Geo3En
Geothermal Energy
European Education Network

Co-funded by the
Erasmus+ Programme
of the European Union

INTERNATIONAL STUDY PROGRAMS

Summary Report – Intellectual Output 2

1. Introduction: *2*

2. International Study Programs *3*

2.1. University of Zagreb ISP Program **3**

2.1.1. Online Lectures 3

2.1.2. Workplan site visits Croatia 6

2.2. UniLaSalle ISP Program **7**

2.2.1. Online lectures 7

2.2.2. Workplan on-site visits France and Germany 9

2.3. TU Darmstadt ISP Program **10**

2.3.1. Online Lectures 10

2.3.2. Work plan site visit Darmstadt 11

2.4. Reykjavík University ISP Program **12**

2.4.1. Online Lectures 12

2.4.2. Work plan site visits Iceland 13

2.5. Assessment Methods: **14**

3. Discussion **14**

1. INTRODUCTION:

The Intensive Study Program (ISP) is composed of lectures covering some of the major aspects of the Geo3EN course catalog. The chosen lectures cover the basics concepts of geothermal energy utilization including geological reservoirs, reservoir engineering, energy production, utilization, transportation and environmental impact, societal acceptance and economics.

As part of these ISPs, each partner organized a series of online lectures dedicated to these fundamental concepts representing the corresponding competencies of each partner organization. These lectures gave the participants and students the necessary knowledge and skills required to participate in the follow-up site visits, field and laboratory work.

These ISPs are intended to test an interdisciplinary geothermal education program. It is designed to instigate interactions between students with a wide variety of backgrounds in the disciplines of geology, energy engineering and business, project management and economics. In these ISPs the lecturers developed student working groups with one representative from different backgrounds and institutions. We have a primary focus on promoting cross-disciplinary and international cooperation.

Our vision is to give a common knowledge baseline in the students. This baseline knowledge will promote international and cross-disciplinary interactions and lead to a better, more holistic capability of the students to engage in the analysis of geothermal utilization. The project will consider all the steps to be considered when dealing with the development of a real geothermal system.

Depending on student feedback both lectures and site visits proposition can be modified to be integrated in the final Geo3EN course catalog.

2. INTERNATIONAL STUDY PROGRAMS

The following sections include information regarding the ISP programs at each of the partner institutions at UniLaSalle, UniZagreb, TUDarmstadt and RU.

2.1. UNIVERSITY OF ZAGREB ISP PROGRAM

The lectures given at University of Zagreb, Faculty of electrical engineering and computing (FER) are focused on fundamentals and applications of electrical power engineering. Since it is a multidisciplinary field that explores efficient power generation, transmission, distribution, and utilization, lesson materials cover wide range of topics in electrical and mechanical engineering. Students will learn not only about the physical principle of operation of geothermal power plants and their operating characteristics but generally about energy processes in technical facilities.

2.1.1. ONLINE LECTURES

1. Introduction to power engineering

The idea of this lecture is to introduce the concept of energy (energy conversion) to students with low/ or without any previous education in electrical engineering. It should briefly explain how electricity is produced and what systems are used for energy conversion from mechanical/thermal energy to electrical energy. It should also provide the basic information about the electrical power system that is used for energy production, transmission and distribution of electricity to final consumers. The students should be able to understand and explain the power flow form the energy source (geothermal reservoir, coal, gas, nuclear fuel, etc.) to electricity consumers.

- Electric power system outline – power generation, transmission and distribution
- Forms of energy, energy conversion
- First and second laws of thermodynamics
- Conversion of primary energy sources into heat and work (electrical energy)

2. Power plant operation

Learning outcomes of this lecture cover basic knowledge of the processes, components and physical principles of power plant operation.

- Basic operation of different power plant types
- Thermal power plant cycles (Rankine, Brayton)
- Power plant components, operating characteristics and efficiencies

3. Turbines

Turbines are components in power plants used for conversion of enthalpy, potential or kinetic energy into useful work.

- Classification of turbines
- Steam, gas and water turbines; impulse and reaction turbines
- Turbine characteristics and performance

4.Geothermal power

The use of geothermal energy is the focus of this program. The goal is for students to learn the types of geothermal power plants, operation and their selection depending on the geothermal reservoir.

- geothermal power plant types (dry steam, flash steam and binary plants)

- organic Rankine cycle

- plant selection based on heat input (mass flow and enthalpy of geothermal fluid)

5. Electrical generators and transformers

Electric generators are used to transform mechanical work into electrical energy (electromechanical energy conversion). The output voltage of the generator should be increased using transformers to transmission voltage.

