Action Plan EU-Mexico on EGS and superhot systems

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Executive summary

This report aims at envisaging the future of the cooperation with Mexico: it will assess the implementation of the EU EGS and superhot system flagship programs (geothermal technology roadmap), make a SWOT analysis with focus on non-technical barriers for geothermal development in Mexico, prepare replication of best practices from Europe on environmental aspects and public acceptance (liaison with task 7.4).

The report explores the differences between the European and Mexican geothermal markets, in terms of resources, geothermal industry and policy and regulatory frameworks, laying the ground and identifying possible cooperation axis for the development of EGS and superhot technologies and the deployment of systems.

In many areas, the EU and Mexican technology roadmaps have very similar priorities. In both cases, **reducing uncertainty is a top priority**, as is reducing the risk and costs involved in drilling for geothermal projects. Moreover, both regions aim to **improve the quality of the use of geothermal energy in surface systems**, and to **allow for the emergence of new geothermal technologies** such as EGS. Besides, both the Mexican technology roadmap and the ETIP DG Strategic Research and Innovation highlight the importance of **improving knowledge sharing**, and **notably circulation of information** between academia and the industry. In that regard, the GEMex project is definitely well suited to serve a basis for initiating such cooperation including across regions.

The EU-Mexico geothermal collaboration started by the GEMex project should serve as a basis for an increased degree of industrial cooperation, notably regarding the implementation of EGS and superhot projects. This supposes a greater degree of integration between the research community that is well represented in the GEMex project consortium and the geothermal industry, which is mostly involved in the GEMex project through participation in the Stakeholder Board, providing inputs to the work of the project.

Thanks to extensive investments in research, development and innovation, both public and by the industry, the European geothermal sector is a leader in RD&I globally. It is notably in Europe that the concept of EGS was first demonstrated, and the sector has a unique expertise in developing unconventional resources and valorising geothermal resources. The GEMex project, and the collaboration it aims to enshrine between the Mexican and European geothermal sectors – either academic or industrial – can deliver innovation and enable further developments both in the European Union and Mexico.

1 Introduction

1.1 Technologies: state of play and developments

Until little over a century ago, the exploitation of geothermal resources was primarily for therapeutic and leisure purposes, in hot springs and geothermal baths. It was at the beginning of the 20th century that the active development of geothermal resources for electricity supply began. Successful production of electricity from geothermal heat was first achieved in Larderello, Italy, in 1904. Since then, the production of geothermal electricity has steadily increased, though it has been concentrated in areas where high temperature hydrothermal resources are available.

Geothermal energy has the potential to make a more significant contribution to the European and Mexican energy mix through the development of advanced technologies, especially the development of hot rock resources using EGS techniques and superhot systems that would enable thermal energy recovery from outside of traditionally favourable regions.

An EGS is an underground reservoir that has been created or improved artificially. The EGS concept is going to greatly increase geothermal potential as it allows for the production of geothermal electricity nearly anywhere in Europe and Mexico with medium and low temperature resources. In practice however, the industry tends to focus on enhancing areas with poor hydraulic performances (compensated by advantageous temperature gradients). All currently existing EGS projects in Europe are located within the Upper Rhine Graben.

The geothermal development in Mexico is thus far based on high temperature resources for electricity generation. So far only conventional hydrothermal resources have been exploited. It is the declared goal of GEMex to investigate the possibility of broadening the resource base by including EGS and potentially superhot systems in the future.

Different technological systems (i.e., plants typology) for geothermal electricity production are used based on temperature ranges:

Minimum production temperature: 80°C - 150°C (Medium Temperature resources): this range of temperature is appropriate for use with binary plants (Organic Rankine or Kalina cycles), with typical power in the range 0.1-10 MWe. Some EGS systems may fall in the upper hand of this category. These systems are also suitable for heat & power co-generation, typically for single edifice to small town heating;

Minimum production temperature: 150°C - 390°C (High Temperature resources): temperatures in this range can be exploited with dry steam, flash, hybrid and binary plants, with typical power in the range 10-100 MWe. Existing EGS systems in Europe typically are below or at the lower end of this category. These systems also allow heat cogeneration for large towns' district heating. Above 200°C, these resources are generally limited to volcanic areas.

Minimum production temperature 390°C (Supercritical unconventional resources): temperatures in this range, generally limited to volcanic areas, generally involve superheated dry steam plants, with power per unit volume of fluid up to one order of magnitude larger than conventional resources.

Besides the temperature range, the methods of exploitation can be further subdivided in two categories: conventional (dry steam and flash steam turbines) and low temperature (binary) geothermal electricity.

1.1.1 Technologies: EGS and superhot systems

The industrial exploitation of geothermal energy is a century old technology in Europe. The exploitation of steam produced from a geothermal well to drive a turbine for electricity generation or for industrial processes is a well-established technology that has greatly improved since its inception in Larderello at the beginning of the 20th century. The production of geothermal electricity is based on a system that combines a geothermal reservoir with the right capacity to supply geothermal energy, in the form of steam and/or hot water. Depending on the quality of the geothermal resource produced at the geothermal well, a specific turbine technology can be installed to generate electricity. In addition, geothermal power plants can be set up as combined heat and power plants, meaning that they can supply heat –in the form of steam and/or hot water– for industrial processes, district heating or the agri-food sector. While there is not a strong emphasis on such type of plants in Mexico, it is well developed in Europe, as it enables a greater use of the same amount of geothermal energy produced.

For geothermal power production, the conventional technology is based on flash or dry steam plants. It is also the most widespread technology in Mexico to this day. Typically, it is used for superhot systems, where the geothermal brine reaches the surface at very high temperature. Conventional dry steam turbines require fluids of at least 150°C. Such turbines are typically divided between atmospheric (backpressure) or condensing exhausts. In the backpressure systems, steam drives the turbines and is then vented to atmosphere. This cycle consumes almost twice more steam per produced kilowatt-hour (kWh), at identical turbine inlet pressure, than a condensing cycle. However, backpressure turbines may prove rewarding as pilot, initial or/and stand by plants in case of small supplies from remote isolated wells and for generating electricity in the early stages of field development. They become necessary in case of high non condensable gas contents, in excess of 12% in weight, in the vapour phase. Condensing units have more complex designs, requiring more ancillary equipment and space, as well as construction/installation delays nearly twice as long. In terms of size, plants with installed capacity in the 55 to 60 MWe plant range are quite common, but 110 MWe plants have been commissioned recently and are currently operating.

Flash steam plants are more widespread. They allow power production from water dominated reservoirs and temperatures above 180°C. The hot pressurised water flows up the well until its pressure decreases to the point at which it 'flashes' or vaporises, leading to a two-phase water-steam mixture. The steam, separated from the water, drives a turbine for electricity generation. The remaining brine, along with the condensed steam following power production, is piped back into the source reservoir. This injection process is essential to meet waste disposal, heat recovery, pressure maintenance and, last but not least, resource sustainability requirements. Flash steam plants can also be of backpressure or condensing type, with the same pros and cons of the dry steam plants of both types. The capacity of the condensing flash plants is usually higher than the dry steam ones. In Mexico there are four 110-MWe plants commissioned in 1986 and 1987 that are still in operation.

A rapidly emerging technology however, binary cycle turbines are a particularly interesting type of turbine for the development of geothermal electricity. First, they allow for the production of electricity from lower temperature geothermal resources (in theory down to 80°C). They are also a solution to minimise the release of non-condensable gases in the atmosphere – therefore reducing the local impact of the geothermal plant. In binary plants, the heat is recovered from the geothermal fluid, via a heat exchanger, to vaporize a working fluid with a low boiling point and drive a turbine. The heat depleted geothermal brine is pumped back into the source reservoir, thus securing sustainable resource exploitation. Since the geothermal and working fluids are kept separated during the process there are little if any, atmospheric emissions. According to the working fluid selected, the temperature range at which binary power production is possible could be comprised between 180°C-75°C. Binary plants are particularly interesting for the setup of combined heat and power plants, as they allow the production of heat at no additional mining costs, since the heat can be extracted from the cooling of the working fluid or from the hot water exiting the heat exchanger, before to be returned to the reservoir. Binary plants are also interesting for EGS plants, such as the one in Soultz-sous Forêt, as they allow a "closed loop" exploitation of the reservoir (minimising brine losses).

Traditionally, a major requirement for enabling deep geothermal energy projects was the availability of a geothermal reservoir from which high temperature water or steam could be produced. In past decades, a new technology has been emerging, allowing for geothermal heat and power production in a greater number of areas, thanks to the possibility to engineer geothermal reservoirs. Such engineered or enhanced geothermal systems (EGS as they are typically referred to) remain an emerging technology but has much potential in Mexico or in Europe. The European industry has been a pioneer in the development of this technology.

