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D8.2 Report on policy modelling to overcome barriers

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CONTENTS

Summary

The objective of Deliverable 8.2 is to report on policy modelling and present proposals for overcoming barriers. It maps EU and national energy policies, decision-making processes and business models to identify opportunities for geothermal deployment. It is part of Work Package 8, 'that examines the techno-economic performance of the GeoSmart innovations in detail and maps them against the future scenarios for geothermal energy in Europe, to develop new policy formulations to be communicated to high level policy makers and decision makers through the industry'.

The first section deals with the role of geothermal energy in the European electricity system as a flexible, base-load energy source, followed by an overview of the broader policy framework of the EU Renewable Energy Targets, the Green Deal and their relevance to the geothermal sector. In section 1.3, the current and planned energy-related regulations and policies as well as the decision-making processes of the selected European countries and regions are mapped, namely Italy, Türkiye, Croatia, and Germany. Section 1.4 then highlights the general barriers to the deployment of geothermal electricity, such as data availability, regulatory complexity or a lack of consistency in requirements, and presents some solutions for financing and risk management. The second chapter provides an overview of existing business models to then identify those business models that form an integrated and overarching EU view, to promote a more level playing field between energy sources. In chapter 3 the project partners from Italy, Türkiye, Iceland and Belgium report on the results of the consultation of key stakeholders such as utility managers and policy makers for wider dissemination. Finally, in chapter 4, a new model for pricing and tariffication is proposed which takes into account additional services to the electricity system provided by geothermal that are not included in the conventional pricing mechanism and disadvantage geothermal energy.

The results of this deliverable have been and will be presented to key stakeholders such as utility managers and policy makers for wider dissemination and for the development of new models for pricing and tariffication.

1. INTRODUCTION

Geothermal has been a valuable resource for the European electricity grid during 2021. There has been nearly 20 TWh of electricity produced, mostly in Türkiye (7.8 TWh), Italy (5.9 TWh) and Iceland (5.6 TWh). In a period of uncertainty on electricity availability, geothermal power plants have distinguished themselves with a high 76% average capacity factor. More than ever, the state of the European electricity market in 2021 highlighted the importance of technologies such as geothermal energy, in providing stability and security of supply.

At the beginning of summer 2021, due to a wide array of factors, gas prices started increasing tremendously worldwide. From an exceptionally cold winter in Europe in 2020, to macroeconomic fallouts of the COVID 19 pandemic, geopolitics, to technical issues in infrastructure bottlenecks of the fossil fuel production infrastructure. As a result, gas prices on the European spot market increased dramatically from 5-10 €/MWh in 2019-2020 to 50 €/MWh in September 2021 and has continued to 2022.

The structure of the European electricity market means that electricity prices are defined by the producer supplying the last MWh at a given time. Prices are therefore a function of the demand curve and the generation of variable renewable electricity (which is always dispatched whenever it can be produced). This gives gas power plants a major role in defining the European electricity prices because, in many cases, they are the main provider of flexibility. In reaction to the surge in gas prices, the electricity prices on the European spot market shot up from 30-50 €/MWh in 2020 to 150-200 €/MWh in the summer of 2021, with spikes as high as 300€/MWh. In February 2022, following the invasion of Ukraine by Russia – which is respectively a key gas pipeline hub and the largest supplier of fossil fuels to Europe – prices spiked further, deepening the crisis and pushing the European Commission to come up with the RePowerEU. This communication presents new tools for reducing the exposure of the EU economy to Russian fossil fuel imports. In reaction to the electricity market's lack of resilience, and the vulnerability to gas prices, many stakeholders, including EU Member States such as Spain or France, have been calling for a revision of the European electricity market rules. This revision, which is being considered by the European Commission in 2022 will aim to reinforce the provisions for flexibility and broadening schemes to incentivise flexibility in resource deployment. The question for the geothermal power industry is what will be the impact on project development?

Most of the policy proposals focus on further increasing the resilience of the electricity system from the perspective of infrastructure, i.e. increasing interconnection to the level defined in the 2018 Electricity Market Regulation. The other priority is to structure the financial flows in the electricity market to reward flexibility, baseload generation and dispatchability, notably to unlock new investments. For geothermal power plants, such schemes can allow developers to monetise the specific benefits of their installations more easily. Indeed, the current incentive framework on the electricity system is not beneficial to geothermal plants, as it does not specifically seek baseload generation or flexibility from renewable power plants. A shift in the direction of more adequate incentives for flexibility of deployment could greatly benefit geothermal and make the business model of geothermal power plants more attractive. The current trend is another step towards a renewable based electricity market, a departure from the current framework inherited from the Third Internal Market Package, which provides definition of the European electricity market around gas power plants.

Meanwhile, the energy price crisis of 2021 has highlighted the vulnerability of the European electricity system when weather conditions are not aligned with energy demand. One of the results is a general demand for a more diversified electricity system, which may lead to a renewed political interest towards geothermal power plants in Europe.

During 2021, six new geothermal power plants were commissioned, representing an addition of more than 35 MWe new geothermal electricity capacity to the European electricity system. Four of the newly commissioned plants are in Türkiye, which has been the main driver of new developments for geothermal power plants for more than a decade and represents nearly all additional capacity. The increased demand for electricity in Türkiye has been a key driver.

The two other plants were commissioned in Germany with a capacity of 1 MWe and 5 MWe respectively. The plants commissioned in 2021 represent a double trend in the geothermal industry with the maturity of binary technologies allowing larger plant size on the one hand, and with the industry embracing smaller scale plants with a renewed interest for combined heat and power plants. These new additions bring the total installed capacity for geothermal power plants to 3,4 GWe in Europe, for 142 plants which generate at least 19 TWh of geothermal electricity at an average capacity factor 76%. The capacity factor of geothermal plants is the highest of all technologies and has been so for decades.

In a year that has faced energy supply security challenges, and instability on the electricity market, geothermal base load electricity production has played a crucial role for resilience locally – predominantly in Iceland where the country faced challenges with its otherwise plentiful hydroelectric production following drought. 2021 is marked by a slowdown in the commissioning of new geothermal power capacity in Europe compared to previous years.

The overall reduced rate of commissioning new geothermal power capacity is largely due to the slowing Turkish market following several years of rapid capacity additions. The past few years saw Türkiye consistently leading the global market for geothermal power plant development. The geothermal industry in Türkiye is adapting to the recent changes in the support framework, which reduced the level of incentives for the development of new projects. It is notable that Türkiye has a relatively low number of projects currently in development or planning phases (17) in relation to the size of the market (72 operating plants) and the rate of new plants commissioning in recent years. For example in 2020, 8 new Turkish geothermal power plants came online. Since the adaptation to the support framework which featured a lowered feed-in premium, geothermal plant developers have experienced several years of prolonged uncertainty, leading up to the looming regulatory changes. This uncertainty largely inhibited project developments and new planning. The Turkish industry is therefore in a transitory period, looking to adapt its business models and plan its development within the boundaries of a changed incentive framework.

Meanwhile across Europe, in geothermal power generation we see renewed interest from policy makers and the energy industry, although the trend remains timid (see figure 1).

Geothermal electricity plants in Europe (EGEC Market Report 2022)

Countries	Operational plants (MW)	Construction(MW)	Planned (MW)
Austria	2 (1.2 MW)	0	2 (? MW)
Belgium	1 (4 MW)	0	1 (2 MW)
Croatia	1 (17.5 MW)	1 (4.3 MW)	9 (103.2 MW)
France	3 (17 MW)	5 (15.5 MW)	15 (97 MW)
Germany	12 (46 MW)	5 (77.55 MW)	17 (155 MW)
Greece	0	0	6 (42.5 MW)
Hungary	1 (MW)	2 (22 MW)	0
Italy	36 (915 MW)	2 (25 MW)	35 (325 MW)
Portugal	3 (33 MW)	1 (5 MW)	0
Slovakia	0	1 (20 MW)	2 (22.4 MW)
Iceland	10 (754 MW)	2 (30 MW)	8 (450 MW)
Switzerland	0	0	2 (5 MW)
Turkey	72 (1653 MW)	2 (31.6 MW)	15 (381.9 MW)
United Kingdom	0	2 (8.15 MW)	2 (5 MW)
EU total	59 (1,051.7 MW)	17 (269.3 MW)	87 (747.4 MW)
Rest of Europe total	82 (2,407 MW)	6 (69.7 MW)	27 (841.9 MW)
Total	141 (3,458.7 MW)	23 (339.1 MW)	114 (1589.3 MW)

Table 1 Geothermal electricity plants in Europe

The soaring price of electricity price and security of electricity supply crises emerging in the second half of 2021 and intensifying at the beginning of 2022 due to the invasion of Ukraine by Russia, is motivating a renewed interest for base load geothermal energy. While most of the focus has been on geothermal heating and cooling technologies, geothermal power plants have received greater interest as well. This was illustrated by British investor Equitix who acquired the combined heat and power geothermal plant of Traunreut in Bavaria, Germany in 2021.

Moreover, the general decarbonisation trends call for solutions to enable transformation of the electricity system. Geothermal power plants appear to be a viable solution. Figure 3 highlights the interest for new geothermal power plants beyond traditional production areas. While we can expect most of the upcoming additional capacity to be deployed in relatively high temperature fields, the introduction of geothermal power production in new parts of Europe could have a significant impact on the structure of electricity systems locally. Even the relatively small plants such as the 1MWe unit commissioned in 2021 in Kirchweidach, Germany can have an important impact on the stability of the DSO, reducing the need for new power lines or batteries to maintain grid frequency and keep the lights on.

"High temperature systems" are defined by larger than average size plants, such as in Iceland (see figure 2). Therefore the 17 projects in development in Türkiye will have a much greater impact than the 16 projects in development in Germany. Indeed, the average capacity of a plant is 23 MWe in Türkiye, six times larger than the size of an average plant in Germany. Locally however, geothermal power plants providing a small capacity can play a crucial role in balancing the electricity grid. Meanwhile, tremendous potential remains untapped in absolute terms. This is the case in Italy, where regulatory uncertainty continues to prevent any project development, despite 32 projects at various stages of development or planning – sometimes in limbo for well over a decade. Although they are still emerging, it is likely that the core new markets for geothermal power production in the coming decade will likely be in Croatia and Greece, and possibly in lithium rich areas including the Rhine Graben (Germany and France) where the promises of EGS have remained largely unfulfilled thus far. After the acquisition of the Plant in Insheim, Vulcan secured five additional geothermal exploration licenses on the German side of the Upper Rhine Valley to develop this resource, while other companies such as Lithium de France (into which the Norwegian national energy company, Equinor, invested a stake) and EnBW are also looking to develop projects in the area.