- Electromechanical energy conversion and the basic laws
- Electric generators
- Operation of a synchronous generator online
- Voltage/frequency control
- Drive characteristics, power charts
- Excitation systems

6. Transmission and distribution of electric energy

Electricity should be delivered to consumers using the transmission and distribution network. Energy transmission takes place at high voltages and distribution at lower voltages.

- Electric power system outline
- Daily load diagram and power plant selection
- Active and reactive power in a power system
- Electrical grids, smart grids
- Electrical substations
- Alternating and direct transmission

7. Heat exchangers and heat pumps

Heat exchangers are used in power plants for heating/cooling/evaporation in components: boilers/steam generators, condensers, evaporators, combustion chambers, regenerators, etc. Refrigerators and heat pumps use reversed heat cycles to transfer heat from a low-temperature reservoir to a high-temperature reservoir.

- The overall heat transfer coefficient
- Analysis of the heat exchanger
- Logarithmic mean temperature difference
- Heat exchanger efficiency
- Heat pump types and operation
- Compression and absorption heat pumps
-

8. High Voltage Technology

The intent is to explain methods for selecting materials, devices and measurement types for safe application of high voltage technology which, as already said, are used in transmission networks.

- Basic definitions and applications of high voltage

- Materials in the electric field

- Electromagnetic fields

- Electrical arc characteristics

- High voltage insulators

- High voltage tests and measurements

2.1.2. WORKPLAN SITE VISITS CROATIA

Day		8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
1	Monday		FER Introduction	Electrical substation Žerjavinec				High voltage laboratory	Welcome reception FER	
2	Tuesday		Geothermal power plant Velika 1							
3	Wednesday		Hydroelectric power plant Varaždin							
4	Thursday		INETEC – Institute for nuclear technology			Cogeneration power plant EL-TO Zagreb				
5	Friday		Company Končar DST (distribution and special transformers)	Geology of north-western Croatia (field trip to Medvednica/Sljeme)						

2.2. UNILASALLE ISP PROGRAM

The ISP given at UniLaSalle consists of a series of lectures where insights of large scale geodynamic processes, fluid rock interactions processes, stress and strain are presented as it is proven that these parameters play a crucial role in reservoir exploitation potential through time. All lessons use material from geothermal reservoir analogues, i.e. sites chosen to gain input in understanding the evolution of given key processes at depth on certain types of geological structures within geothermal reservoirs.

2.2.1. ONLINE LECTURES

The lecture is constructed in a way to cover tectonic processes favoring the development of a geothermal reservoir at depth from large scale plate tectonics considerations down to rheological processes affecting geological materials in both brittle and ductile fields. Considerations of metamorphism and rock alteration processes are presented as these drastically influence reservoir rock properties. A particular emphasis is given to the coupling between fluid/rock interaction processes and strain on fault zone petrophysical properties evolution.An innovative 3D outcrop visualization method is used to virtually visit outcrops affected by polyphase deformation. This method is of particular interest when dealing with fracture network and strain gradient reconstruction coupled to fault overprinting relationship recognition . Working hypothesis to be verified in the field can be established avoiding the difficult field conditions and limited time that can be spent in front of the outcrop.

Lectures are given over a time period of 5 days (April 11th to 15th) with contributions from several researcher and teachers from UniLaSalle.

1. 3D outcrop visualization
    a. Basic principles of photogrammetric techniques
    b. 3D visualization software presentation
    c. Recognition of overprinting deformation phases and strain gradients
    d. Reconstruction of outcrop structural modelto be verified in the field
2. Introduction to low grade metamorphism
    a. Presentation of the different metamorphic faciès
    b. Low grade metamorphism: presentation and applications
    c. Alteration minerals
    d. Methods of investigation
3. Large scale geodynamic processes
    a. Lithosphere and asthenosphere definition
    b. Plate tectonics
    c. Geothermal gradient
    d. Crustal extension processes
4. Stress and strain in geological materials
5. Brittle deformation processes
6. Ductile deformation processes

2.2.2. WORKPLAN ON-SITE VISITS FRANCE AND GERMANY

In order to visualize a real reservoir geometry and describe fault structure all students will visit mines within the Upper Rhine Graben shoulders in Vosges and Black Forest massifs. Ore deposits have been exploited along meter thick veins, i.e. filled fractures cutting through gneissic variscan basement.

Ore mineral veins have been chosen as their formation is considered to be a good analogue to present day fluid circulation in active deep geothermal reservoirs within fractured basement rocks. Several outcrops chosen according to their degree of deformation will be investigated in order to construct a conceptual fluid circulation model taking into account the role of tectonic heritage and anisotropy development.