EGS is a key technology to harness the heat stored in deep seated, conductive/radiogenic dominated, tight sediments and hard crystalline basement rocks. The essence of EGS technology is the engineering of geothermal reservoirs by stimulating these low permeability/low connectivity rock environments. Based on experience acquired in past EGS projects, the geothermal industry has moved towards exploiting existing fractures and naturally present geological features as a basis for EGS reservoirs. Typically, the development of EGS systems follows these steps:

- identify and exploit the natural fracture networks hosted in basement rocks ;
- boost their conductivity/connectivity via massive stimulation techniques to favour the creation and reactivation of -large existing fractured rock volumes and related heat exchange areas;
- complete a heat extraction system based on a multi-production/injection-well array;
- circulate large amounts of water via pumping/lifting/buoyancy into this "man-made geothermal reservoir" to maximise heat and power production;
- achieve adequate heat recovery and system life to secure system sustainability.

1.1.2 Benefits of geothermal power production

The production of geothermal electricity presents many benefits in the context of the energy transition triggered by the drive to decarbonise the global economy and so mitigate the impact of climate change. First, geothermal energy is a renewable resource that is widely available, although technologies for its development in many areas (such as for instance EGS) are not yet entirely mature nor widely available at a commercial scale. In several electricity markets however, geothermal already plays a crucial role. Geothermal power production is typically baseload, producing electricity at full capacity up to 100% of the time in some cases (meaning the power plant is operating every hour of the year). As a basis for comparison, Figure 1 highlights the high capacity factor of geothermal energy compared with other renewable sources, and even compared to fossil fuels and nuclear. Indeed, unlike other types of renewable electricity generation, geothermal energy is not intermittent or dependant on climate variations. On the contrary, geothermal power is dispatchable and flexible, although the flexibility of geothermal power production depends on the design of the power plant.

The high capacity factor of geothermal plants is also due to the economic rules of electricity markets, where marginal costs tend to define which plants are effectively supplying power to the grid at a given moment. Geothermal power plants are characterised by a cost structure with very small operational costs, and they are usually able to provide power whatever the price on the market, notably by being more competitive than fossil or nuclear generation on a marginal cost basis. In addition, other schemes may contribute to this trend, such as agreements to supply baseload power to an industrial facility (e.g. corporate PPA with an aluminium smelter), or feed-in-tariff schemes that further incentivise the baseload supply of electricity.

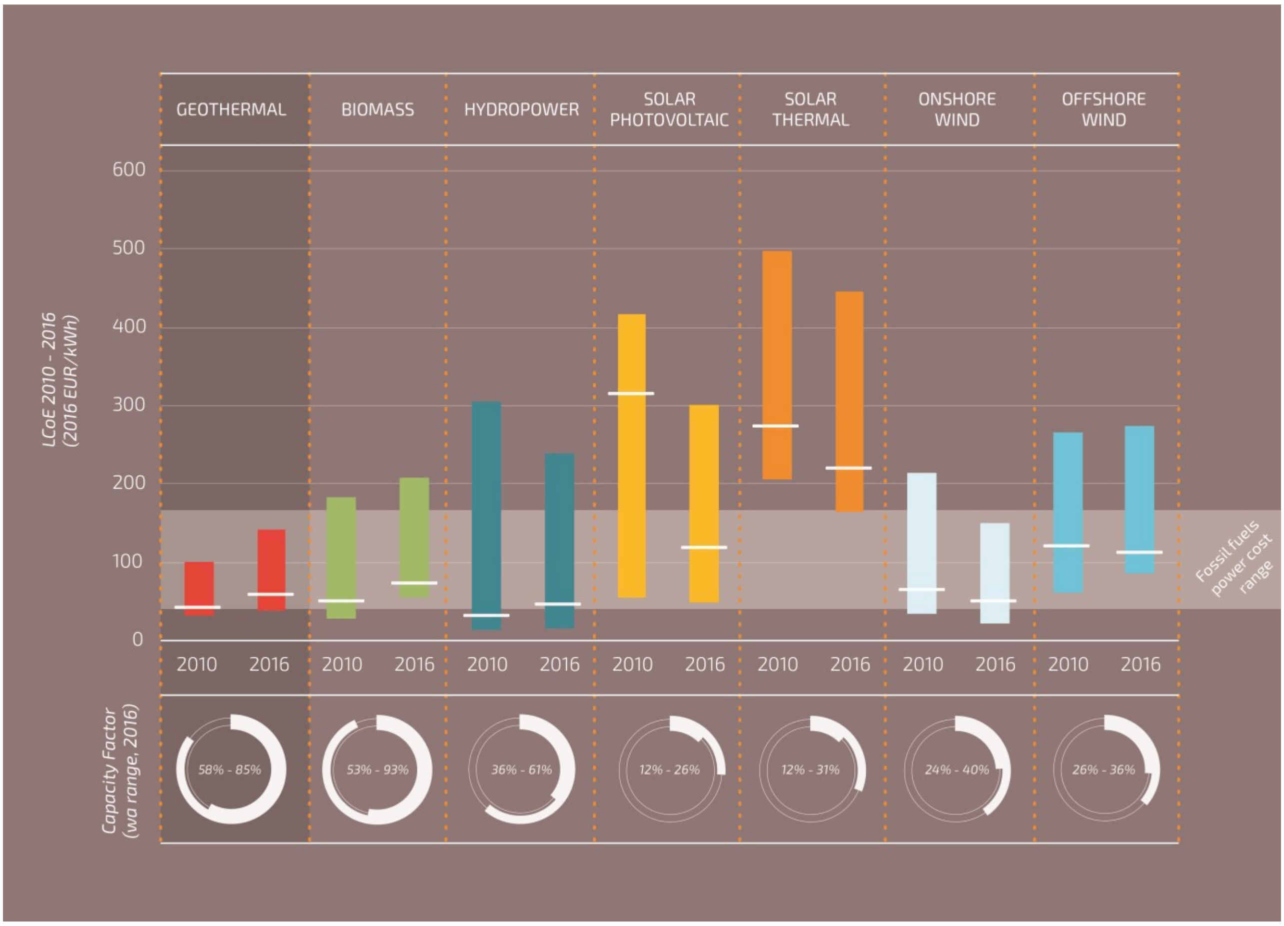

Figure 1. Comparison of capacity factors and levelised cost range for different renewable energy technologies and fossil fuels (the horizontal white bar is the mean in all cases) (sources: ETIP-DG).

Another benefit of geothermal power production is the possibility to co-generate electricity and heat from geothermal energy in the same facility, increasing the amount of renewable energy supplied for the same investment. In Europe, the exploitation of geothermal power plants for co-generation is quite widespread. Geothermal heat can be supplied to district heating networks, to agri-food businesses or for industry. In some cases, notably in recent projects, the plant is designed and its business plan is justified by the joint supply of heat and electricity in order to further maximise the geothermal resource. In other cases, the use of geothermal heat is more recent, notably driven by a desire to exploit optimally available renewable resources. The supply of heat by a geothermal plant to surrounding communities has also proven to contribute to social acceptance, either through the supply of cheap heat to businesses or villages –as it would otherwise be reinjected in the reservoir, which is the case when the plant is only used to generate electricity-- or by the ownership and involvement of local authorities in the geothermal project to valorise a local renewable resource benefiting to the community.

Typically, conventional geothermal energy projects tend to be quite competitive on an LCOE basis, notably when compared to other renewable technologies. Indeed, in Mexico, NREL estimates that the LCOE for geothermal energy is in the 57-84 USD/MWh range for flash steam plants, and 50-104 USD/MWh for binary plants[1]. This price range is well within the one highlighted as the current fossil fuel range in the Figure 1 and is actually quite below the range of geothermal costs estimated for Europe.

By the other hand, geothermal projects are very capital-intensive investments, as the cost-structure of the project is dominated by capital expenditures, and operational expenditures are very low and predictable, owing to the absence of fuel costs and the limiting O&M costs (see below). The investment costs in a geothermal project are considerably variable as they depend on a wide range of conditions, including resource temperature and pressure, reservoir depth, location, drilling market etc. A range of estimates, considering all the upfront investments since exploration up to commissioning of the plant, is presented in Figure 2.

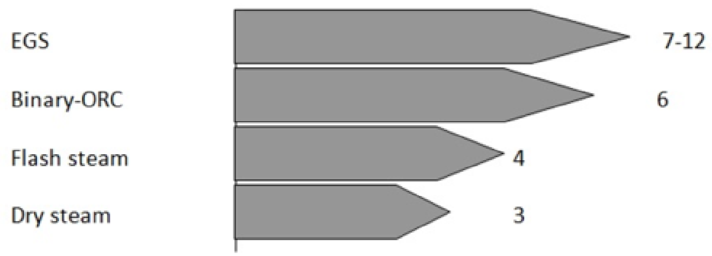

Figure 2. Capital costs, € million/MWe installed (source: EGEC)

A key feature of geothermal projects development, however, is the crucial impact of the geological resource risk, which includes:

- The short-term risk of not finding an economically sustainable geothermal resource after drilling;
- The long-term risk of the geothermal resource naturally depleting rendering its exploitation economically unprofitable.