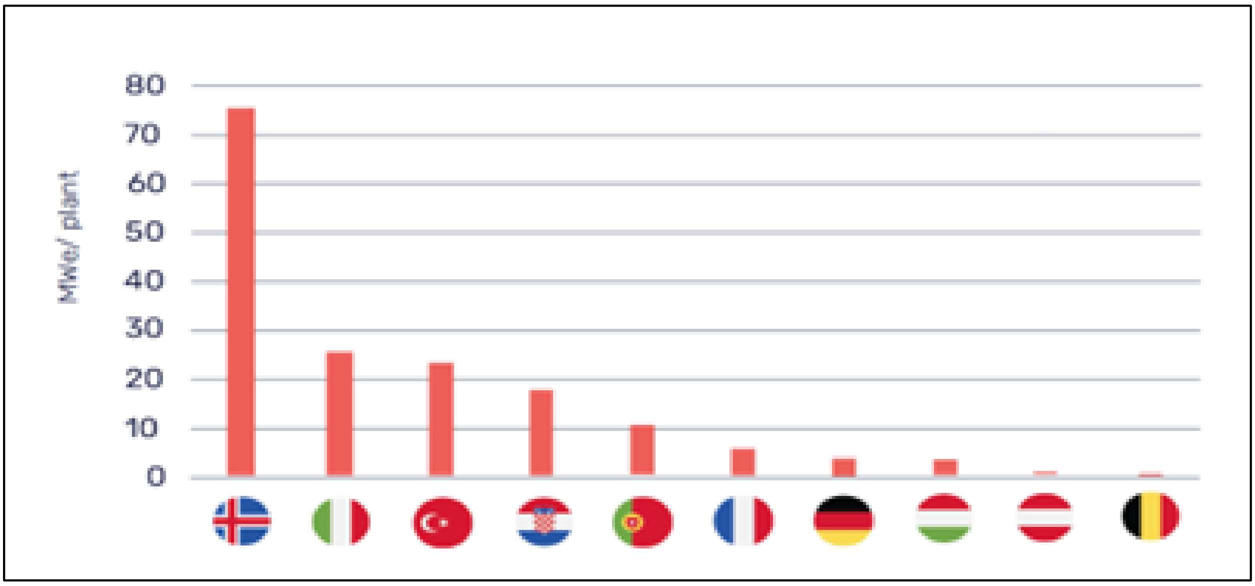


Figure 1 Average size of geothermal power plant per country

As ever in the geothermal sector, the quality of the resource – i.e. temperature – is a very important factor in market developments. Türkiye and Iceland, two of the largest users of geothermal power in Europe, and among the "high temperature" markets will continue developing. In the case of Türkiye as mentioned above, some adjustments to business models and the industry may be required to adapt to a new regulatory framework. In the case of Iceland, steady new developments will continue as the country is looking to strengthen its energy independence, notably for the supply of energy to energy intensive industries, and for the increased electricity demand created by transport electrification. In many lower temperature markets however, geothermal power plants developers must identify new strategies to attract public support and consolidate their market. The focus is increasingly on the development of projects primarily focused on heat production – possibly high temperature heat for industry – with a smaller electricity turbine as a complement to the business model. This was the case for German Kirchweidach plant which installed a small ORC unit in the second part of project development; the initial having been district heating and cooling.

Another important segment of the European geothermal electricity industry that is seeing renewed activity for project planning and development in 2021 is that of volcanic islands. Beyond the Azores, which have been steadily building up their geothermal capacity – and are planning further developments, several projects are at the planning phase in most French volcanic islands (Guadeloupe, Martinique, Reunion, Mayotte). Planning and exploration have begun in the high potential volcanic archipelago of the Canaries in Spain involving O&G major Repsol. The development of geothermal power plants to further the decarbonisation of island energy grids (which primarily rely on oil for power generation) notably aligns exactly with the European Commission initiative "Clean Energy for Islands".

2. CHAPTER 1 - FRAMEWORK CONDITIONS

2.1 Realigning the EU's renewable energy targets to the EU Green Deal

The European Green Deal, launched in 2020, realigned the EU climate, energy and all other sectors to delivering a -55% greenhouse gas emission reduction by 2030. In this framework, the EU's binding Renewable Energy Directive (RED) target for 2030 was raised from 32% to 42.5% in 2023.

The RED remains the key policy driver for investments in renewable energy capacity. Article 3 establishes the overall renewable energy target and is the main driver for investment in new electricity capacity. Other elements of RED, such as the binding renewable heating and cooling target (Article 23) provide additional business model support for combined power and heat geothermal plants.

It also improved the permitting process (Articles 15 and 16) as well as establishing a requirement for Member States to outline **"renewable acceleration areas**". These are designated *"surface, subsurface, sea or inland waters deemed necessary for the installation of plants for the production of energy from renewable sources, and their related infrastructure necessary for national contributions towards the 2030 renewable energy target"*. Each Member State will have to map these areas within 18 months after the entry into force of this directive, then outline planned investment in these areas within 27 months of the implementation of the Directive.

In these areas, the permit-granting processes should not take longer than one year for renewables projects, and two years for offshore renewables projects (with exceptions). Moreover, a shorter deadline of 6 months for areas already designated as suitable for an accelerated renewables deployment. As for the repowering of plants and new installations with an electrical capacity of less than 150 kW, and co-located energy storage facilities as their grid connection, the processes should be limited to six months, and one year if they concern offshore wind energy projects (with exceptions).

For areas outside go-to areas, the permit-granting processes should not exceed two years, and three years for offshore renewables projects (with exceptions). The time during which the plants, their grid connections and the related necessary grid infrastructure are being built or repowered should not be counted within these deadlines.

RED also encouraged Member States to establish **financial risk mitigation schemes** (Article 23) to aid heating and cooling plant, which supports multi-purpose geothermal plants.

The **Electricity Market Design (EMD),** agreed in December 2023, also provides a driver for investment in geothermal power capacity by supporting two-way Contracts for Difference (CfDs) as a means of financing geothermal and other new power capacity. It also outlines a business case for flexibility services and storage.

Under the **Net-Zero Industry Act** (NZIA) strategic net-zero technologies are selected based on the three criteria of (1) technology readiness level, (2) contribution to decarbonisation and competitiveness, and (3) resilience of the energy system. Heat pumps and geothermal energy technologies are included in the list of strategic technologies and can thus profit from the NZIA measures that include faster **permits** with only one authority as reference; a facilitated access to markets in public procurement procedures and auctions, as well as schemes aimed at supporting private demand by consumers; European Skills Academies to enhance quality job creation; regulatory sandboxes to test innovative net-zero technologies.

The **Council regulation on emergency measures**, December 2022, and valid for 18 months is also concerned with faster permitting. Renewable energy plants are classified to be of overriding public interest which allows new permitting procedures to benefit with immediate effect from a simplified assessment for specific derogations foreseen in EU environmental legislation. Moreover, the permit-granting process for the installation of heat pumps below 50MW shall not exceed one month, in case of ground-source heat pumps three months. The procedure for the grid connection of small heat pumps is to be simplified. Member States agreed that these faster permitting rules are also applied to ongoing permit requests.

Overall, the regulatory drivers for geothermal power were considerably improved. However, the need for clear support for the construction of projects, where there is a gap from the initial investment and the first financial returns, requires more attention as does the need for more national or a supranational financial de-risking project.

2.2 Mapping the decision-making process of the top EU countries and regions

The EU **Ordinary legislative procedure**, the default decision making process, is based on a multi-level governance and a collaborative process to agree legal rules. The legislative process can be initiated by different actors (states, companies and citizens) at different territorial scale (EU, state, regional, local). This governance model implies the transition from a strictly hierarchical (vertical) form of legislation to one based on networks (horizontal), applying the principles for an efficient policymaking: participation, cooperation, openness, transparency, inclusiveness and policy coherence. The European Commission assesses the possible impacts a new law could have before proposing the initiative. An impact assessment is conducted with the participation of NGOs, expert groups, national authorities and industry.

In additional public consultations, organisations, businesses and individuals can give their feedback concerning the Commission's initiative. After these assessments, the Commission proposal is submitted to the Parliament and the Council that can review it and propose amendments. When a final text is agreed on by the institutions the new proposal is adopted into law. National governments then have to implement the law in the individual Member States.

Overview mapping: a tool for understanding barriers

This part of the publication presents an overview of the regulatory and policy framework that affects investments in RD&I in geothermal energy. To that end, three main policy and regulation areas have been identified as being instrumental:

- Climate and energy
- Research, development and innovation
- Environment.

Geothermal energy is a renewable energy source. It is among the resources that the EU's climate and energy policy aims to develop in order to mitigate climate change. As such the EU climate and regulatory framework is a major factor for geothermal RD&I developments. In addition, the general RD&I policy and regulatory framework in the EU is another factor, notably to provide funding from public institutions. Finally, the environmental policy and regulatory framework has a role in determining RD&I orientation, and somehow directing funding, as it sets objectives for mitigating the environmental impacts of projects, which may require innovation and research and development.

For the sake of this publication, which cannot be exhaustive due to the granularity and the diversity of policies and regulations across the European Union, three overview mappings have been realised to present the overarching structure of policies and regulations in the EU for the three areas identified as relevant. These mapping present the EU policies that are the basis for subsequent national policies that further precise a policy and regulatory framework. However, European policies are to be translated in national, or regional in case of some federal states, legislation in all EU Member States. As such the European policies are the right basis to define the policy and regulatory framework for geothermal RD&I.