Students will need to critically review their working hypotheses formulated using the 3D model, develop observation skills and apply all theoretical knowledge gained during the online lectures.

The journey will end visiting three active powerplants at Soultz sous Forêts and Rittershoffen (France) and Insheim (Germany).

Day		**8-9**	**9-10**	**10-11**	**11-12**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**
1	Monday		**Schauinsland Mine visit (Black Forest massif, Germany)**							
2	Tuesday		**Schauinsland Mine visit (Black Forest massif, Germany)**							
3	Wednesday		**Teufelsgrund Mine visit in Münstertal (Black Forest massif, Germany)**				**Lunch break**	**Aborted geothermal project in Staufen (Upper Rhine Graben, Germany)**		
4	Thursday		**GabbeGottes Mine visit in Sainte Marie aux Mines (Vosges massif, France)**							
5	Friday			**Soultz sous Forêts, Rittershoffen and Insheim Powerplans visits (Upper Rhine Graben, France)**						**Travel to Darmstadt**

2.3. TU DARMSTADT ISP PROGRAM

The ISP course at the Technical University Darmstadt will introduce the participants to geothermal systems under different reservoir conditions and will give a possibility to evaluate geothermal reservoir systems using geoscientific and engineering methods. The focus will be on the reservoir potential analyses based on thermo-hydraulic-mechanical datasets. The ISP is partly virtual and partly onside. The online course will consist of 4 recorded lectures, associated reading materials, and four related exercises to give the participants an overview of the topic. This material will be available online via the Teams folder of the ISP from the TU Darmstadt from April 04 until June 28. During the onsite week, event the participants will get an extensive lab course to get familiar with the data acquisition and will also get a visit site on a BHE system currently in construction to point out the direct applicability of the embedded disciplines of the ISP courses and site/laboratory program

2.3.1. ONLINE LECTURES

The goal of this first week of ISP is to give the students an overview of the full process of the life of a geothermal project, from geothermal system identifictaion, potential calculation, to site implementation, drilling and operations

1. Introduction to petrothermal systems and reservoir characteristics
2. Geological and geothermal models
3. Resource Assessment
4. Quantification and identification of deep geothermal potentials
5. Introduction to DMS TOUGE

2.3.2. WORK PLAN SITE VISIT DARMSTADT

This laboratory week is also the occasion for students to team build. It works on their report proposal, and apply what they have been studying in LaSalle and Zagreb ISP (including decision making tool DMS TOUGE). They also will acquire skills on how datasets are acquired, what are the limitations and uncertianties related to rock properties and how to overcome it, for applications in models and economical estimations.

		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Monday 16.05.2022	09:00 to 10:00	Introduction (*Pham*) and Safety instruction (*Schubert*) - Lecture hall					
	10:00 to 12:00	Lab theory and goals - Lecture hall *Pham*					
	12:00 to 13:00	Lunch - Mensa Lichtwiese					
	13:00 to 15:00	Thermo triaxial theory - Lecture hall *Ramirez*					
Tuesday 17.05..2022	09:00 to 11:00	Drilling and cutting *Seehaus&Seib*	Thermo triaxial explanation *Ramirez*	Thermo scan + Heat capacity *Schedel*	P-S + Uniaxial *Wasmer&Schmidt*	Porosity, density, permeablity *Schubert&Homung*	Free
	11:00 to 13:00		Drilling and cutting	Thermo triaxial explanation	Thermo scan + Heat capacity	P-S + Uniaxial	Porosity, density, permeablity
	13:00 to 14:00	Lunch - Mensa Lichtwiese					
	14:00 to 16:00	Porosity, density, permeablity		Drilling and cutting	Thermo triaxial explanation	Thermo scan + Heat capacity	P-S + Uniaxial
Wednesday 18.05.2022	9:00 to 11:00	P-S + Uniaxial	Porosity, density, permeablity		Drilling and cutting	Thermo triaxial explanation	Thermo scan + Heat capacity
	11:00 to 13:00	Thermo scan + Heat capacity	P-S + Uniaxial	Porosity, density, permeablity		Drilling and cutting	Thermo triaxial explanation
	13:00 to 14:00	Lunch - Mensa Lichtwiese					
	14:00 to 16:00	Thermo triaxial explanation	Thermo scan + Heat capacity	P-S + Uniaxial	Porosity, density, permeablity		Drilling and cutting
Thursday 19.05.2022	9:00 to 12:00	Data processing - Lecture hall *Pham*					
	12:00 to 13:00	Lunch - Mensa Lichtwiese					
	13:00 to 15:00	Visit SKEWs site *Bossennec & Seib*					
Friday 20.05.2022	9:00 to 12:00	Questions, answers, and discussion - Lecture hall *Pham & Bossennec*					
	12:00 to 13:00	Lunch - Mensa Lichtwiese					
	Afternoon	Departure					