The resource risk in geothermal project has an outsized impact on the economic viability of many projects, as a significant share of investment must be made before the risk significantly decreases. Considering the capital-intensive nature of geothermal projects, the geological resource risk has a strong impact on the cost and the availability of financing, which impacts the total cost of geothermal project. The impact is greater on innovative technologies, and in areas without prior geothermal energy development ('green-field projects') such as is usually the case for EGS projects.

Geothermal electricity: a pillar of the decarbonisation of electricity system?

The production of geothermal electricity, because it is a renewable, baseload and flexible source of electricity, can be a pillar in the decarbonisation of electricity that is the focus of Europe's climate and energy policy, and is increasingly a concern across the world. Indeed, as electricity systems are increasingly based on renewable electricity –with photovoltaic and wind the cheapest new electricity sources in many markets– electricity systems will increasingly have to deal with variable and intermittent supply. In order to ensure the secure supply of electricity, flexibility will become a key resource, one which geothermal power plants have been proven to be able to provide. In Germany for instance, binary turbines have proven that they ramp up and down their outputs from 100% to 30% in 15 seconds and goes back to 100% in 15 seconds[2]. The energy system is also likely to move towards a greater integration between heating and cooling, electricity and transport, and to be more decentralised. Geothermal power plants have the potential

[1] NREL, Mexico Geothermal Market Assessment Report, 2017.
[2] Source: Turboden.

to stand at a pivotal point of the system, as medium size flexible installations that can also provide heat to local communities (see Figure 3).

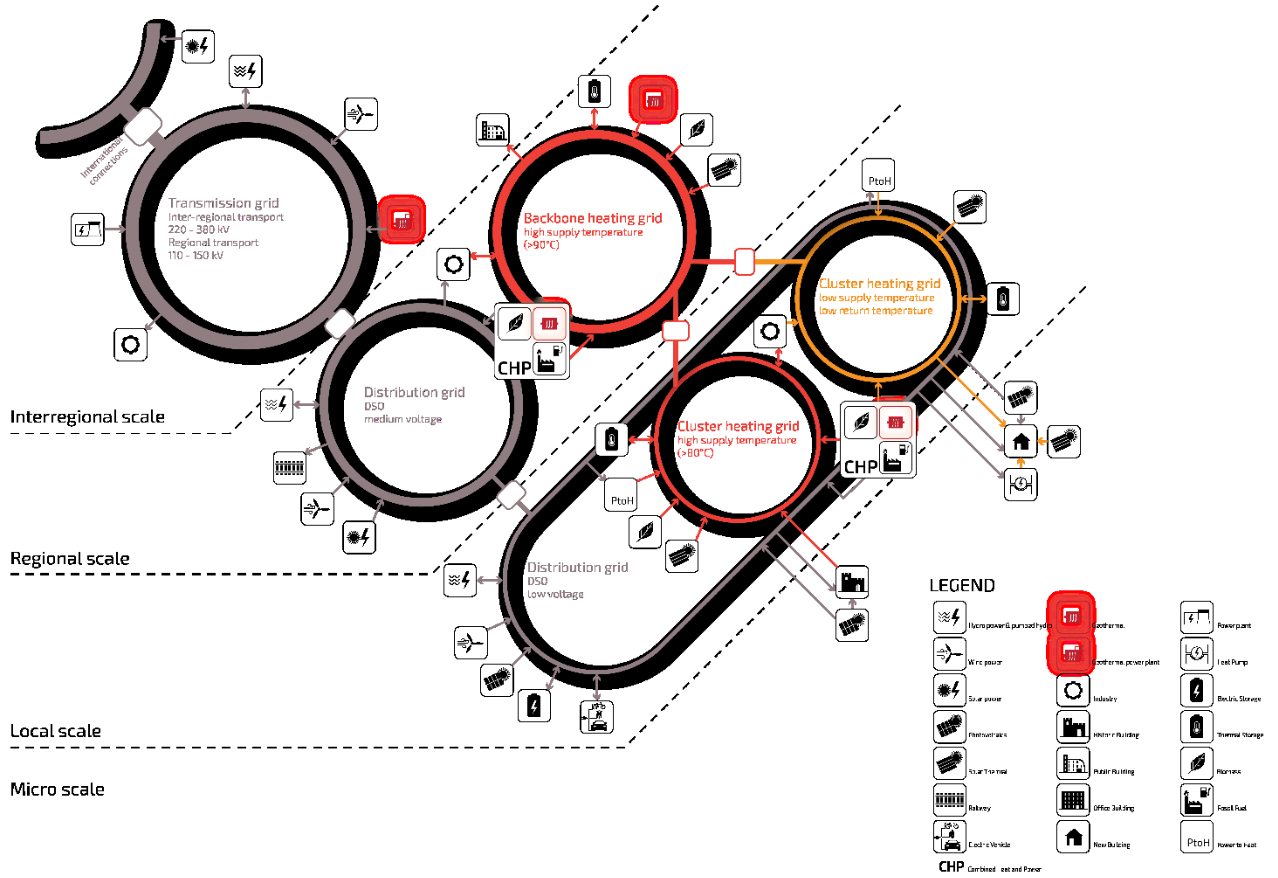

Figure 3. Future electricity systems are likely to be more complex, with higher interconnection, more horizontal and more diverse in terms of energy mix and ownership. Geothermal energy fits at the crossroad of these systems, providing flexible and dispatchable heat and power at the local or medium scale (source: ETIP DG).

2 Geothermal resource base assessment

2.1 Market development in the EU and in Mexico

The European and Mexican markets for geothermal energy are very different. First, in Europe, shallow geothermal system represents the bulk of geothermal energy capacity, even though they are not considered in this publication. More generally, the difference between the European and Mexican geothermal markets lies in the greater focus on the exploitation of geothermal energy for heating and cooling, notably low temperature resources in Europe, while the Mexican market has been more narrowly oriented towards the production of electricity through conventional technologies.

This difference is partly explained by the greater availability of conventional high temperature geothermal resources in Mexico compared to Europe. The difference in climate, with much higher heating and cooling demands in Europe, notably for space heating, is another factor explaining a greater interest in developing deep geothermal projects for heating and cooling or cogeneration in Europe.

2.1.1 Europe's geothermal market

In 2018, the European geothermal sector represents over 3GWe of geothermal electricity capacity, with leading countries being Turkey (1318 MWe), Italy (916 MWe) and Iceland (753MWe). In total, there are 11 countries in Europe that produce electricity from geothermal energy, with Croatia having inaugurated its first geothermal power plant in 2018. The installed capacity in Europe has been growing at rate of approximately 10% per year over the past five years.

The market for deep geothermal heating and cooling is also well developed in Europe, representing a total installed capacity of 5.1GWth over 300 deep geothermal systems for heating and cooling. In this space, Iceland is by far the largest user of geothermal energy, with 2.2 GWth of installed capacity. Turkey with 872MWth and France at 544MWth follow. There are 24 European countries with some installed capacity for deep geothermal heating and cooling (Fig. 4).

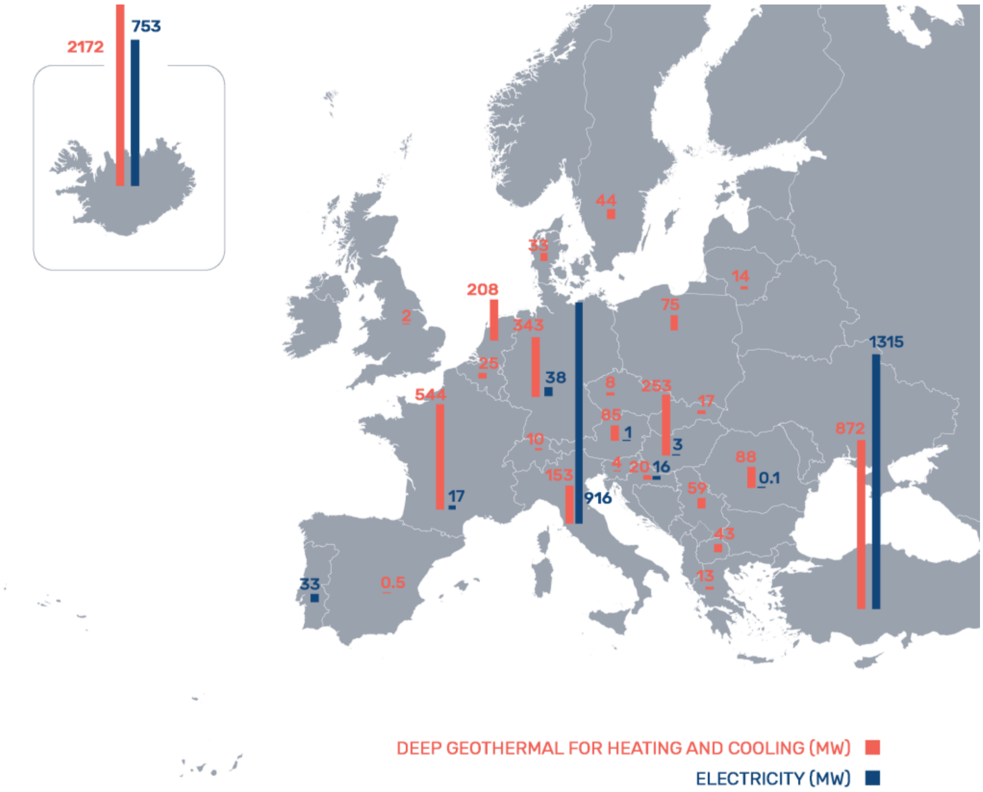

Figure 4. Deep geothermal installed capacity in Europe for heating and cooling (red, in MWth) and for electricity (blue, in MWe) (source: EGEC market report 2018).