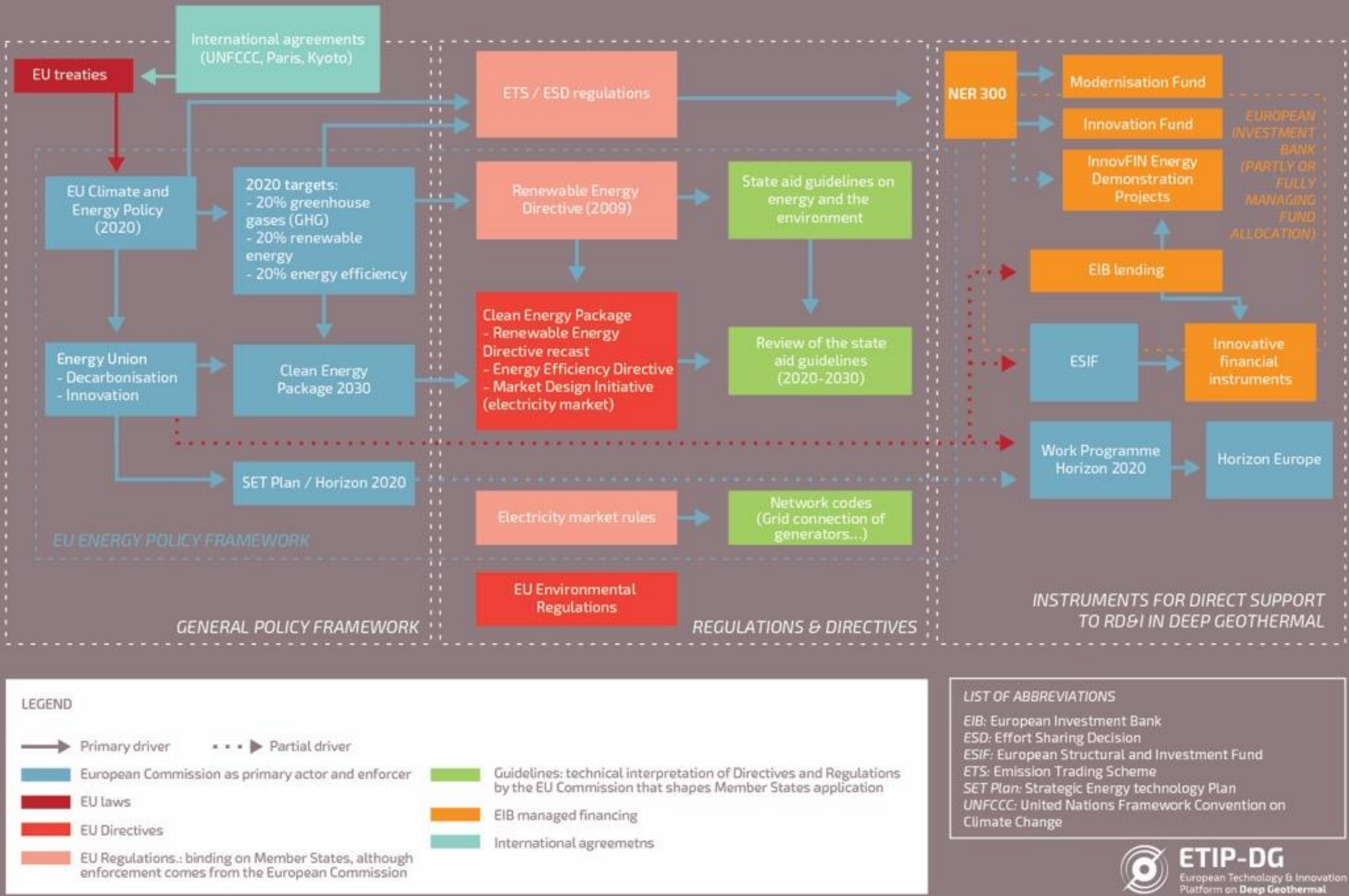
The purpose of the proposed maps is to identify how general policy objectives translate into regulations and into RD&I funding. The purpose of this dynamic mapping is to identify the link between policies and RD&I public funding, which informs the purpose that geothermal RD&I investments should pursue.

Overview of the European regulatory and Policy framework

The next 3 pages give an overview of European policies:

- on Climate and Energy for supporting deep geothermal
- on Research, Development and Innovation relating to deep geothermal projects
- on Environment, relevant to deep geothermal projects

OVERVIEW OF THE **EUROPEAN REGULATORY AND POLICY FRAMEWORK ON CLIMATE AND ENERGY** FOR SUPPORTING DEEP GEOTHERMAL

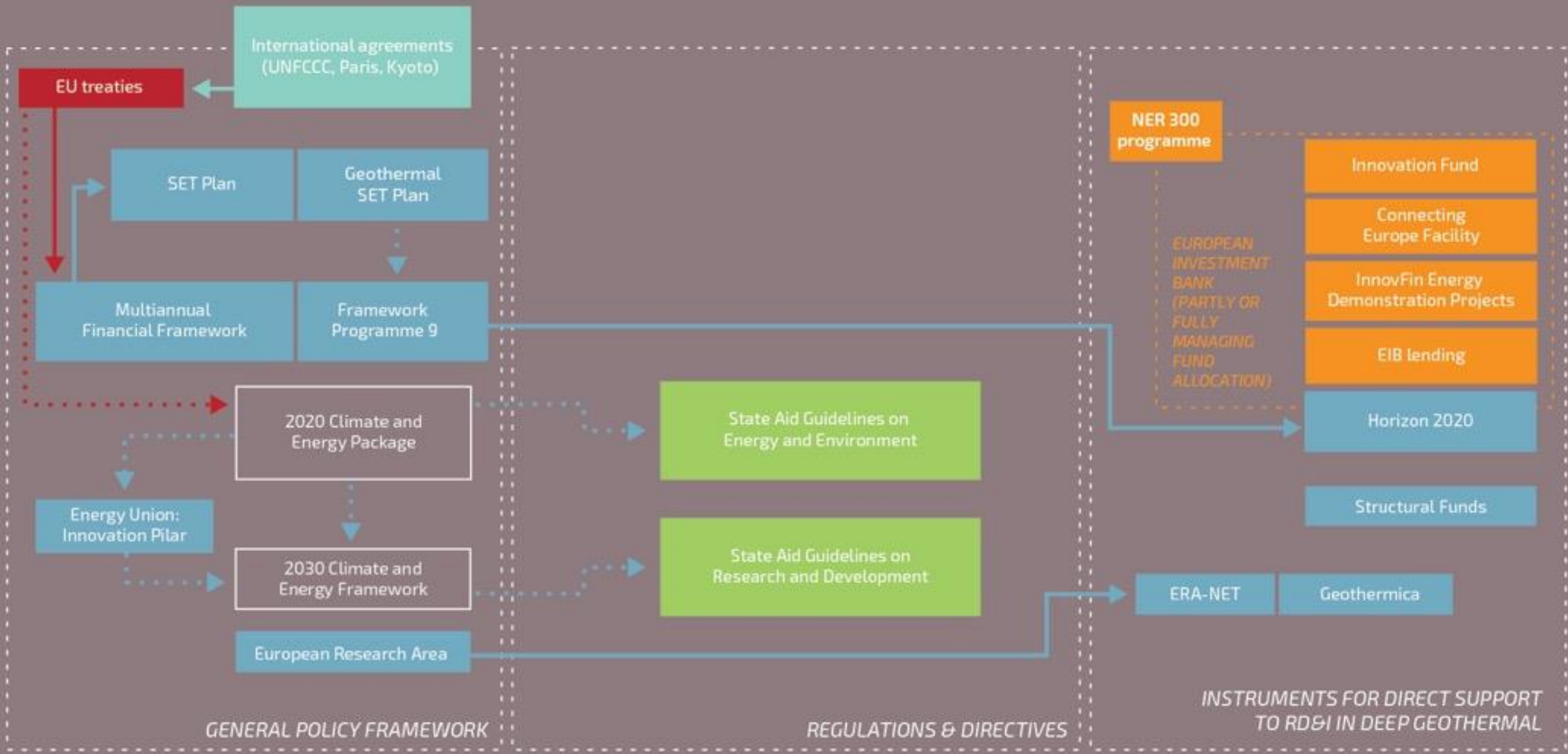


LIST OF ABBREVIATIONS

EIB: European Investment Bank
ESD: Effort Sharing Decision
ESIF: European Structural and Investment Fund
ETS: Emission Trading Scheme
SET Plan: Strategic Energy technology Plan
UNFCCC: United Nations Framework Convention on Climate Change

ETIP-DG
European Technology & Innovation Platform on **Deep Geothermal**

OVERVIEW OF THE **EUROPEAN REGULATORY AND POLICY FRAMEWORK ON RESEARCH, DEVELOPMENT AND INNOVATION** RELATING TO DEEP GEOTHERMAL PROJECTS



LEGEND

- Primary driver
- Partial driver
- European Commission as primary actor and enforcer
- EU laws
- EU Directives
- EU Regulations.: binding on Member States, although enforcement comes from the European Commission
- Guidelines: technical interpretation of Directives and Regulations by the EU Commission that shapes Member States application
- EIB managed financing
- International agreemetns

LIST OF ABBREVIATIONS

ERA: European Research Area
EIB: European Investment Bank
ETS: Emission Trading Scheme
SET Plan: Strategic Energy technology Plan
UNFCCC: United Nations Framework Convention on Climate Change

