between individual disciplines in the fields of mining, mineral processing, environment and related sectors found traditionally, by training experts both with a technological-engineering and environmental and resource management background. PhD graduates will be able to apply environmentally friendly technologies for sustainable mining, land reclamation, environmental biotechnologies, and protection and management of natural resources.

Concept of the project. The project "EcoMining: development of integrated PhD program for sustainable mining & environmental activities" will develop a PhD curriculum for students of DUT and associated partner universities based on courses, workshops, lab research internships and a Summer School in the field of environmentally friendly mining and related activities at an inter- and transdisciplinary level for graduate students in the mining, environment and related sectors.

Young and experienced scientists of both universities and associated partners will be involved in

all activities during and beyond the project. Moreover, at present, the leading tutors from partner Universities are negotiating perspective steps and joint activities including teaching and research work, academic mobility, mentorship and supervising PhD students in the framework of planned activities. This will contribute to establishing a network of TU BAF, Ukrainian universities and associated partners from industry on generation of new technologies in the field of environmentally friendly mining and their transfer into practice.

Outputs. The most important outputs of the project will be the establishment of four courses, three workshops, three fieldtrips, four lab research internships and a Summer School in the fields of Sustainable Mining and Environmental Activities for PhD students from DUT, TA BAF and associated universities. In addition, a lecture on "Microbiology for resource scientists" is presently recorded at TU BAF in German language, which – after translation in English language via subtitles and preparation of corresponding teaching material – could be offered as an online course for the project.

Courses will deal with basic aspects of geology & mineralogy of Ukraine and transport processes in soils, and applied aspects of geochemical modeling and environmental systems analysis, anthropogenic deposits, phytoremediation technologies, biomining, bioenergy and physico-chemical extraction procedures.

Concepts, objectives, topics of course contents and methods of teaching will be developed in close cooperation between staff from DUT, TU BAF and associated partners. Thus teaching staff at the Ukrainian universities and also staff from industrial partners will be qualified in teaching graduate students and supervising their research work on interdisciplinary topics not only in their own field of expertise, but also considering topics, concepts, approaches and methods from related subjects.

The project will run for four years, finishing with an international conference.

The courses developed will be integrated into DUT curricula of the following PhD Programs at the Department of Ecology and Technologies of Environmental Protection: 101 "Ecology", 183 "Technologies for Environmental Protection" and 91"Biology" (with specialization in "Applied Biotechnology"). Also, the selective courses will be integrated into PhD Programs of the specialities "Industrial Technologies" at the Department of Open Cast Mining and Department of Mineral Processing.

Towards the end of the project a consortium for common education by both universities will be established for double supervised PhD theses with graduate students from both and also associated universities being involved in (common) research projects.

Furthermore, the PhD theses commonly supervised by TU BAF and Ukrainian universities and in cooperation with associated partners from industry will contribute to establishment and consolidation of contacts between academia and industry from Ukraine and Germany.

Activities. Development of courses (lectures, seminars, practical training) for PhD students will be developed and implemented by staff both from DUT and TU BAF in years 1 and 2 of the project in the following disciplines:

1. Environmental Technologies in Mining
2. Innovative Technologies in Mining and Technical Reclamation
3. Biotechnology in Mining

Individual topics addressed in the courses are:

- Geology and minerals of the Ukrainian Shield
- Water and mass transport in soils
- Methods of system analysis of the quality of the environment and ecosystems based on the use of geographic information technology and systems
- Formation and mining of man-caused deposits
- Geomechanical modeling of mines and dumps to minimize the disturbed lands areas in mining operations
- Phytoremediation technologies for land reclamation: best available practices on international and national level
- Optimization and simulation measures for energy accumulation and elements uptake with plant biomass as source for the novel goods production in the abandoned minelands
- Forest tree reclamation, phytostabilization and phytoremediation of coal mining heaps

- Forestry remediation systems on mining rock in Ukraine.
- Plant-soil interactions in phytoextraction, rhizosphere processes
- Microbiology for resource scientists
- Biotechnology in mining
- Trace elements bioleaching from coal mining spoil dumps in Ukraine.
- Bioremediation and biomining with microalgae and cyanobacteria cultures
- Suitability of second generation biofuel grasses for post-mining land remediation and phytomining
- Ash-and-slag components as valuable mineral raw materials
- Extraction of rare and noble metals using plant extracts
- High-gradient magnetic separation of feebly magnetic ores.

Field trips. Two field trips will be organized in the first and third year of the project by DUT and associated partners from industry for PhD students from DUT and associated universities to (open pit) mines, mineral processing and metallurgical plants of associated industrial partners in order to demonstrate environmental problems due to mining and processing activities and attempts of industrial companies to solve respectively avoid them.

Workshops. Three workshops for PhD students from DUT and associated universities will be offered by both DUT and TU BAF in each of years 1–3 of the project on (i) structure and requirements of a PhD study, (ii) case-studies and advanced research in the field of sustainable mining, (iii) scientific communication and project management.

Lab Research Internships. Four Lab Research Internships will be organized in each four years of the project at TU BAF on the basis of tutor–PhD student "tandems" (8 PhD students from Ukrainian universities with 4 supervisors) to work in the laboratories of Mining – Surface Mining, Environmental Microbiology and Biology / Ecology for one month each.

Summer School "Eco-mining; geological, biotechnological, geobotanical and environmental approaches". A Summer School on EcoMining will be offered by DUT and TU BAF for 25–30 PhD students from DUT, associated and international universities in the second year at the University investigation site in the vicinity of Berdyansk City (Surozh golden-ore deposit). Major issues to be addressed are innovative technologies of mineral deposits development, biotechnologies, geological, hydrogeological and geobotanical aspects, environmental issues and phytoremediation approaches in mining.

Students will study these topics in practical field work, computer exercises (statistical data evaluation and GIS application) and finally present their results via talks and posters.

International Conference. An international conference for young and established researchers and interested participants from industry and administration on "EcoMining: Sustainable Existing of Nature and Industry" will be organized by DUT in the fourth year of the project.

Conclusions. Ukraine is one of the most important countries worldwide for mining of resources; however, mining activities cause a wide range of environmental problems which are not properly solved yet. One of the reasons therefore is the lack of specialists trained in interdisciplinary approaches of environmentally friendly mining and mine land reclamation. Thus the implementation of inter- and transdisciplinary approaches in the education of specialists for sustainable mining is an essential component of contemporary re-orientation and re-definition of traditional curricula in mining.

Former DAAD educational project "Biotechnology in mining – integration of new technologies into educational practice" (2015–2018) between Dnipro University of Technology (Ukraine) and Technical University Bergakademie Freiberg (Germany) provided outstanding opportunity for students to consolidate theoretical knowledge and practical skills in the field of innovative biotechnologies in mining industry. Implementation of above mentioned academic courses in the area of mining biotechnology into DUT curriculum created a beneficial background for development of the comprehensive Master program aimed at the preparation of highly skilled specialists in mining.

The new DAAD project "EcoMining: Development of Integrated PhD Program for Sustainable Mining & Environmental Activities" (2019–2022) widens opportunities of academic mobility and research for PhD students from both universities towards modern biotechnological techniques in mining.