2.1.2 Mexican geothermal market

The Mexican geothermal market is dominated by high temperature geothermal power production. There are currently five geothermal fields in operation, located at the center of the country, in states such as Michoacan, Puebla and Nayarit, and in the Baja California peninsula. The total installed capacity is 981 MWe, representing around 1.2% of the total installed capacity of the country, with electricity generation of around 6 TWh, which represents 1.7% of the national generation of electricity. The running capacity is 923 MW, since some old power plants are only used as backup (Fig. 5).

Geothermal energy has been used in Mexico since the Pre-Columbian times. For electric purposes, the first geothermal exploration wells were drilled in the decade of 1950s and the first power plant, of 3.5 MW in capacity, started to operate in November 1959 in the Pathé geothermal field located in central Mexico. This plant operated at a fraction of its capacity for several years, and was finally dismantled in 1973. In the same year (1973) were commissioned the first power units of 37.5 MWe in capacity in the Cerro Prieto field, which is the oldest and largest field in the country.

Four of the current geothermal fields under commercial operation (Cerro Prieto, Las Tres Vírgenes, Los Azufres and Los Humeros) were developed and are operated by the governmental utility Comisión Federal de Electricidad (CFE), who holds the exploitation concessions granted by the Mexican Ministry of Energy (SENER), while the Domo San Pedro field is operated by a private company (Grupo Dragón) (Fig. 5).

Field, State	Capacity (MW) Installed	Capacity (MW) Running
Cerro Prieto, BC	570.0	570.0
Los Azufres, Mich.	246.6	223.6
Los Humeros, Pue.	118.4	93.9
Las Tres Vírgenes, BCS	10.0	10.0
Domo San Pedro, Nay.	35.5	25.5
Total	**981.0**	**923.0**

Figure 5. Geothermal fields in Mexico (Source: Gutiérrez-Negrín, 2019)

2.2 EU

In the European Union, the exploitation of geothermal energy is primarily made for the production of heating and cooling. Indeed, heating and cooling represents half of Europe’s energy consumption, with quite high needs for space heating in winter times. The agri-food sectors and the industry are also sectors that utilise geothermal heat. The production of heat from deep geothermal energy is quite widespread in Europe as highlighted above. The production of geothermal electricity is however much more localised in the Tuscany region of Italy where there are plentiful high temperature geothermal resources. Beyond the European Union, conventional geothermal energy is well developed in Turkey and in Iceland where high temperature resources are also significant. The production of geothermal electricity is however possible across the whole of the European Union in theory thanks to technologies such as EGS and low temperature binary turbines.

Some recent milestone in enabling the resource potential of the European Union include the development of EGS systems in Alsace, France and the Pest region in Hungary –which allowed mainland France and Hungary to enter the club of geothermal electricity producing countries. Croatia started to operate its first geothermal power plant, a binary cycle unit of 17.5 MWe, in December 2018, also entering in that club. New projects are ongoing across Europe. Figure 6 maps out the potential for geothermal electricity in Europe, based on the estimated LCOE by 2030 as calculated by the Geoelec project. Regions of Iceland, Turkey and Italy will likely continue to be the core area for geothermal electricity in Europe due to the lowest estimated LCOEs.

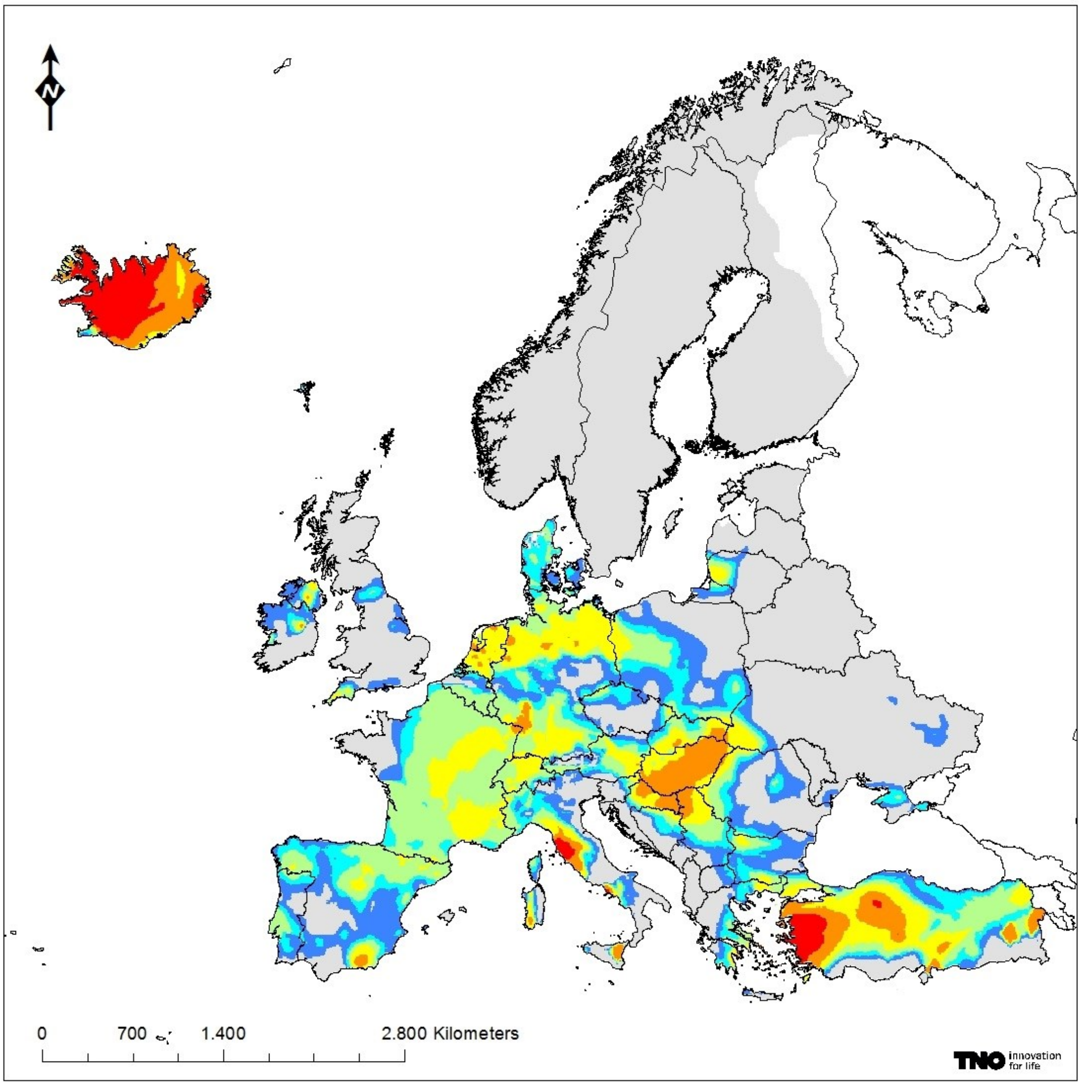

Figure 6. Minimum LCOE for deep geothermal electricity projects in Europe in 2030 (figures in euros per MWh; source: GEOELEC) Legend: Red: <100, Orange: 100 – 150; Yellow: 150-200; Green: 200-250; Cyan: 250-300; Blue: 300-400.

According to the ETIP DG Vision of the Future for deep geothermal, geothermal electricity potential in Europe is plentiful, as geothermal power production could theoretically represent up to 1200 TWh in the European Union in 2050 (Fig. 7). To unlock this potential however, innovative geothermal energy technologies will need to increase in terms of market maturity. In that regard, EGS is a particularly high potential technology for unlocking the geothermal power production potential.