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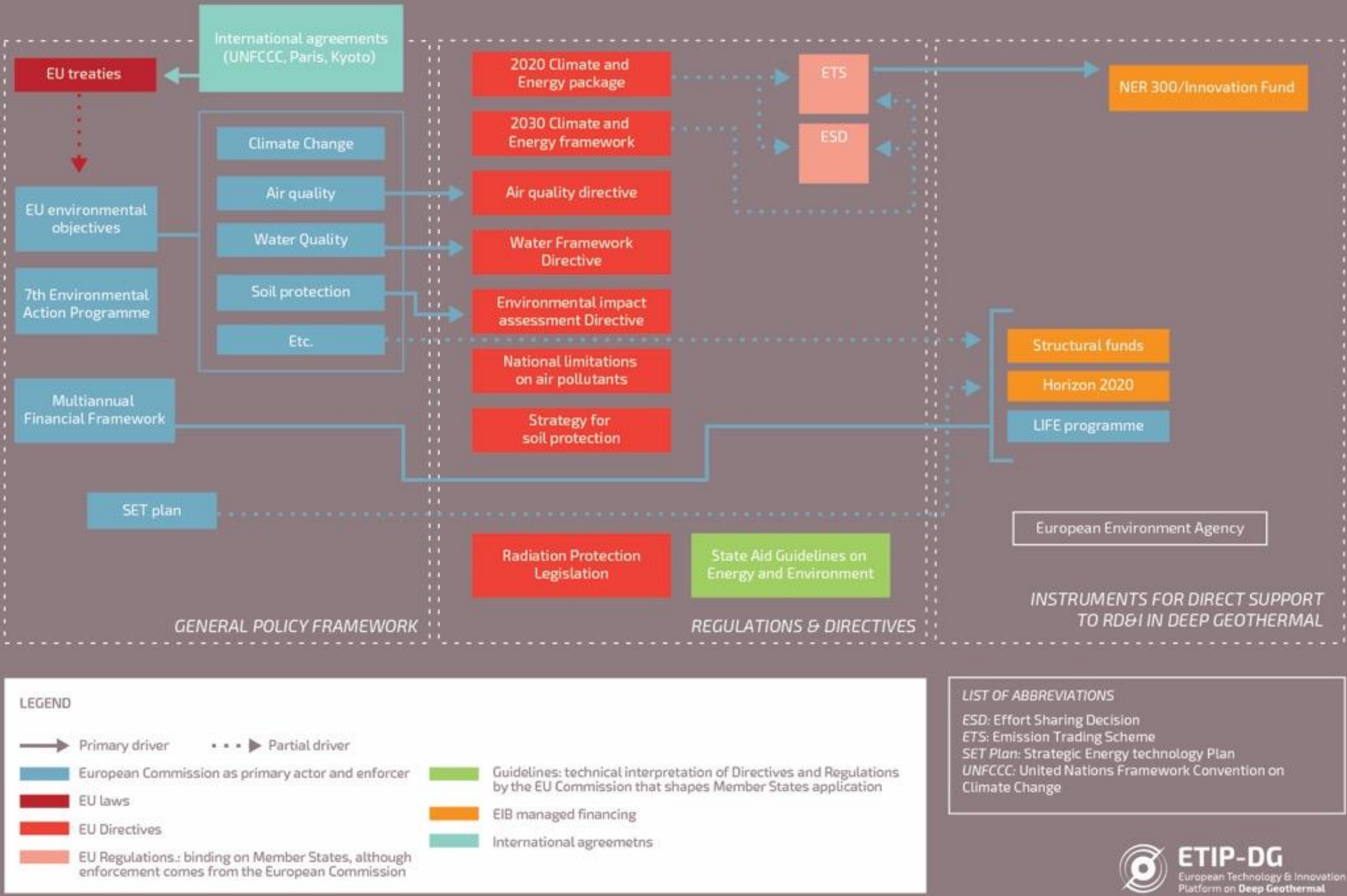
OVERVIEW OF THE **EUROPEAN REGULATORY AND SUPPORT FRAMEWORK ON ENVIRONMENT** RELEVANT TO DEEP GEOTHERMAL PROJECTS



LIST OF ABBREVIATIONS

ESD: Effort Sharing Decision
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2.3 Overview assessment of the current and planned energy-related regulations and policies in each country and relevant region,

As well as reviewing the associated bodies/institutions that apply them, this Section provides a description of the energy policy framework impacting the development of a geothermal project. Actual energy-related regulations or policy in each country and each relevant region will be listed, including the associated bodies/institutions that own them.

Germany[2]

Germany is the first country to decommission turbines installed in geothermal combined heat & power plant to concentrate solely on heat supply. The Unteraching combined heat and power plant closed its 3.4 MW power generation plant to focus on supplying heat. However, this trend does not seem to be replicated at a large scale, at present. The electricity price crisis caused by the invasion of Ukraine radically changed this dynamic. The guaranteed feed-in tariff for geothermal energy introduced by the 'Renewable Energy Act' (EEG, 2000) have led to an increased interest in geothermal electricity especially in the Upper Rhine Plane and in Upper Bavaria.

In the whole country, 12 plants are in operation with a total of 50 MWe installed capacity producing 207 GWh. 17 projects are under development and 18 more are planned. There are two key projects which could have significant bearing on the future of geothermal in Germany and beyond.

Firstly, Baker Hughes, one of the largest multinational subsurface services companies was awarded a geothermal exploration permit. The State Office for Mining, Energy, and Geology (LBEG) in Lower Saxony, Germany has assigned the Altencelle permit field to Baker Hughes InteQ GmbH, based in Celle. This grants Baker Hughes a five-year permit for geothermal energy exploration for commercial purposes until 14 April 2028. The Altencelle permit field has an area of 133 km^2 encircling Celle.

Secondly, a similar permit was granted to Eavor GmbH for the Buchholz permit field, also in Lower Saxony. The LBEG has now reached a new peak in the number of permits allocated to geothermal exploration – 14 in Lower Saxony, and 1 in Hamburg. In Geretsried, Eavor is installing its first closed-loop geothermal system where a benign working fluid circulates in an industrial-sized, underground heat exchanger without the need for a pumping system. Once commercially demonstrated, this could dramatically change the application of geothermal heating and power across Europe and elsewhere.

Italy

Italy is the home of the first geothermal electricity plant in Larderello in 1913. ENEL Green Power operates all the existing 34 power plants, with an installed capacity of 915.79 MWe which generated nearly 6 TWh in 2022, from three geothermal fields within the Tuscany Region.

[2] EGEC Market Report 2022

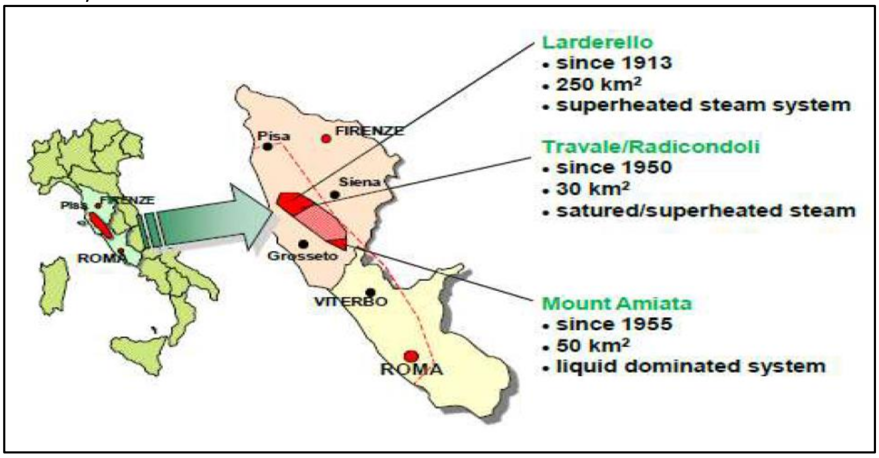


Figure 2 Location of the geothermal fields in Italy[3]

Two projects are in development, representing a capacity of 25 MWe, and 43 projects, equating to an additional 372 MWe, are under investigation. The awaited approval by the European Commission of the new support scheme FER2, which should include support measures for traditional geothermal plants with innovation and innovative new "zero emission" geothermal plants[4] (Della Vedova et al. 2022) and the long lasting authorization processes are slowing down the projects' developments.

In Tuscany, geothermal power plants manage to produce enough electricity to meet over 30% of the region's electricity needs. Electricity is, however, fed into the national grid, and so does not offer particularly advantageous conditions in the bills of local users, at least directly. Pending possible developments in national legislation, the Municipality of Radicondoli has therefore chosen to use part of the geothermal royalties for this very purpose. In agreement with the Consortium for the Development of Geothermal Areas (CoSviG), calls for applications have been published for families and businesses, which can now apply for a contribution to offset the 30% increase in electricity in 2022: there are up to €400 per family and €5,000 per business[5]. In addition, companies that directly use geothermal for space heating and in their production processes, and citizens connected to the 21 district heating networks in the Tuscan geothermal areas, can benefit from advantageous tariffs, thanks to agreements signed between Enel, municipalities and the Tuscany Region.

Legislative Decree number 22, dated 11th February 2010, liberalised access to the geothermal market, allowing many new players to enter into the geothermal sector and the opportunity to apply for an exploration lease to the regional authority. The main points of the measure concern: classification of geothermal energy as reported in Table 1., (based on temperature and depth) and plants (based on the installed capacity), a publicly available inventory of geothermal resources, regulation of exploration permits and geothermal leases, provisions for small local utilizations of geothermal resources, license fees. The law also provides that the authorities in charge for the management of authorizations (research and use of resources) are the regions, while simplified authorizations are envisaged for zero-emission pilot plants, for which the relevant competent authority is the Ministry of the Environment and energy security. The recent Law 181 of November 2023 reports measures that will act in the field of business support, promotion of renewable energy, energy security and decarbonisation and could help investments in geothermal production.

[3] Della Vedova et al. 2022

[4] Della Vedova et al. 2022: Della Vedova, B., Bottio, I., Cei, M., Conti, P., Giudetti, G., Gola, G., Spadoni, S., Vaccaro, M., Xodo L. (2022). Geothermal Energy Use, Country Update for Italy, European Geothermal Congress 2022, Berlin, Germany, 17-21 October 2022.

[5] EGEC Market Report 2022

The Law 134 of 2012, declares geothermal energy a strategic energy source for Italy, and its potential to support the energy transition is recognized thanks to the combined production of electricity and heat and the high national potential to develop district heating and heating and cooling systems that use renewable energy (Della Vedova et al. 2022).

