UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

# COURSE SYLLABUS

# Science and Economics of Renewable and Non Renewable Resources

**2627-1-F7603Q003**

## Aims

This course provides the knowledge relevnt for the sustainable use of natural resources, both renewable and non-reneable, in terms of geological aspects as well as economic aspects, in an integrated fashion using shared case studies.

The module on geological resources provides the technical, scientific and socio-economic basis required to address the most recent issues of raw materials in the mining sector.
The teaching of this module is aimed at providing knowledge and the methodological basis to know and understand the principles that define the raw materials sector, from finding ore deposits and exploitation to environmental sustainability. The course will focus on some processes and practices currently attributable to the concept of sustainability and respect for the environment in various sectors of society, as examples for specific in-depth discussions on the issues addressed during the course.

This module on resource economics and their management presents different rules proposed by economists to manage care resources. It also introduces the main metrics to measure economic features of resource use. It also provides methods to evaluate how projects and policies can be efficient to meet social needs when some resources are scarce. The course will also illustrate how the proposed methods apply to a number of real-world situations.

*Knowledge and understanding*
At the end of the course the student will have a fundamental understanding of:
• the methodological basis to know and understand the principles defining the raw materials sector;
• methods and technologies for finding ore deposits;
• methods and technologies for the exploitation while forstering environmental sustainability;
• enviromental economics with respect to natural resources.

*Applying knowledge and understanding*
At the end of the course the student will be able to:
• apply the concepts regarding resource extraction;

• exploit in sustainable fashion natural resource deposits;
• apply theoretical concepts regarding natural resource economics with changing realities.

*Making judgements*
At the end of the course the student will be able to:
• apply the acquired knowledge in various contexts;
• transfer the concepts and approaches introduced in a certain context to connected fields;
• elaborate the concepts of sustainable resource extraction discussed in the course;
• elaborate the concepts related to resource economics.

*Communication skills*
At the end of the course the student should be able to
• analyse problems in the ares covered by the course in a clear and concise way;
• explain orally with a suitable language the objectives, the procedures and the results of the elaborations carried out.

*Learning skills*
At the end of the course the student should be able to:
• understand scientific literature in the contexts of the covered topics;
• follow new developments in the covered scientific areas related to sustainability;
• combine aspects of various topics at the interface between geological and economical aspects of sustainability.

## Contents

• Ore and industrial minerals, concept of mineral deposit, grade or tenor, tonnage and Clarke (mean crustal tenor).
• Extraction and processing of metallic and industrial minerals, mineral processing, related environmental problems (e.g. AMD - acid mine drainage), mining wastes.
• Energy minerals: oil, gas, coal, uranium, geothermal energy.
• Quarries and mines, national and international legislation. Open and underground mining techniques.
• Open cast and underground mining techniques.
• Evolution of the Earth's crust from the Archean to the Phanerozoic, main metallogenic events.
• Mineral resources and reserves, geochemical and geophysical mineral prospecting, core drilling, examples.
• Critical metals, construction minerals, energy minerals and industrial minerals: key concepts, definitions, and terminology.
• Will we run out of minerals? Considerations of supply and demand.
• The concept of criticality: assessment and implications of criticality for corporate and governmental policy.
• The mining industry and the supply of critical minerals: suppliers of minerals, miners and explorers, industry dynamics.
• Constraints on mineral supply response: natural, economic, and institutional, and the role of China.
• Fundamental economics concepts for resource economics.
• Static models of natural resource use.
• Dynamic models of natural resource use.

## Detailed program

*Ore minerals & industrial minerals*
• ore deposits;
• ore minerals;
• gangue, tonnage, tenor, tout-vènant, Clarke and concentration Clarke;

• mineral and metal ore prices, commercial classification;
• "critical" metals: REE and PGE;
• import and export of raw materials, Italian and European production;
• recovery and by-products;
• mineralogical form of metals;
• unwanted substances;
• melting processes and ore dressing;
• environmental problems;
• mining waste;
• waste rock and tailings;
• environmental remediation;
• regulatory classification of raw materials: I and II category materials, quarries and mines;
• energy minerals: oil, gas, coal, uranium, geothermal energy;
• concept of EROEI (energy recovered over energy invested);
• capacity factor;
• criticality of renewable energy.