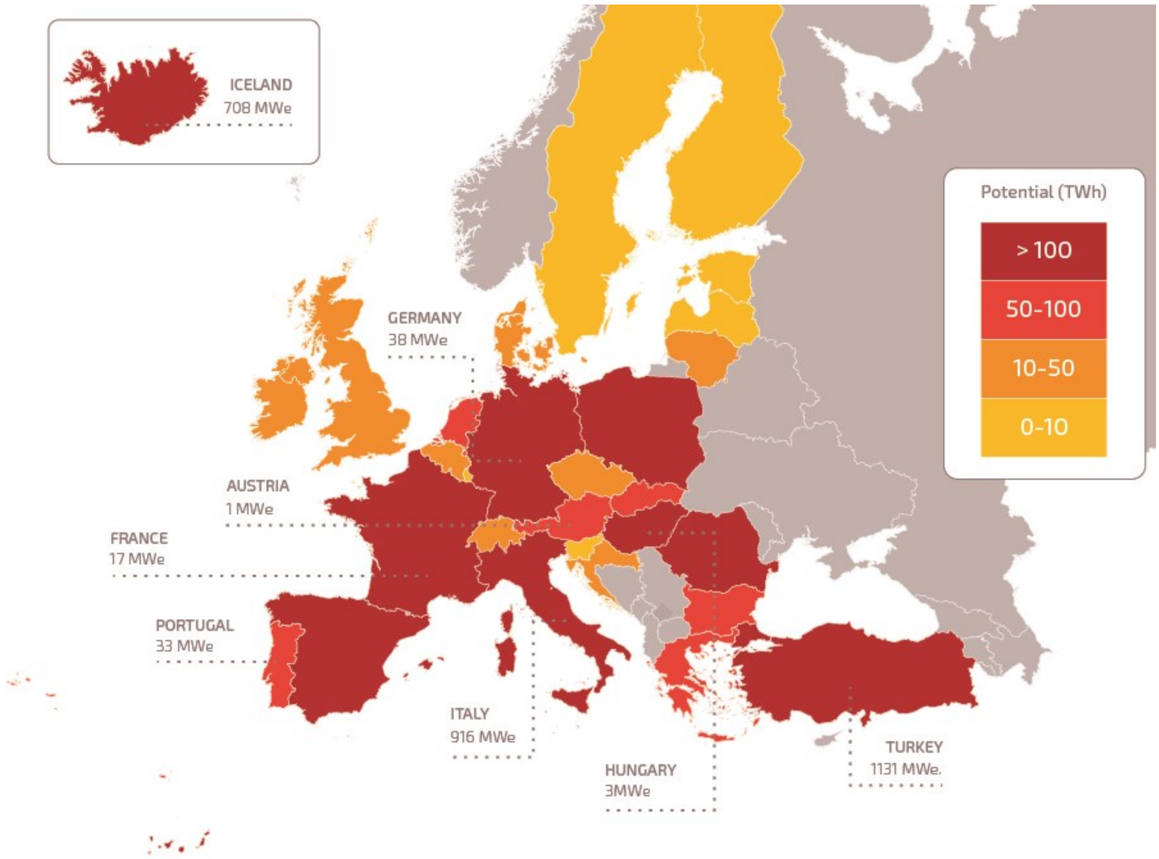

Figure 7. Geothermal electricity production potential in European Countries in 2050 (in TWh) versus currently installed capacity (in MWe) (source: ETIP-DG)

2.3 Mexico

Mexico's geothermal industry exploits high temperature geothermal resources, which are quite plentiful across the country, thanks to its presence on the so-called "ring of Fire" which circles the Pacific Ocean. As a result, Mexico's geology is particularly well suited for conventional high temperature geothermal energy development.

The tectonic location of the country, near the intersection of three main tectonic plates (North America, Pacific and Cocos), and one microplate (Rivera) also favours the presence of hydrothermal geothermal resources. The subduction of the Cocos Plate beneath the North America Plate has produced the Mexican Volcanic Belt (MVB), composed of volcanoes and volcanic products of Pliocene-Quaternary age, where three of the geothermal fields in operation are located (see Fig. 5).

The sliding process between the Pacific and the North American plates along the series of transform faults in the north-western part of Mexico, is the ultimate cause of the other two geothermal fields in operation (Cerro Prieto and Las Tres Vírgenes). This process, which started in the Middle-Late Miocene, has separated the Baja California Peninsula from the mainland Mexico and eventually will convert this peninsula in a new island, including part of the current U.S. state of California, at the west of the San Andreas Fault.

The unexploited geothermal potential of the country has been estimated using the concept of geothermal reserves and resources defined by the Australian Geothermal Code (AGEG-AGEA, 2010). According to that estimation, the national geothermal potential from conventional, hydrothermal reservoirs is around 2500 MWe, coming from fluids with temperatures above 150°C. This potential is composed of proven and probable reserves, and measured, indicated and inferred resources (Gutiérrez-Negrín, 2019). From that potential, the Geothermal Roadmap for Mexico estimates 750 MWe to be developed by 2030 (SENER, 2017), which represents a little more than 75% of the current geothermal power installed capacity.

Moreover, although historical developments in Mexico were only based on high temperature conventional geothermal resources, innovation in new technologies such as EGS and superhot systems can lead to a greater exploitation of the large geothermal potential available in Mexico.

3 SWOT analysis with focus on non-technical barriers for geothermal development, in particular EGS and Superhot systems

The geothermal energy sector is as complex and heterogeneous as geothermal energy projects are diverse and serve different purposes. Keeping a focus on deep geothermal projects suitable for power production, below is a swot assessment of the geothermal industry:

- Strengths: A unique source of renewable energy, geothermal can supply electricity as well as heating and cooling as a dispatchable and flexible resource. As such, geothermal energy is well suited to be a cornerstone of the energy transition, acting as a stabilizing force in energy systems faced with higher shares of variable and intermittent power sources. Moreover, if operating as a baseload source, geothermal plants produce far more renewable energy for the same capacity as a variable or intermittent source. A well-established and mature technology with a century of experience in some areas, the geothermal industry is nonetheless very innovative, and new technologies allow for it to be deployed virtually everywhere. In economic terms, the cost structure of geothermal energy projects guarantees a stability of energy prices on the long term, as well as the possibility to generate value locally through the utilization of heat for processes, leisure (e.g. balneology) or mitigating energy poverty, or the exploitation of geothermal side products (e.g. lithium and cosmetic products). New geothermal technologies enable geothermal to be developed everywhere (EGS) in theory, or to develop projects with higher energy production per well drilled (superhot systems).
- Weaknesses: Due to high upfront costs, project development for geothermal is expensive. Typically, developing geothermal projects is one order of magnitude more expensive than other renewable sources of comparable capacity. Large companies or financial institutions, or the public sector are usually required for development of deep geothermal at scale. Moreover, geothermal energy projects are very exposed to the geological mining risk, which has a huge impact on capital costs and makes project development much harder. There are also significant operational risks, such as well failure or decreasing productivity due to scaling/corrosion or degassing. An additional weakness, is that greenfield geothermal projects take between four and five years to be completed, since the exploration stage up to the commissioning of the plant, which is almost three times more than other power projects need. The geothermal energy sector remains a small sector as well, which may limit the speed of scaling of the use of this energy source. Moreover, geothermal is a complex and highly technical sector, which makes its marketing more difficult to expand installed capacity. Geothermal environmental impacts can be an issue in project development, with power plants being in some cases responsible for high atmospheric emissions of non-condensable gases. Technology solutions are however available to mitigate this issue. Associated to innovative geothermal electricity technologies are some specific weaknesses, such as for EGS, heightened seismic risks during reservoir engineering, or for superhot systems higher risks of corrosion and scaling.
- Opportunities: The global drive to limit the impact of climate change is a major opportunity for the geothermal energy sector considering its mentioned strengths. Geothermal also represents more

generally an opportunity for the electrification and the economic development of many regions, and the energy independence of some isolated territories such as islands. Moreover, the high degree of innovation in the geothermal sector represents a huge opportunity, as emerging geothermal technologies have the potential to unlock many more geothermal resources than are currently commercially accessible (e.g. EGS…)

- Threats: Geothermal energy faces several threats for deploying its full potential, the first of which being market structures that are usually not well suited for such capital-intensive, high-risk projects. The low and scarce knowledge and general lack of recognition of geothermal energy, in particular by policy makers, and the lack of understanding of the specific characteristics of this energy sector, are another key threats to future development. Moreover, there may be issues in terms of public engagement, which may correspond to varying level of acceptance by communities according to countries or even regions.

3.1 EU

The European Union is a somewhat specific area for geothermal development, as it is simultaneously the birthplace of conventional geothermal power production and of some of the most innovative geothermal energy technologies currently promising to unlock the potential of this renewable resource. The European geothermal industry is moreover robust, with a high degree of expertise and high capacity for innovation. In general, the European Union being at the forefront of the global action for the energy transition, the general policy and regulatory for the geothermal sector is altogether rather positive. Besides, the quite developed use of geothermal for heating and cooling in Europe, has produced a robust expertise of the EU industry in this area.

However, the European Union is also a very segmented market for geothermal energy, with many national industries that are rather competing within national markets. Besides, accessible conventional resources for geothermal electricity production are only concentrated in some parts of Europe, which explains a high concentration of geothermal electricity capacity in three markets (Turkey, Italy, Iceland), being only Italy part of the European Union. Moreover, despite a robust political support for renewable development, the geothermal sector remains penalised by an energy market that remains heavily favourable to fossil energy, notably in the form of support to fossil energy infrastructure.