Table 2: Classification of geothermal resources in Italy

Classification	Characteristics	Authority in charge
Resources of national interest *(considered as mining resources)*	Fluids > 150°C Deliverable power > 20 MWth	Regions or delegated authorities
	Geothermal resources in the sea	The State
	Fluids > 90°C Used in < 5 MW zero emission pilot plants	The State
Resources of local interest *(considered as mining resources)*	Fluids < 150°C Deliverable power < 20 MWth	Regions or delegated authorities
Small local utilizations *(not considered as mining resources)*	Deliverable power < 2 MWth Resources from < 400 m deep wells	Regions or delegated authorities

The publication of the RePowerEU plan in 2022 resulted in great expectations regarding improved regulation and support measures for the geothermal sector. Eighty requests for research permits were submitted in the Tuscany region alone, in 2022, whereas 14 research permits were issued across the provinces of Grosseto, Siena and Pisa for an area of around 1,000 km² in total. The 14 permits have been attributed to 10 different developers.

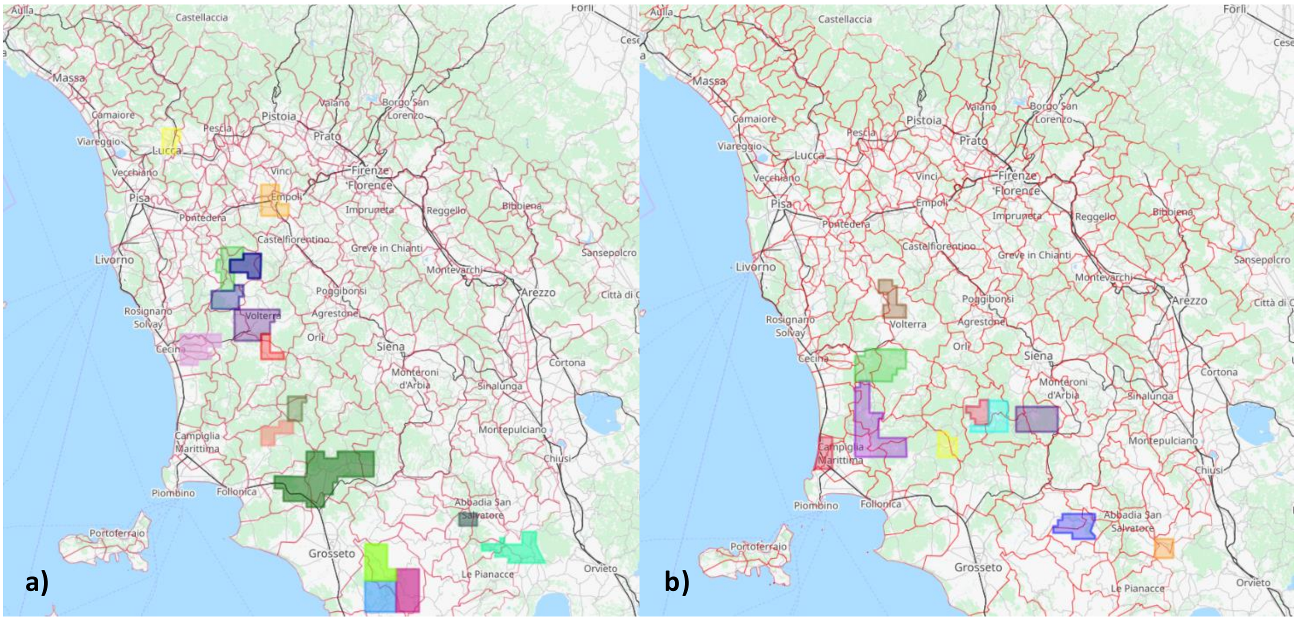


Figure 3 Existing (a) and pending (b) exploration permits in Tuscany in September 2023[6]

[6] the Region of Tuscany: Webpage of the Region of Tuscany with information on geothermal exploration permits, leases and plants: https://www.regione.toscana.it/-/permessi-concessioni-e-impianti.

Despite what is reported above, the lack of adequate tools concerning the regulation of the district heating sector led to delays of several years its development and the geothermal power sector has not seen further developments for about 20 years, and it awaits policies supporting its deployment (Della Vedova et al. 2022).

Following the April 2015 resolution of UNECE (United Nations Economic Commission of Europe) on geothermal energy, the Italian government drafted the "Guidelines for the use of medium and high enthalpy geothermal resources" in 2016 and a document for the "Geothermal zoning of the Italian territory" was drafted in 2017, to provide criteria for identifying suitable areas for geothermal exploitation.

At regional level, law 7/2019 of the Tuscany Region provides that geothermal leases and authorizations for new plants are issued if best available technologies and measures to mitigate impacts on the landscape are adopted, such as a monitoring plan for air quality. The law also provides that at least 50% of the waste heat from plants shall be used for DH networks or industry and to use in the network at least 10% of geothermal CO_2. Concerning the policies, UGI (the Italian Geothermal Union) and AIRU (the Italian Association for Urban Heating), with the support of EGEC, launched a Technical Roundtable in February 2022 to highlight the role of geothermal for the energy transition in Italy, identifying the barriers that still prevent its development. This roundtable aims to support political decision makers in highlighting and developing the Italian geothermal potential, through the FER2 which should lead to the deployment of innovative plants for the next 5 years. The Italian Ministry of Environment and Energy Security (MASE) sent a proposal to the EU to update the National Integrated Energy and Climate Plan (PNIEC) 2023 in July 2023. The national plan outlines how the EU countries intend to address the energy related fundamental themes. Regarding geothermal energy, the installed capacity is expected to grow moderately by 183 MW (or 22%) by 2030, but it focuses more on the development of a geothermal supply chain and it considers this energy source as a priority for the Italian research system.

Croatia[7]

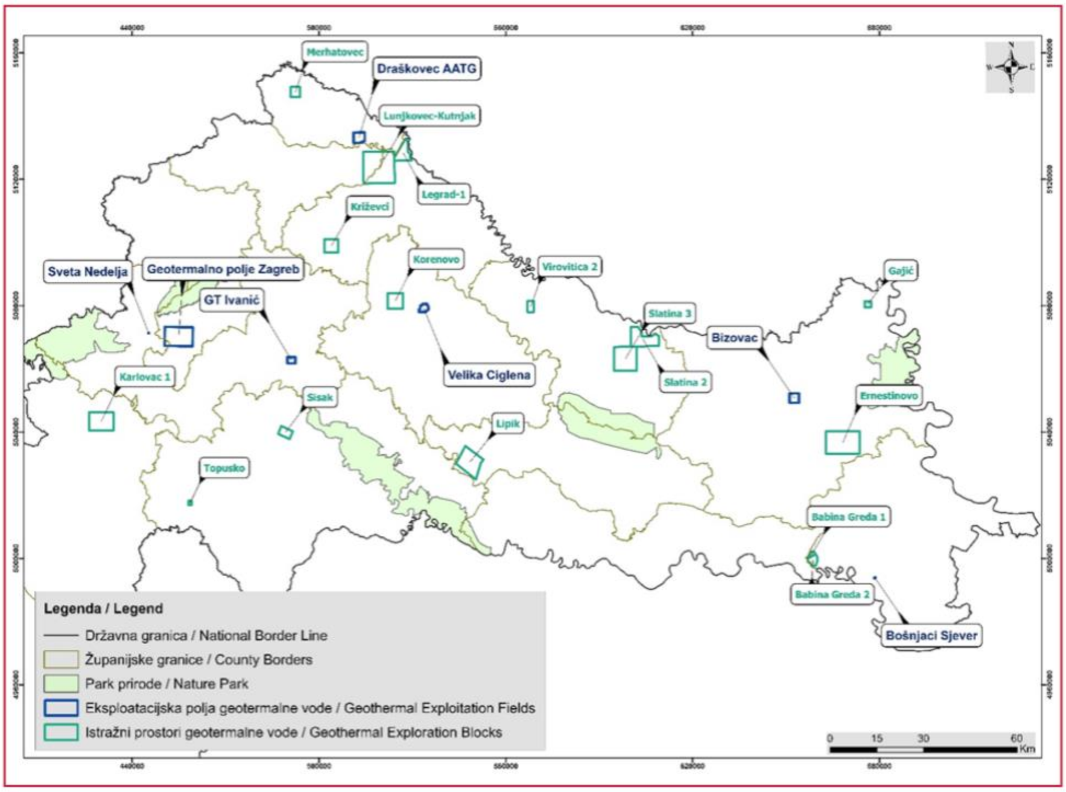
Croatia has installed geothermal power plants over the last 20 years. As of 2022 it had one operational plant and geothermal electricity production of 93.7 GWh and Croatian plants had a load factor between 60% and 75% and 10 plants planned or in development.

The Croatian Hydrocarbon Agency (AZU) issued a tender for exploration in six locations to meet its target of operating 1 GW of geothermal electricity combined with heating networks. The tender closed on 1 June 2023 and is expected to stimulate around €45 million of investment in geothermal energy.

The Act on Exploration and Exploitation of Hydrocarbons governs the exploration of geothermal waters for energy purposes in Croatia. In a unique process, investors compete for an exploration permit, followed by a production permit if all conditions from the exploration phase, which lasts 5 years, are met. In December 2022, six new tenders for the exploration and exploitation of geothermal energy were announced. The application deadline was in June 2023. Many more direct requests were made to the Croatian authorities. Croatia opened the main repository of the national geological database which was used primarily to develop the oil and gas industry. This enables the Croatian Hydrocarbon Agency to provide concrete initial data on the geothermal potentials in specific locations. Available data about water temperatures and reservoir permeability is also made available. This database reports 3,500 wells and seismic data over an area of about 20,000 square kilometres, including a large amount of 3D seismic data. The six exploration blocks are located in four Croatian counties (Međimurje, Koprivnica-Križevci, Podravina, Osijek-Baranja) with a total area of over 200 km^2.

[7] EGEC Market Report 2022

Exploration and exploitation licenses for geothermal water in Croatia



Source: The Croatian Hydrocarbon Agency. December 2022.