*Evolution of the Earth's crust, from the Archean to the Phanerozoic eon*
• nature and morphology of ore bodies;
• syngenesis and epigenesis;
• discordant and concordant ore bodies;
• tabular bodies (lodes and veins);
• tubular bodies (pipes and mantos);
• disseminations, stockwork, replacement (*e.g.*, skarn), stratiform and stratabound bodies;
• main types of host rocks and relationships with ore bodies;
• textures and microstructures of ore and gangue minerals, attitude to ore dressing and processing.

*Genetic classification of mineral deposits*
• magmatic deposits: magmatic crystallization (*e.g.*, diamonds in kimberlites, chromites in stratified basic complexes, feldspars in pegmatites);
• hydrothermal deposits: origin of hydrothermal fluids, ligands, transport, deposition;
• uranium deposits;
• deposits linked to metamorphic processes;
• deposits linked to sedimentary processes, BIF (banded iron formations), placers, evaporites;
• deposits linked to weathering: laterites, bauxites;
• supergene enrichment.

*Mineral resources and reserves; mineral prospecting*
• geological surveys;
• remote sensing;
• geochemistry;
• geophysics core drilling;
• statistical data processing.

*New sources for critical raw materials*
• mining wastes and tailings, from waste to resource;
• landfill and urban mining;
• examples of new approaches in raw materials exploration;
• environmental aspects of critical raw materials: are they really “green”?
• LCA (life cycle assessment) for critical raw materials and recycling potential: is recycling really viable?
• settling the diatribe between “green” and “greenwashing”, an accurate definition of “sustainability” and “circular economy”;
• examples from the mining and quarrying industry in Italy and Europe.

*Concepts, metrics, and measurement*

• economic concepts for examining natural resource use and pricing;
• sustainability and natural resource scarcity;
• Economics of energy production an introduction to environmental resources: externalities and pollution;
• pollution policy in practice.

*Design of policies for non-renewable resources.*
• the economics and regulation of the fishery: an introduction;
• non-renewable resource use: the Theory of Depletion;
• non-renewable natural resource use: departures from the competitive case and from fixed stock size;
• the economics of sustainability.

*Evaluation of projects and policies for renewables and non renewables*
• Evaluation methods: Economic Impact studies, Multicriteria Analysis, Cost Benefit Analysis;
• application to energy generation real world projects and policy;
• application to specific fields: fisheries, forests or others.

## Prerequisites

• Basic knowledge of inorganic chemistry.
• Basic notions of geology.
• Basic notions of economic theories.
• Basic principles of Mathematics (analysis, derivatives).

## Teaching form

12 CFUs of theoretical lessons in the classroom (96 hours):
• 64 two-hour lectures, in person, Delivered Didactics;
• 32 two-hour lectures, online, reading and discussing scientific articles, case studies, and possible integration of guest lectures by experts in the field, Mixed Didactics, Seminar.

Attendance to lectures and interactive exercises is highly recommended.

## Textbook and teaching resource

• John M. Hartwick and Nancy D. Olewiler, The Economics of Natural Resource Use, Harper & Row, 2nd edition 1998.• Arndt & Ganino (2012) - Metals and Society. An introduction to Economic Geology. Springer, 160 pp.
• Kesler & Simon (2015) - Mineral resources, economics and the environment (II edition). Cambridge University Press, 434 pp.
• Gunn (2014) - Critical metals handbook. AGU Wiley, 439 pp.
• Slides.
• Notes shown during lectures and additional material on selected topics, *i.e.*, scientific articles, made available on the e-learning website of the course.

## Semester

I semester (October - January)

## Assessment method

For both modules, a written test is followed by an oral exam comprising topics covered in the two modules comprising the course, with an emphasis also on the connections between economic and geological concepts and processes, such as to arrive at a critical evaluation of work from the point of view of sustainability in mining as a whole.

The final score will be between 18/30 and 30/30 *cum laude*, based on the overall assessment considering the following criteria:
(1) knowledge and understanding;
(2) ability to connect different concepts;
(3) autonomy of analysis and judgment;
(4) ability to correctly use scientific language.

## Office hours

Students are asked to refer to the indications provided in the syllabi of the modules.

## Sustainable Development Goals

QUALITY EDUCATION | CLEAN WATER AND SANITATION | AFFORDABLE AND CLEAN ENERGY | DECENT WORK AND ECONOMIC GROWTH | INDUSTRY, INNOVATION AND INFRASTRUCTURE | SUSTAINABLE CITIES AND COMMUNITIES | RESPONSIBLE CONSUMPTION AND PRODUCTION | LIFE BELOW WATER | LIFE ON LAND