For the European geothermal energy sector, opportunities lie in bringing key innovative technologies to market (in particular EGS, superhot systems, but also other technologies such as mineral extraction, Underground Thermal Energy Storage for instance), and to the political drive of Europe and the global economy to mitigate the impact of climate change by reducing the use of fossil energy and switching to renewable sources, in particular in the heating and cooling sector in Europe. The sum of these two opportunities has already yielded some key milestones for the sector such as Croatia, Hungary, Germany or Mainland France becoming geothermal electricity producers. One of the opportunities represented by the geothermal sector, is to enable the full decarbonisation of the energy system by providing much needed flexibility resources in the electricity sector, and a huge potential for the deployment of renewable heating and cooling production. Prospects lying in innovative technologies such as mineral extraction represent an opportunity to provide the strategic minerals for modern economies such as lithium.

The sector is however faced with the threats poised by unfair market conditions, and strong incumbent conventional energy sources, as well as a lack of awareness of policy makers, which risk limiting developments up to the sector's potential. Moreover, the geothermal energy sector, as an emerging technology in many market, is very dependent on the success of flagship projects and the respect of best practices, notably regarding environmental impacts and community engagement. As such, industry developers are very vulnerable to the perceived negative impacts of geothermal energy when a risk has occurred in a project, in particular flagship projects. To mitigate this threat, the best practices of community engagement must be implemented to increase the awareness about the geothermal industry's benefits. Community engagement is also crucial to dispel some perception of risks which may not be commensurate with the reality of project development. Finally, a key threat to the deployment of geothermal technologies, in particular emerging ones such as EGS or superhot systems, at an industrial scale is the lack of policy and regulatory stability, which may lead to "stop and go" dynamics which are a deterrent for the industry to invest in new developments.

3.2 Mexico

The Mexican geothermal sector has been historically represented by the government, through the geothermal division of the CFE, since for several decades all the geothermal power development was made with public investment. Its strength represented by the relatively large installed capacity, rests on abundant high temperature geothermal resources, which in turn is due to its tectonic location. Thus, the geology of Mexico is a strength for geothermal industry development in the country, as is the well-established oil and gas industry which guarantees a degree of expertise and of knowledge of the underground, which is necessary for further developments. Moreover, decades of use of geothermal in Mexico has made it an important energy source in the country's energy mix. In general, Mexico is consistently listed as one of the most attractive Latin American countries for businesses and investments, which is a key requirement for investments in the country's geothermal sector. Moreover, the recently passed Geothermal Law (2014) has produced a legal frame that offer certainty for private investments in geothermal, even though it was possible to privately invest in geothermal power projects before the passing of the law. More than 25 new geothermal zones have been awarded for exploration to the CFE and private companies by the energy department (SENER).

The Mexican geothermal sector is a global leader in terms of installed capacity, although it is less prominent in terms of recent developments and innovation. These features, as well as some degree of political and economic risk tend to weaken the industry. The lack of a suitable geological resource risk mitigation scheme in Mexico however is a key weakness of the geothermal framework, as it has a negative impact on developments, especially in new areas of the country.

Geothermal energy in Mexico remains quite under tapped, even considering conservative estimates of the country's potential. Moreover, up to now the Mexican market has not developed any EGS project, even at a demonstration or prototype scale. The EGS potential in Mexico, according to the protocol endorsed by the International Geothermal Association (IGA), is still to be published as one of the projects of the Mexican Center for Innovation in Geothermal Energy (CeMIE-Geo). It will surely be several orders of magnitude higher than the hydrothermal potential, but its development will require a stable, consistent framework that reduces technology and resource risk for project developers. The government already started setting up the right framework for enabling geothermal energy's opportunities, by providing an initial regulatory framework, which promotes innovative technologies and know-how, in key areas for developing new geothermal resources. And even though there is place to improve the regulation, the synergies with the extensive knowledge of the local resources by CFE have the potential to allow for accelerated developments.

A major hurdle for the future development of geothermal energy in Mexico however is the lack of tax incentives and/or feed-in tariffs which, in other countries like Turkey, has been the key factor for the quick and huge increase of the Turkish geothermal market in the last decade. For private industry actors, a key threat in the Mexican market is the risk of changes in the regulatory and support framework for geothermal energy, which may dramatically impact the conditions of project development. Such sudden changes are detrimental to the prospects of developers looking to invest in developing geothermal projects in Mexico, notably as geothermal energy projects require a long time to be developed (up to 10 years for such technologies as EGS and Superhot systems). This makes such project extremely vulnerable to such non-technical challenges as regulatory instability, lack of specific incentives and high interest rates for developing projects.

3.3 Recommendations

Considering the above assessments of the geothermal energy sector in Mexico and the European Union, with a specific focus on the electricity sector, here are some key recommendations for the industry, as well as for policy makers to allow the establishment of optimal conditions for the geothermal energy sector –conditions which minimise weaknesses and threats and maximise strengths and enable opportunities.

- Financing: the capital intensive nature of geothermal energy projects require a sound framework for access to financing. Moreover, the impact of the geological resource risk must be mitigated, through risk mitigation schemes (Fig. 8). At the beginning, these schemes should be public, in order to guarantee the upstart of the market, but as noted on the figure below, they can be increasingly market based as the geothermal market gains in maturity and depth.
- In Europe, the regulatory framework should provide consistency to the sector, so as to avoid stop and go effects, which are a huge threats for projects with such long development times as geothermal projects, notably for geothermal electricity. The regulatory framework has a key role in providing legal certainty to geothermal developers, for instance by clarifying the ownership of the resource, by guaranteeing the rights of developers, and setting clear rules for environmental impact. It is also important for the regulatory framework to establish a forward looking support framework that is aligned with the degree of maturity of the geothermal market and considers the specificities of geothermal technologies. In Mexico the Geothermal Law establishes a framework that contributes to setting up such regulatory stability, which should be guaranteed at all levels and throughout the duration of project development and exploitation for ongoing projects and upcoming ones. In that respect, some of the best practices implmented in the EU, such as the provision of the Renewable Energy Directive 2018 forbiding retroactive changes to support framework for renewable energy projects and introducing provisions for notification of upcoming changes to support schemes, provide stability, predicatibility and greater security of investment.
- Tranfer of knowledge: for the success of the development of geothermal energy, transfer of knowledge is a major requirement, as it allows the actors to mitigate risk, and lower costs. In the case of Mexico, the knowledge of the local resource is mainly owned by the historical public operator, although technology know-how is likely to primarily come from private actors, including the European industry operating in Mexico. Good intelligence, transfer of knowledge and cooperation are key for the success of geothermal energy development. Indeed, it reduces the risk of environmental impact, delay in projects, and lowers the cost of developments, which are essential features in the public acceptability of geothermal energy –a pre-condition to upscaling geothermal energy capacity in any market. Here again, a clear framework for rights and ownership is crucial to enable succesful developments.

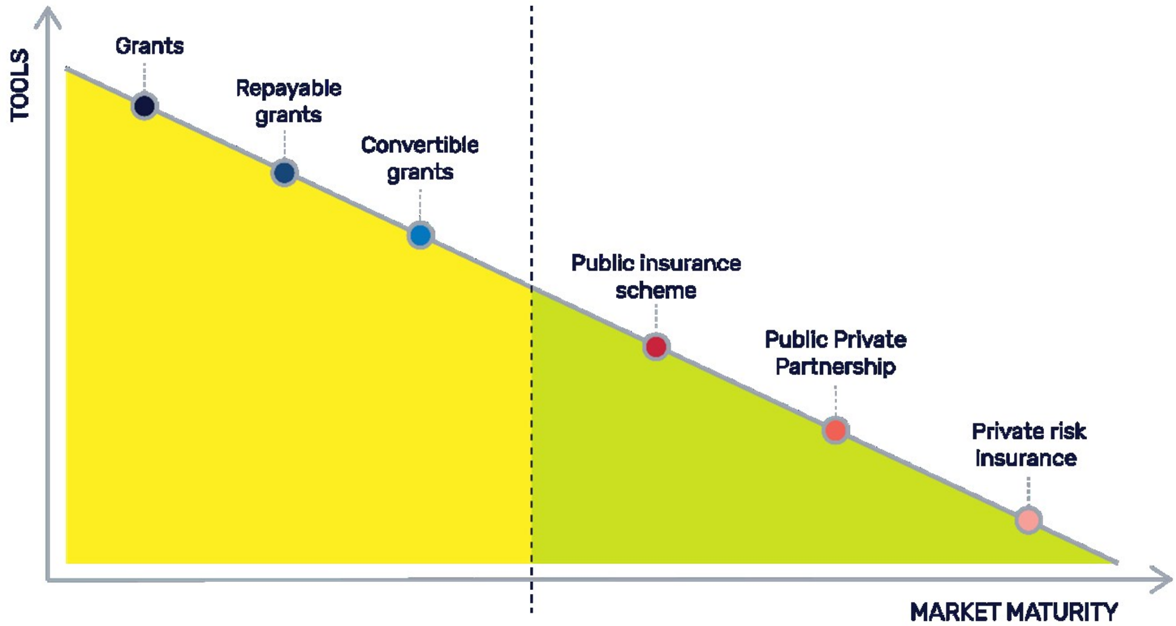

Figure 8. Typology of geothermal risk mitigation schemes according to market maturity (source: EGEC)

4 Good practices on environmental aspects and public concerns / engagement

4.1 Overview of environmental impacts and public concerns

Deep geothermal energy projects require attention to avoid and minimise environmental impacts. Indeed, a complex technology, if not designed and realised properly, geothermal energy projects embed significant risks of environmental impacts. These typically arise from the characteristics of the geothermal brines, which may contain substances with an environmental impact. The general impact linked to any type of industrial activity may also be important. In particular, as Giuseppe Mandrone – professor in Applied Geology at University of Torino – stated about geothermal energy "the majority of the technical problems, if not already solved, may be solved. The hard challenge is social"[1].