Figure 4 Exploration and exploitation licenses for geothermal water in Croatia

Türkiye

Geothermal research and investigations in Türkiye have been carried out since the 1960s and accelerated mainly after the 1970s. Following a pilot power plant with a capacity of 0.5 MWe installed in the Denizli-Kizildere geothermal field in 1974, a plant with a 17.4 MWe was commissioned at the exact location in 1984. Nonetheless, after this promising development, geothermal power generation activities in the country progressed very slowly for over 20 years. Indeed, the adoption of the Law on Geothermal Resources and Natural Mineral Waters in 2007 setting the rules for the exploration and exploitation of geothermal resources, and the amendment in 2010 to the Law to Use the Renewable Energy Resources for Electricity Generation offering a feed-in tariff mechanism (YEKDEM) that was 10.5 USD/MWh and for ten years from the commissioning date, were two critical milestones for the geothermal energy sector. Additional incentives were also provided to the plants for their locally produced equipment. Following these developments, geothermal energy investments for power generation in the country increased dramatically along with the great interest of the private sector. With the amendment in the YEKDEM mechanism in 2021, it was decided to give incentives in Turkish Lira for the power plants that will be put into operation until the end of 2025. Some studies indicate that electricity generation prices of geothermal power plants decreased by over 60% after this change, which accounts for the standstill in new plant investments in the market reached in 2022.

As a recent development, a price floor in USD/MWh has been determined in the YEKDEM with the aim to protect the YEKDEM price in local currency against exchange rate fluctuations. Furthermore, the duration of geothermal power plants to benefit from the support scheme has been increased from 10 years to 15. Other than feed-in tariffs and European Bank for Reconstruction and Development funds, the Development Bank of Türkiye and the World Bank also introduced a risk-sharing mechanism (RSM) in 2018 to cover 40% to 60% of the cost of failed wells and facilitate exploration drilling in new areas. An amendment to the Law on Geothermal

Resources and Natural Mineral Waters is also being considered in a way that it will set the rules and tariffs for regional heating and cooling from geothermal resources.

Different institutions are responsible for geothermal energy resources in Türkiye. While continuing its geothermal exploration, development, and drilling activities, the General Directorate of Mineral Research and Exploration (MTA) provides the appropriate fields to investors through tenders. After the applications for geothermal resource exploration are evaluated by the General Directorate of Mining Affairs (MAPEG), Invest and Coordination Agencies (YIKOB), subordinate to governorates in the provinces, issue the geothermal resource exploration license. The Energy Market Regulatory Authority (EMRA) examines the license applications for electricity generation and issues a license if it deems it appropriate. Furthermore, it examines and accomplishes the applications of plant operators for the feed-in tariffs. The Development Bank of Türkiye and the Turkish Industrial Development Bank acts as an intermediary institution in energy sector funding.

The Ministry of Environment, Urbanization and Climate Change is responsible for monitoring the carbon dioxide and H2S amounts through the monitoring systems placed at the power plants, transmitting the data to the Ministry, and making cumulative impact assessments. The Energy Cities Union aims to make renewable energy sources the most efficient and environmentally sensitive way, with the contribution of municipalities, to provide the highest added value to local development, national welfare, economy and employment. In Türkiye, there are two different geothermal energy associations namely the Geothermal Power Plant Investors Association (JESDER) established in 2014 and the Geothermal Energy Association (JED) in 2020. JED mainly consists of large and institutional firms that parted from JESDER.

2.4 Highlighting the barriers for geothermal electricity deployment

The lack of harmonised guidance on licensing and permitting is a significant barrier to the deployment of geothermal and could jeopardise the achievement of geothermal electricity projects. The following factors contribute to delays:

Geological data availability: the acquisition of geological data can be a barrier when the data purchase is too expensive and when confidentiality blocks the communication of the data. In the case of publicly funded projects, data protection is rather short but for private developers the confidentiality can remain for several years, with a copy of the geological surveys. A Best practice comes from The Netherlands where geological data becomes publicly available after a short period. Access to geological information from previous exploration activities (e.g. oil and gas) is crucial.

Complexity: geothermal energy is regulated by many entities and regulations, treating underground activities as mining and the surface as an industrial application, but also for the environmental, water and energy regulations. As illustrated in the delegated acts on EU taxonomy, the geothermal resource is combined with several engines: a turbine for Combined heat and power plants, District heating and Cooling systems, Heat pumps, and Underground Thermal Energy Storage. Each engine has additional regulations and technical standards.

Capacity: the skillsets required for geothermal assessment are often underutilised or there is a lack of qualified professionals at national, regional and local levels to undertake the necessary checks and approvals. This is compounded by a lack of harmonised terminology sometimes within a Member State and across the internal market. These factors create avoidable administrative delays and bottlenecks.

Engagement: there is a lack of consistency and clarity in the formation required from project developers which causes delays. Furthermore, transparent and time-sensitive processes are required to manage potential legal challenges and subsequent mediation in an application.

Permitting: The permit-granting process for geothermal technologies is different to all other renewables. This is because geothermal provides both small and large-scale applications to three final energy-consuming sectors

– heating, cooling and power generation. Large-scale geothermal energy requires two permits – the first for exploration and the second for exploitation of renewable resources. Small-scale geothermal energy requires a tri-zonal approach to permitting, sometimes referred to as a 'traffic light system' indicating zones where a simple notification is required, where a permit is required and where drilling is prohibited.

From the project developer's point of view, realising a geothermal project requires several authorisations and the compliance with several national and local regulations, and legal and financial safeguards.

The main requirements/permits that may be required for a geothermal power project development are the following:

- Water, mineral, and mining rights
- Exploration permits
- Well construction permit
- Development rights
- Payment of fees or royalties
- Environmental impact assessment (EIA)
- Environmental permit
- Building permit for the plant/distribution network, with a possible spatial planning obligation to realise a DH-network
- Dismantling permit

Skills: For larger-scale geothermal applications, providing baseload electricity, heat and cooling for district heating and cooling systems, renewable cogeneration systems, and industrial and agricultural installations an additional 10.000 designers and 20.000 installers will be required by 2030 in Europe to develop projects for reaching 45 %RES. The main competencies include exploration, prospecting, drilling, installation, control and maintenance of geothermal energy plants as well as the expertise of permitting agencies.

De-risking new capacity: Exploration is necessary to identify potential geothermal resources. However, beyond exploration, the bankability of a geothermal project is threatened by a resource risk: 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.

Mitigating this risk is crucial for the profitability of a geothermal project. At the technical level, this includes improved exploration techniques. Non-technical measures that have proven effective include sharing geological data from existing projects. A widely proven solution to facilitate market uptake of geothermal energy against this challenge however is the establishment of financial derisking schemes such as insurance.

Which risks to cover?

Large upfront capital expenditure (CAPEX), with low to negligible operational and maintenance costs, is the typical profile of renewable energy technologies. For geothermal, CAPEX is about 80-90% of total project cost. Up to half of a project CAPEX needs to be invested before the level of a risk of the project decreases significantly.

Geothermal energy projects face a resource risk during project development phase: the possibility of not finding the economically viable resource expected (e.g., the reservoir temperature is too low or flow rates are unsuitable for commercial exploitation). The impact of partial success may require additional investment such as exploration or development, and equipment like heat pumps.

How to cover risks

Project developers need to cover these risks. Experiences in risk insurance schemes for de-risking geothermal have been successful, with huge leverage effects like in France: every €1 paid by the State, €42 of investments were guaranteed. In a well-functioning market these risks can be easily addressed through private insurance products. In less mature markets public and public/private risk instruments are required.

De-risking instruments can take many forms. This is dependent on the overall maturity of the market. They provide geothermal energy developers with a means to reduce and manage their exposure to project risk. It is very relevant for small developers and vital for cities developing heat & power projects.

- **Grant schemes** are especially suitable for markets where there is little information about the geothermal resource and few projects for reference. In such instances grant schemes are needed for initial development of the market. Convertible loans or grants are also relevant at early market development, allowing investors to be shielded from the excessive amount of risk linked to the development of an innovative technology while the resource is not yet well understood.
- **Public-Private Partnerships and insurance**: where there is a liquid geothermal market with many projects and plentiful information about resources and understanding of the risk, public-private partnerships can establish insurance schemes. These schemes can be publicly funded initially with an important leverage effect of on private financing. Private actors, providing traditional insurance projects, are likely to enter the market when it is mature.

Risk mitigation schemes can be set up at a regional scale, but it is more efficient to pool the risk of more projects on a wide scale. Establishing a financing of geothermal de-risking at the European Union level would allow to reduce the costs for policy makers and developers. In the meantime, it is fundamental to apply the provision of the Renewable Energy Directive that states that each Member State shall create mitigation frameworks to reduce the cost of capital for renewable heat and cooling projects.

The following key elements are needed in a risk mitigation scheme:

- electricity, heat and cogeneration plants should be covered;
- both green and brown fields should be covered;
- 60% coverage should be the strict minimum (up to 80-90% if possible)
- low premiums in the range of 3 to 7% are needed to encourage a great number of subscribers in order to mutualise the risk.

However, in the current framework, most of the risk mitigation schemes focus on geothermal heat production. For example, in France, since the 1980s the SAF Environment Fund[8] has covered both the short-term risk (insufficient geothermal resources) and the long-term risk (reduced exploitability of the geothermal resource) for projects aimed at producing heat in the Paris region. It was based on one principle: successes pay for failures and thanks to the very low rate of failure in well-resourced regions (like the Paris basin), wells entailing higher risks can be drilled in regions where little exploration has been conducted. For short-term risk the premium payment is 1.5 % of the covered cost, while for long-term risk an initial payment of 3.2% of insured costs is required. The current reform will allow to cover the geological risks all over France.

Another example comes from the Netherlands. The Dutch government provides a guarantee scheme which covers only geothermal heat production (RNES Aardwarmte, Geothermal Heat Guarantee Scheme)[9], under which investors are protected against the financial risks of potential unsuccessful drilling. It requires a premium

[8] For more information see https://www.ecologie.gouv.fr/geothermie.

[9] For more information see https://www.rvo.nl/subsidies-financiering/rnes.

payment equal to 7% of the maximum subsidy amount, with separate maximum amounts applying to regular and ultradeep geothermal energy projects.

Therefore, some good examples of legislation already exist, but they should be extended to geothermal electricity production.

Regulatory barriers and long-administrative procedures can result in additional costs. It is therefore crucial that a fair, transparent and not too burdensome regulatory framework for geothermal electricity production is in place.