2.4. REYKJAVÍK UNIVERSITY ISP PROGRAM

This course from the Iceland School of Energy at Reykjavík University introduces geothermal utilization and efficient use of the resource by looking at a range of components of geothermal fluid, and value in geothermal areas. The lectures cover efficient resource utilization of geothermal energy by looking at the potential economic opportunities of production by-products. The course will consist of 4 recorded lectures, associated reading materials, a short quiz after each lecture and a final capstone project. These lectures will be available online via the RU learning management system, Canvas, and available for review from May 30 until June 16. Two discussion sessions will be hosted to help the students formulate their capstone project. These discussion sessions will consist of one online session held via Teams on June 15 and one in-person on June 22. A final presentation of the capstone project will be held in person at Reykjavik University on June 24. The final report for the Geo3en program will be due the following week on June 28th.

2.4.1. ONLINE LECTURES

- Conceptual models of Icelandic geothermal systems.
    - This is an introduction to the important components of convecting geothermal systems in an extensional tectonic environment. This uses a generalized conceptual model, which removes the complexity of real systems.
- Geothermal power plant configurations. Describes:
    - Steam turbine electricity generation - fluid flow from a water-dominated reservoir with two stage separation, through a turbine, condenser, and cooling tower, and separated geothermal water flows to reinjection or to cascaded use.
    - ORC electricity generation - fluid flows through a 'binary' power plant, where the hot geothermal fluid heats a secondary organic fluid which flows on a closed loop through a turbine, then condensers, and back to the heat exchangers, while the geothermal fluid is reinjected (or more heat is extracted before reinjection. –
    - District heating and geothermal,
    - Examples of different cascade processes.
- Environmental & resource impact of geothermal utilization: extracting maximum value from the geothermal project. A brief discussion of components and aspects of geothermal fluid and systems, focusing on potential for economic value or disruption. (1.5 hrs)
    - Water
    - Heat
    - NCGs (predominantly CO_2 and H_2S)

  - Separated Geothermal Water: silica & other dissolved solids (minerals)
  - Subsidence
  - Seismicity
  - Tourism
  - Balneology
  - Social acceptance
- Economics of geothermal utilization
  - This lecture is a basic introduction to the macro and micro economic models present in geothermal project development.
  - Students are given a broad introduction to a range of subjects in energy economics with a focus on geothermal finance and development models

2.4.2. WORK PLAN SITE VISITS ICELAND

Day		8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
1	Monday		**RU Introduction**				**OR Visit**			
2	Tuesday	**Highlands, society and energy development visit**								**RU Capstone Discussion Session**
3	Wednesday	**Highlands, society and environment visit**								
4	Thursday	**Geothermal development visits with hike**								
5	Friday			**RU Capstone Presentations**						**Dinner**

2.5. ASSESSMENT METHODS:

As part of the ISPs, students were given individual assignments, short quizzes and a final capstone, group project with a presentation. The partner organizations agreed to give a common grade for all four ISPs. The grades for each student were determined with the ratios described below.

- Assignments – 15%
- Participation – 15%
- Capstone project paper – 40%
- Capstone presentation – 30%

A final grade is given among the lead organizers of each ISP and then credits are given at each institution for their participating students and reflected in their transcript of records. A final evaluation is distributed twice during the ISPs. This evaluation will be discussed in further detail in IO10. Recognition of participation in the Geo3en ISPs are also included in their diploma supplements upon gradution.

3. DISCUSSION

The COVID-19 pandemic required an adjustment of the original plan for the ISPs between the partners. Indeed, the four ISP originally planned were seperated in four online training activities (4 x 5 days of online preparation courses) and four onsite training activities (4 x 5 days of training on the field or in laboratories). The pedagogical model above can be best described as a hybrid model by including a mixture of theoretical lecture delivered online which is supplemented by field visits to each location. We argue that this model will likely prove to be a valuable addition to future teaching methods as it allows flexible learning, promotes more financially sustainable travel opportunities and fits closer to the direction that upper education is moving. The major advantage of a hybrid model of teaching over either online-only methods or traditional in-person pedagogy is that we can structure courses to take advantage of both teaching styles. One disadvantage that was worsened by the pandemic is the extremely intensive nature of how the ISP programs were organized. Each program took place consecutively with little downtime in between the travel periods. It is our recommendation that future programs that adopt a similar model space the coursework over a longer period of time. A more detailed discussion on this will be discussed further in detail in IO10.