Among the potential environmental impacts, the following have to be assessed:

- Surface-visual effect (land use, landscape, flora and fauna)
- Physical effects (Induced seismicity: micro-seismicity related to all the operational phases of the exploitation, including reservoir connection and fluid reinjection into the reservoir, subsidence, geological hazards, groundwater resource depletion, natural radioactivity)
- Acoustic effects (noise during drilling, construction and management)
- Thermal effects (release of steam in the air, ground heating and cooling for fluid withdrawal or injection)
- Chemical effects (gaseous emissions into the atmosphere, incondensable gases, pollution and emissions, re-injection of fluids, disposal of liquid and solid waste)

Among large industrial projects, geothermal energy developments contribute to satisfy social needs (provision of energy) while addressing contemporary challenges such as reducing greenhouse gas emissions and fostering a more sustainable model of development. However, geothermal energy developments receive opposition, not only due to technical issues but also to issues related to the inability of public or private actors to manage the – usually local – drawbacks perceived by people. A multidisciplinary approach is built on the activities carried out by Task 7.4 – Public Engagement of the GEMex project, and a review of concepts and themes relating to the relationship between stakeholders and public engagement is developed, accounting from different perspectives. The private sector tends to consider this challenge from the lens of Corporate Social Responsibility (CSR) to establish partnership and respond to concerns. The public sector tends to approach it from the angle of public and local authorities' actions.

Table 1. Private sector CSR engagement strategies (Source: GEMex Task 7.4)

Transactional strategies	Transitional strategies	Transformational strategies	Integrational strategies
Minimal level of relations, based on a "giving-back" approach	Relations in which the community can express complaints and	General understanding between parties	Merger of aspects from the three strategies, embracing flexibility towards community engagement

[1] From an in-depth interview submitted to Giuseppe Mandrone, associate professor in Applied Geology at the University of Torino, in order to collect all the information needed to understand the technological variety of geothermal applications and related potential impacts and criticalities.

One-direction communication flows Companies are reactive and do not perceive community relations as strategic	expectations regarding companies' practices Two-way asymmetric communication (more firms-to-community than v.v.)	Focus on common issues and on building social capital Two-way symmetric communication	

Table 2. Social impact Assessment (Source: GEMex Task 7.4)

Screening	**Community Profiling**	**Scoping**	**Assessing Impacts**	**Monitorning**
Review of the main features of the project and expected	Description of the main economic, social and cultural aspects of the community involved	Identification of the social domains likely to be affected	Foreseeing who will be affected, how and when	Definition of methods, techniques and processes for the ongoing evaluation of the impacts

Developing Alternatives	**Mitigation**	**Management and Evaluation**	**Participatory process**
Finding different options and/or refinements that may vary from the first projects	Defining the best way to address any relevant negative effect	Putting in place the right organizational and methodological tools for an effective measurement of the effects	Beyond the mere information and consultation, the actual involvement of the expected targets, e.g. community

Table 3. The role of public authorities (Source: GEMex Task 7.4)

Provider	**Mediator**	**Motivator**	**Co-designer**
Basic legal obligation	Deliberative process (focus on reaching consensus through discussion, debate and information)	Participatory process (focus on empowering citizens to take action)	Co-participant

There are several factors that lead the European geothermal sector to strive to minimising the impact of its development, and to improve the environmental quality of existing installations:

- Ongoing geothermal energy developments are in large parts, at least in the European Union, the result of a drive towards decarbonisation. Therefore, geothermal projects should not have an adverse impact on climate change (i.e. their carbon footprint should be lower than that of the fossil assets they aim to replace) in order to justify any support they may receive.
- Environmental impact resulting from a given geothermal project can have a severe impact on the reputation of the geothermal sector as a whole, driving public concerns about new developments

from nearby communities. Mitigating environmental impact during development, and ensuring the project obeys sound environmental standards reduces the negative spillover effects in terms of public perception of the geothermal sector. This increases the prospect for acceptance of additional projects, and therefore development of the sector.

In order to minimise geothermal projects environmental impacts, the Life Cycle Assessment has proven an effective tool. LCA (Life Cycle Assessment) has emerged as an approach to quantify and account for environmental impacts from cradle to grave. Originally focused on accounting for current or past impacts in existing projects, LCA has become forward looking to assess future impacts of a more consequential nature. LCA is a valuable tool to help formulate policies and to help taking decisions in creating environmental regulation. Information from LCA is useful to draft different policy instruments that concern economic actors and consumers, such as label, standard, taxation, incentives, subsidy, etc. It also helps to establish the prices of energy that reflect the cost of the associated environmental damages.

4.2 Case studies in Mexico

Numerous cases can be identified where infrastructural projects were poorly developed and managed, causing social and environmental problems such as losses of jobs and damages to the environment. In addition, it can be fairly stated that even if such projects provided benefits at the state (or global) level, they certainly caused issues at the local level, where drawbacks usually outweighed the advantages. Citizens have thus started to question such an idea of progress and have started to challenge the development of large industrial projects, asking for the adoption of few key principles: transparency and openness of project developments, involvement of citizens and accountability.

Transparency and openness of project developments refer to the opening up of the project to stakeholders as much as possible, thus strengthening trust among them and legitimating the activities carried out. Moreover, involvement of citizens relates, instead, to the engagement of citizens who are directly and locally affected by the project, adopting new forms of debate and democratic procedures for reinforcing their interest in the public sphere. Last, accountability refers to the process of defining, measuring and implementing impact reduction and compensation measures.

4.3 Recommendations

These key principles can be adopted by public or private actors when developing large industrial projects. For example, in the public authorities’ realm, the concept and practice of participatory democracy receives acceptance as an essential complement of representative democracy, since it allows people to obtain an immediate and strong voice over certain projects, and reinforce their critical and analytical spirit as taxpayers. In the private actors’ realm, instead, CSR has gained strong importance as a theoretical concept and practical tool for ensuring good relationships with all stakeholders while simultaneously pursuing profitability objectives. This is the result of the growing recognition that companies are accountable not only for pursuing profits (shareholders’ interest), but also for creating value for all society (stakeholders’ interest). Lastly, as accountability has gained momentum, new and more sophisticated measurement methods are needed to consider the impacts – especially the social and environmental ones – of large industrial projects.

For geothermal energy projects, experiences for recent developments in Europe constitute an important set of lessons to be learned for ongoing and upcoming projects in Mexico, especially for innovative technologies that may require longer development periods (i.e., industrial developments), and carry greater uncertainty on the capacity of the project to deliver results, as well as some additional risks or perceived risks for instance linked to topics such as reservoir engineering. In Europe, recent projects where risks have materialized - from air emissions (e.g., Italy, Turkey) to induced seismicity (e.g., Switzerland) - have had a dramatic effect on the perception of geothermal industry in the local market or even throughout Europe. Community engagement is a strategic component of geothermal project development for several reasons:

- Geothermal energy is heavily dependent on a stable policy and regulatory framework in place, which entails a strong degree of political legitimacy of the technology. Geothermal developers, be they private or public developers need to ensure that the implementation of their projects does not negatively impact the general support for the technology.
- Local communities can either be a crucial proponent of additional geothermal project development or a major barrier to increased market uptake. It is therefore crucial to approach communities that may be impacted by project developments in a way to engage them in the project, allowing them to grasp the benefits of this clean renewable energy technology and limiting the risk of public opposition based on a misunderstanding of the impact of project developments.
- Some impacts of geothermal energy projects may fall within the scope of environmental regulations but may be extremely negatively perceived locally. A key example is the smell of Sulphur. The engagement of local communities is crucial to ensure a good understanding of developers and citizens, limiting the risk of opposition to future projects based on bad experiences for the local communities.