On this topic, again some developments should come from the revised RED and EED and from the EU emergency measures on permitting (see above Chapter 1.1). However, the biggest issue would be the implementation of this legislation at the national level.

The market rules and the regulations for the electricity market in Europe are defined at European level, but the energy mix and specific regulations are defined at national or local levels. To illustrate it, a case study of Turkey is presented below.

Case study: Türkiye

The country needs integrated and centralized management of geothermal energy. From exploration to operation, lengthy permission and approval processes wait for the investors, and they should always apply to different institutions to complete all these bureaucratic procedures. This causes many projects to be delayed or not realized. In addition, the absence of clear and comprehensive regulations regarding land use and exploration rights makes negotiating between investors, landowners, and local communities more challenging. Inadequate monitoring and auditing leads to the plant operators' improper practices. Indeed, legislative gaps in the monitoring system resulted in environmental and social problems over time, and they continue.

The YEKDEM mechanism offering incentives to plants in Turkish lira rather than USD have been an important obstacle to attracting new investments. Furthermore, the lack of another mechanism for incentivizing direct utilization practices hinders revealing the country's real potential. The country also needs the legislations that will enable heat markets to be established, so geothermal district heating investments will accelerate.

3. CHAPTER 2 - BUSINESS MODELS TRANSFORMATION

3.1 A conceptual framework for assessing the viability of business models across different Member States

Overview of the current business models

In situation of monopoly, utilities developed geothermal projects being partially integrated: engineering, drilling for some companies, turbines, connection to the grid, operation of the plant, and transmission & distribution of the electricity. The prices were often fixed by the State, so the business models had to adapt to this fact. As mentioned above, the need for more power was an opportunity to develop geothermal plants without this constraint.

The main change for the business models in the geothermal sector has been the European legislation developed from the nineties to liberalise the electricity and gas markets. The second key change has been the climate and energy package 2020 and 2030 allowing an important development of renewable energy with support policies.

Today, geothermal companies seem less integrated than before. The newcomers are rather small companies and specialised. Integrated companies are rather rare and often only specialised in the underground or the surface systems. Recently, some mergers and acquisition lead to a consolidation of the companies in the sector.

The business models of the geothermal companies will continue to evolve but more due to the customer behaviour than to a centralised decision.

The geothermal electricity sector is composed by project developers, drillers, manufacturers, operators and utilities.

The business models aim at selling power at a competitive price, taking into account the high capital costs and the risk associated. Regarding economics of geothermal power technologies, where high-temperature hydrothermal resources are available, in many cases geothermal electricity is competitive with newly built conventional power plants. Binary systems can also achieve reasonable and competitive costs in several cases, but costs vary considerably depending on the size of the plant, the temperature level of the resource and the geographic location. EGS cost cannot yet be assessed accurately because of the limited experience derived from pilot plants.

Levelised generation costs of geothermal power plants vary widely. New plant generation costs in some countries (e.g. Tuscany-Italy) are highly competitive (even without subsidies) at ca. € 50/MWh for known high-temperature resources. They are largely depending on the main cost components: drilling which can be 30% for high-temperature plants 50% for low temperature and 70% for EGS. The very high capacity factor >90% (the highest of all energy technologies including nuclear) mitigates the capital intensity to render geothermal technologies competitive.

Project developers are diverse. Utilities are large companies but many developers in Europe are rather small and specialised in a phase of the project.

Utilities and oil&gas companies active in the geothermal sector are integrated vertically, having in general already the drilling rigs and crew.

For some years a new generation of developers in Europe proposes innovative business models. A Turbine manufacturer like Ormat is now proposing also to build power plants and sell electricity. The turbines manufacturer sector has been the most innovative. Mergers have led to horizontal integration (Turboden and MHI, Alstom and GE…). Small developers are specialised in project management and form consortia to develop the project. One of them, Fonroche, decided to acquire a rig to be less dependent from the drilling market. Finally, we have seen in Türkiye holdings diversifying their portfolio in being active in the power sector by developing geothermal projects. They have financial resources and often they create a geothermal company for the project development.

Factors influencing the business models

- **Extraction of materials from the geothermal brine: an emerging revenue**
  Increasingly, geothermal project developers are looking at various ways to increase the profitability of projects. Beyond the sale of energy, innovation has allowed the geothermal industry to consider the potential of extracting materials from geothermal brines.
- **Innovative tools**
  Innovation, both technical, financial and organisational impact the business models of geothermal projects. Tools such as smart meters, which are widely being deployed throughout the European Union and digital technologies are crucial to enable the operation of equipment such as geothermal heat pumps as participants in the European electricity markets instead of being merely price takers. Such tools are also necessary – along with the deployment of some innovative technologies within the geothermal industry – to enable the development of business models around geothermal thermal energy storage. For such projects, knowing when to store energy and when to release it is crucial, but even more crucial is knowing which moments will allow the operator to extract the highest margin since the economic case of energy storage is the current European energy system entirely structured around the hourly price volatility in the electricity market. Overall, innovative tools to provide access to a higher quality and higher granularity of information has a major impact on the business models of geothermal energy system, since it enables in theory to better maximise the value of energy services provided. It is also enabling the emergence of new markets for energy services, typically such as demand response.
  Beyond technical system, financial innovation is a very important feature of the organisation of geothermal project business models. The industry overall is steadily preparing for a future with a much higher degree of private finance, notably as public financial support has been gradually reduced or abruptly suppressed in several European countries over recent years. The recently adopted European Sustainable Finance framework highlights the growing involvement of the financial sector in the deployment of renewable energy technologies that European institutions are wishing for. The Sustainable Finance Framework, while poorly integrated thus far by both the financial sector and the geothermal industry, has the potential to greatly impact the capacity of geothermal projects to raise capital, but also the nature of these projects.
  Another of these innovative financial instruments include crowdfunding, which is used notably for larger geothermal energy projects. Crowdfunding has been clearly identified as a valuable tool to foster community engagement towards a project. However, it is not limited to that, and has proven efficient to raise significant sums of money at crucial points of project developments, for instance in the case of the United Downs projects in the UK.
- Policies: market liberalisation, state aid
  The market conditions in the EU electricity and heat sectors prevent geothermal from fully competing with conventional technologies developed historically under protected, monopolistic market structures where costs reduction and risks were borne by consumers rather than by plant suppliers and operators. The internal market is still far from being perfect and transparent. Firstly, in many countries electricity and gas prices are regulated, thus they do not reflect the full costs of the electricity and/or heat generation. Secondly, fossil fuel and nuclear sectors still receive many subsidies. Thirdly, there is lack of market transparency, including lack of information provision to customers and tax-payers and a clear billing.
- Heat and electricity demands
  The demand for more electricity in Europe is mainly linked with the economic development, and its increase is due to more demand for comfort and new IT applications. But energy efficiency policies and measures have an impact on the electricity demand. We can forecast a stagnation or a small decrease at the horizon 2030. The transition towards a low carbon economy means also more demand for green electricity replacing fossil fuels power plants. Finally, Customer behaviour has an impact on the power

demand, and the trends towards decentralised production will affect the electricity sector and also the geothermal market.

- Geothermal Risk mitigation (see Chapter 1.3)
- Capital costs and financing:
  Geothermal electricity development costs vary considerably as they depend on a wide range of conditions, including resource temperature and pressure, reservoir depth, location, drilling market etc. The capital costs per geothermal technology range from 3-4 €mio/MWe for high temperature to 6 €mio/MWe for low temperature and more than 7 €mio/MWe for EGS.
  Operation and Maintenance costs in geothermal electricity plants are limited, as geothermal plants require little or no fuel. Commercial costs associated with developments also need to be included in costing a geothermal project. These include financing charges (including establishment costs and interest), interest during construction, corporate overhead, legal costs, insurances. For geothermal, risk insurance is the main issue. It depends on the origin of the resources invested and the way they are secured, as well the amount of initial capital investment.
- Prices options and new market design
  Prices reflecting actual scarcity in terms of time, location, and available transmission capacity will indeed be key ingredients of the new market design, particularly to reward flexible production/consumption and a more balanced electricity technology mix having complementary specificities in terms of load factor, regional potential etc. As far as the generation side is concerned, flexibility should be rewarded also from the new generation of flexible renewable electricity technologies, including geothermal plants. Flexible RES technologies can be used in partial load operation and in certain cases can quickly ramp their output up and down on demand. With these technologies even changes in the range of 20 to 100% with a speed of 2% per second could be achieved with proper management of turbine and by-pass valves, as has already been used according to the requirements of German legislation. Operators of flexible RES installations can therefore offer ancillary services to system operators and provide valuable short and long-term flexibility at a regional level (including trans-border), a step between centralised and decentralised systems. In this regard, it is worth highlighting how most balancing regimes (Germany being an exception) and infrastructure planners rarely take the potential flexibility from these technologies into consideration. The new market design should contribute to change this picture through methods including prices better reflecting scarcity. This approach can reduce over-capacity and alleviate the need for additional transmission and distribution infrastructure as well as costly storage. Overall, this will result in improved system adequacy, lower system costs and more social support for the transformation of our energy system.

Key drivers of new business model developments

- The operation itself can be the source of problems that inhibit, greatly delay, or impede efficiency of a geothermal project. Sometimes the involved individuals can lack proper knowledge on various aspects of a geothermal project.
- The system of how the geothermal project can be best implemented is constantly changing. The great amount of innovation requires that it adapt on a case-by-case basis.
- De-risking of geothermal projects has not only come from the availability of public funds, but also through other technical and financial aspects;
  - Heat or Power purchase agreements (H/P PAs) are essentially pricing contracts, which in the end facilitate the business model in question.
  - Pricing contract.

3.2 Identifying business models that form an integrated and overarching EU view, to promote a more level playing field between energy sources as the landscape changes and reduce the opportunity cost losses across the Union.

The justification for a geothermal project may be entirely economic, offering local economic development. Other elements may also factor in from the need for energy security, environmental concerns or the specific benefits of geothermal energy such as cogeneration of electricity and heat or the capacity to provide flexible, dispatchable and baseload energy supply. In terms of business models, notably regarding cash flows, key differences exist between the various geothermal technologies, though many nuances exist.