5 Conclusion: EGS and superhot systems Action Plan for EU-Mexico

EGS and superhot systems are particularly well suited for electricity production. They are also complex systems that require extensive scientific knowledge, and sound technical know-how to reduce project development costs, ensure environmental impacts are minimal and optimise the geothermal project. For EGS and superhot systems, cooperation is therefore a key requirement both in the European Union and in Mexico. The European industry is currently at the forefront of technology innovation with respect to EGS and superhot geothermal systems, and cooperation with the Mexican industry can contribute to raise the know-how of Mexican actors, and unlock the EGS and Superhot potential in Mexico. Beyond industrial know-how, academic collaboration between Mexican and European scientific communities on geothermal energy is a crucial factor in enabling future projects, and in allowing further innovation to emerge.

Among the priority topics for geothermal energy research, the following can be identified:

From a European perspective: Strategic Research and Innovation Agenda (ETIP Deep Geothermal):

- Prediction and assessment of geothermal resources: better understand the complex geological dynamics, for better predictability of underground conditions, in order to reduce exploration costs and increase project sucess.
- Resource access and development: improve and ease the extraction through new drilling techniques and technologies, ensure drilling operations are up to the best environmental standards, and maximise the lifetime of boreholes.
- Heat and electricity generation system integration: maximise the generation of heat or electricity from the geothermal brine at the lowest cost.
- Transversal challenges: sound policy and regulatory framework, to remove barriers to deployment and innovation (and indeed deployment of innovative technologies) in the geothermal sector.
- Knowledge sharing: establish an open-access policy to geothermal information, for a better flow of knowledge and an accelerated spread of innovation and learing in the geothermal academic and industrial communities.

From a Mexican perspective: Mapa de Ruta Tecnológica en Geotermia

- Medium to high temperature resources:
  - Reduce uncertainty linked to exploration;
  - Innovative and integrated methods for mapping the geothermal resource potential;
  - Reduce cost, uncertainty and risk during drilling;
  - Optimise energy use in the plant (reduce losses);
  - Increase the collaboration between academia and industry.
- Non-conventional resources: EGS and superhot systems;
  - Improve the understanding, modelling and simulation of the water-rock interaction;
  - Develop technologies, materials, techniques for the exploitation of superhot systems, mitigating the scaling and corrosion.
  - Develop thermodynamic models for exploiting superhot geothermal systems;
  - Develop new and improve existing technologies and techniques for exploration of low permeability systems;
  - Develop technologies compliant with environmental imperatives for increasing reservoir permeability.

In many areas, the EU and Mexican technology roadmaps have very similar priorities. In both cases, **reducing uncertainty is a top priority**, as is reducing the risk and costs involved in drilling for geothermal projects. Moreover, both regions aim to **improve the quality of the use of geothermal energy in surface systems**, and to **allow for the emergence of new geothermal technologies** such as EGS. Besides, both the Mexican technology roadmap and the ETIP DG Strategic Research and Innovation highlight the importance of **improving knowledge sharing**, and **notably circulation of information** between academia and the industry. In that regard, the GEMex project is definitely well suited to serve a basis for initiating such cooperation including across regions.

The EU-Mexico geothermal collaboration started by the GEMex project should serve as a basis for an increased degree of industrial cooperation, notably regarding the implementation of EGS and superhot projects. This supposes a greater degree of integration between the research community that is well represented in the GEMex project consortium and the geothermal industry, which is mostly involved in the GEMex project through participation in the Stakeholder Board, providing input to the work of the project.

GEMex has been successful at producing key research for the implementation of EGS and Superhot projects in Mexico, and although additional research is indeed necessary, this should be implemented in the framework of a greater cooperation between academia and industry to ensure the implementation of the findings in the market through flagship projects, and maximise replicability of such projects. Moreover, the opening of the Mexican geothermal market to private developers, including from the European industry, allows for such cooperation to be established, notably in the framework of an EU/Mexico cooperation on innovation.

From a Mexican perspective, a possible approach could be to define several small projects, focused on one specific geothermal zone each, with industry partners holding the license for that particular area. Such projects could be focused on various aspects, from fostering research about Mexican geothermal resources to the implementation of a flagship EGS/Superhot system. Possible basis for partnerships could include developers with an exploration or development permit (be they private or public, Mexican or European companies), research centers in Mexico and Europe, and possible industrial partners that could bring expertise and resources in the implementation of geothermal energy developments when relevant for the scope of the project. These partnerships could address challenges such as identified specific technological challenges in the zone under exploration, which can go from exploration techniques to the design of the power plant to be installed later.

The purpose of such an approach would be to facilitate the uptake of innovative technologies such as EGS and superhot systems in the Mexican geothermal markets, by connecting the European academic and industrial expertise and needs, notably resulting from the implementation of several EGS projects in Europe, with that of Mexican academia and industry in the implementation of geothermal projects. This enables a greater degree of academic cooperation through the multiplication of projects and allowing the implementation of findings. Many study methodologies were applied in both geothermal systems and therefore there were many results. For future projects it would be convenient to analyse which techniques are indispensable tools to continue studying these types of systems. And based on this, put together strategies for new research projects.

Europe-Mexico knowledge transfer

Setting up EU/Mexico projects in the field of geothermal energy, including both academia and industry, could be the best way to foster the interaction and exchange of technical knowledge between Mexico and the EU.

Additional prospects for cooperation include more decentralised cooperation opportunities from the organisation of technical workshops or meetings in the framework of key EU/Mexico projects. The utilisation of national funds could play a major role in supporting networking activities or smaller projects which focus on a specific topic.

Furthermore, joint education programs, such as joint PhD programmes, scientific networks or EU-Mexican research training groups could be used to increase the knowledge exchange across nationalities as well as across generations. Many national research associations in Europe already have agreements with CONACyT on joint research, which could serve as a basis for the establishment of joint education programmes.

Progressing research in superhot geothermal resources in Mexico

For the development of the superhot resources at Los Humeros, it will be of utmost importance to make use of the results achieved in GEMex and perform advanced conceptual modelling with the available data. This should include data mining and deep learning. In parallel, efforts have to be dedicated to the preparation of a deep drilling project, to verify the developed concepts.

One option to progress research on superhot geothermal resources in Mexico could be the drilling of a superhot well in the framework of the International Continental Scientific Drilling Program (ICDP) – which supports international projects with a specific scientific question with some co-funding (if Mexico is an ICDP member) and operational support for the drilling. The GEMex project has already covered most of the requirements for a successful application to ICDP.

Also, to advance exploration methods for superhot sites in general, the "value of information" of the different methods applied in GEMex should be assessed by an in-depth analysis of (a) the effort necessary to apply the methods, (b) the results obtained and (c) the influence of those results on the development of the investigated geothermal field.

Progressing research in EGS technology

Another possible future project is a continuation of an EGS project development in Acoculco, after the stimulation test is completed, and based on the outcomes of it. The aim could be to drill a new well to be interconnected at depth with the EAC-1 (or EAC-2), encompassing the following activities:

- Select the location of the new well and design its main features: total depth (≤ 2000 m?), high(?) deviation angle, casings-open hole, etc.
- Collect and study enough core samples
- Design a specific stimulation test
- Run all of the possible studies and logs to obtain the necessary data
- Modelling the possible enhanced reservoir
- Preliminary feasibility study, if possible

The funding could come partially from the mentioned ICDP and partially from some Mexican fund, including industrial funding.

Possible paths of future EGS activities building upon GEMex results could include:

- Future EGS project in Acoculco with one new well drilled into the stimulated reservoir volume of EAC-1 or EAC-2.

- Future EGS project in Acoculco with two wells specifically designed for stimulation (e.g., deviated cased and perforated wells), if stimulation results in EAC-1 and EAC-2 is not promising due to the location (no open fractures) or wellbore design (e.g., long open hole section does not allow target oriented stimulation).

- Future EGS project in Los Humeros by stimulation of existing low productivity wells based on the extensive exploration studies performed within GEMex

Strengthening innovation in the European and Mexican Geothermal energy sectors:

Thanks to extensive investments in research, development and innovation, both public and by the industry, the European geothermal sector is a leader in RD&I globally. It is notably in Europe that the concept of EGS was first demonstrated, and the sector has a unique expertise in developing unconventional resources and valorising geothermal resources. The GEMex project, and the collaboration it aims to enshrine between the Mexican and European geothermal sectors – either academic or industrial – can deliver innovation and enable further developments both in the European Union and Mexico.

The outcomes of the GEMex project are a key source of experience for the development of the EGS technology and superhot systems, thanks to the cooperation of a diverse array of actors within an extensive and international consortium to assess specific application in a new market for these technologies. GEMex can yield a blueprint for further EGS/superhot system developments, and it can produce a set of best practices that will be valuable both in the European and the Mexican markets. The transparency of the GEMex project is also crucial for the replicability of these best practices and the spread of this know how.

The transversal approach of the project, notably with an emphasis on mitigating the environmental impact and ensuring community acceptance, is particularly valuable to ensure the acceptability of an increased number of geothermal energy projects. Exchanges of best practices between the European and Mexican industries can build on the conclusions of the GEMex project in that regard.

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