- **Incomes from the sale of energy:** geothermal investments may be undertaken with the objective to earn a profit from the sale of energy. In many cases, considering the typical business models of geothermal projects, long term power purchasing agreements may be contracted or operational aid secured. This guarantees cash flow once the power plant is operational.

- **Reducing energy costs:** geothermal projects have minimal operation costs compared to many alternative energy technologies (in particular fossil), which may make them profitable to reduce energy expenditures.

Beyond the pure economics of geothermal energy projects, many other business models and income streams may justify geothermal investments. The emerging need for market flexibility in the electricity market is for instance a promising income stream for geothermal power plants (but also for geothermal energy storage projects and geothermal heat pumps able to participate in demand-response schemes). As seen above, the prospect to market some minerals contained into geothermal brine is another possible economic case in favour of geothermal projects.

If we consider the energy policies, the heat and electricity demands, the prices options and new market design mainly defined at a macro-level, the micro-levels influencing the geothermal business models are geological risk mitigation, capital costs and financing.

The risk associated with geothermal exploration and the need for upfront capital costs required for project development are two important elements which need to be integrated. When presenting a geothermal project to a client or a financial institution, these two elements impose long discussion and negotiation. It has a cost.

One proposal to overcome this barrier would be to integrate all the geothermal development project phases into a 'single geothermal product' where the client receives proposal for electricity and heat supply.

The idea is not to hide the risk associated with geothermal exploration and the huge capital costs required for project development, but to propose a package where the quality of the geothermal energy is highlighted, and the management of the project phases is done by the 'geothermal product' company or consortia.

- There is a need to define the products: heat, power, or power&heat, base load or flexible supply, heat temperature etc.
- It implies some vertical integration, at minima in the form of a consortia: consultancy, services, manufacturing, building.
- Marketing will be a key aspect while selling a product to the customers. It will include price definition, location of the project, kind of geothermal product and promotion of the geothermal product.

When promoting a geothermal product, one should go beyond the tangible product itself – geothermal electricity, heating and cooling. It must be combined with an increased product: the added value of the product – security and firmness, installation and service, financing, etc; and by the product benefits offered: comfort, low operational costs, environmental.

Finally, adding more IT tools and applications in the geothermal product will increase its marketing power.

3.2.1 Capacity and flexibility payments for geothermal power plants

Electricity production from geothermal energy is a renewable, dispatchable and flexible resource. The high capacity factor of existing geothermal plants show that they are currently able to meet the demand of baseload production. Tests on German plants also show that geothermal capacity can be ramped up or down in a matter of seconds. These characteristics open the opportunity for geothermal power to benefit from support in the form of a grid premium or capacity remuneration.

In a system where there is an increasingly high share of intermittent electricity production (namely PV and wind power), policy makers are challenged to develop incentives to support technologies that are at the same time compliant with climate imperatives and contribute to ensuring the continuous supply of electricity to consumers. Some options such as capacity remuneration mechanisms (CRM) are being debated as part of the proposal for an electricity market regulation. The purpose of CRM is to provide a payment to a producer of electricity for its capacity to supply power at a given time, to meet imbalances that may arise between production and demand. Grid premium is a more general idea for remunerating flexible and dispatchable – and ideally prioritising renewable - capacity if it has to be displaced by intermittent renewable production.

CRM or grid premium are an interesting support scheme perspective for geothermal energy, as it highlights the specific benefits that geothermal electricity production provides in addition to the simple "capacity" figure. Able to provide baseload power, or to meet sharp ramp up or down requirements, the capabilities of geothermal power plants have a value for the stability of the system. A framework that captures this value and fairly distributes it to the geothermal plants can incentivize the development of a more robust electricity network and spur the development of flexible and dispatchable renewable capacity, notably geothermal electricity.

The value of the flexibility provided by geothermal power plants is difficult to estimate considering the current market structure where this service is not usually rewarded, and the abundance of publicly subsidized fossil flexibility resources (gas, oil power plants), in the price of which carbon externalities are not suitably included. However, some studies allow a conservative estimate of the value of flexibility of geothermal power plants between 15-50 €/MWh[10].

For a geothermal power plant selling its output at 40€/MWh, as can be the case in Tuscany considering costs, this may entail an average 10€/MWh net subsidy from the geothermal operator in flexibility costs to the rest of the system.

3.2.2 Special cogeneration business models

I) Public Private Partnership

In a normal decoupling model, usually a heating company subscribes a long-term purchase agreement to supply heat to the district heating managed by the utility of a municipality. In this peculiar model, the same thing is done by a geothermal power plant.

For example, the Enel Green Power is selling the geothermal brine used in the "Cornia 2" power plant[11] to several villages in the surrounding area. These villages then supply heat through district heating to the citizens.

[10] Approximated value based on the Committee on Climate Change study "Value of Flexibility in a Decarbonised Grid and System Externalities of Low-Carbon Generation Technologies", 2015.

[11] https://www.thinkgeoenergy.com/enel-inaugurates-combined-biomass-and-geothermal-plant-in-italy/.

source: Cosvig

Figure 5 “Cornia 2” power plant

II) Acquisition of a geothermal project

The combined heat and power geothermal plant of Traunreut in Bavaria is a quite rare business model schema – perhaps the first of its kind, where the geothermal project was undertaken and finished under another type of business model, and then acquired or inherited by another entity after the project development finished[12]. The entity in question is Equitix, a British investment group specializing in infrastructure projects.

source: Equitix

Figure 6 Power geothermal plant of Traunreut

3.3 Comparison of the economic parameters for geothermal plants and the market conditions in the different European countries.

A geothermal heat plant typically needs 5 years to become operational. For electricity, it takes between 6 to 8 years.

[12] https://www.thinkgeoenergy.com/traunreut-geothermal-plant-in-bavaria-sold-to-british-investment-group/.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Status	**Under Investigation**		**Under Development**				**In Operation**		
Prefeasibility	Services								
Exploration		Exploration & test drilling							
Resource development				Drilling					

Table 3 Phases and Timeline for project development

But Geothermal plants have long lifetime typically over 30 years. The EGEC Maret Report, for example, lists several power plants which are still running since the 1980s (see for example the power plants in Radicondoli, Tuscany, Italy): the oldest geothermal power plant still in operation is from 1986. 4 running plants are from the 80's, 17 from the 90's and 32 plants run from the 2000's. 21 power plants are more than 25 years old and 53 are more than 15 years old.
Several district heating plants are still running since the 1970s (see for example the DH plant in Occitanie, Haute-Garonne, Blagnac 2, France).

Heat Plant

For a geothermal heat plant, we assume that a plant will supply heat to a district heating network, to nearby greenhouses and agricultural businesses, or process heat to nearby industrial customers. Our reference plant is a geothermal doublet system accessing a reservoir at a depth between 2000-3000 m and a production temperature of around 80 °C. Operational hours range from 3800 to 6000 hours annually

Power plant

For the power plant, the reference plant has at least two wells to a depth between 2500-5000 m and a reservoir temperature in excess of 150 °C. Operational hours range from 6000-8000 annually.

Capital investment

Exploration and adaptation of a given technology to an unexplored geological context, presenting a higher degree of risk than in commonly known and well-understood areas, and possibly the ambient temperature, are key concerns and cost drivers for geothermal projects. Geothermal energy projects require substantial up-front investments and from the investor's point of view long time horizons before a venture becomes profitable. Furthermore, drilling and exploration may take several years, and 3 to 6 years can pass between exploration and first production, with the cumulative cash-flow becoming positive quite a number of years after production has commenced.

Overall, unit costs for installed capacity for geothermal power generation per MW_e range between 1.8 to 10.6 million of euro (€ million) in Europe, and for heat generation about €1.2 and 2.9 million per MW_{th}; costs for the distribution systems excluded. Unit costs are higher than for virtually all other renewable energy technologies and depend highly on the specific site and technology chosen.

Capital costs depend strongly on the:

- Number of geothermal wells required;
- Depth of the reservoir, and hence drilling;
- Geological conditions;
- Location and access to drilling site(s) and size of the plant.

Cost structure

Geothermal energy projects are rather capital intensive, which requires addressing the challenge of financing. As with many technologies, geothermal costs tend to fall when the technology progresses along its learning curve and market maturity. The structural dynamics of the energy market, in particular for heating and cooling, tend however to favour technologies with higher operational expenditure (typically fossil technologies), which creates a market imbalance that is detrimental to geothermal technologies.

The cost structure of geothermal projects highlights their capital-intensive nature. Typically, as noted below in figures 9 to 11, a geothermal flash power plant would have a cost range between EUR 60-80 million for a 20MWe installation. For a 5MWe project for a low/medium temperature installation (typically EGS plants) the cost would be expected to be between EUR 35-60 million.

The figures below illustrate the capital cost structure which underlines structural differences from one type of installation to the other:

• Figure 7: Cost range for the development of a 20 MWe conventional high temperature plant with a flash turbine. The graph shows the cost range for the different steps in field development and the construction of the power plant.

• Figure 8: Cost range for the development of a 10 MW e medium temperature plant with a binary turbine. The graph shows the cost range for the different steps in field development and the construction of the power plant.

• Figure 9: Cost range for the development of a 5 MW e (or thermal 25 MWth) EGS plant. The graph shows the cost range for the different steps in field development and the construction of the power plant with a turbo-generator. For EGS plant, cost differences are attributable to the topside facilities such as those required for electricity generation (turbine, generator, substation and peripherals).

• Also, cost information is provided for a 10 MWth geothermal district heating (DH) plant utilizing a well doublet (Figure 10: Cost range for the development of a 10 MWth geothermal DH (doublet) systems, producing 40.000 MWh/year (investment cost = €1.3-1.8 million/ MWth). Capital costs do not include costs for the installation of the district heating grid (about €1 million/km).),

• a 10 MWth heating plant integrated with large heat pumps to maximize energy yield (Figure 11: Cost range for the development of a 10 MWth geothermal DH (doublet) systems, assisted with two large heat pumps of 4 MWth.), and

• a combined heat and power (CHP) plant with an installed capacity of 5 MWe and 20 MWth (Figure 12: Cost range for the development of a 5 MW e and 20 MWth CHP plant (including a turbo-generator).).

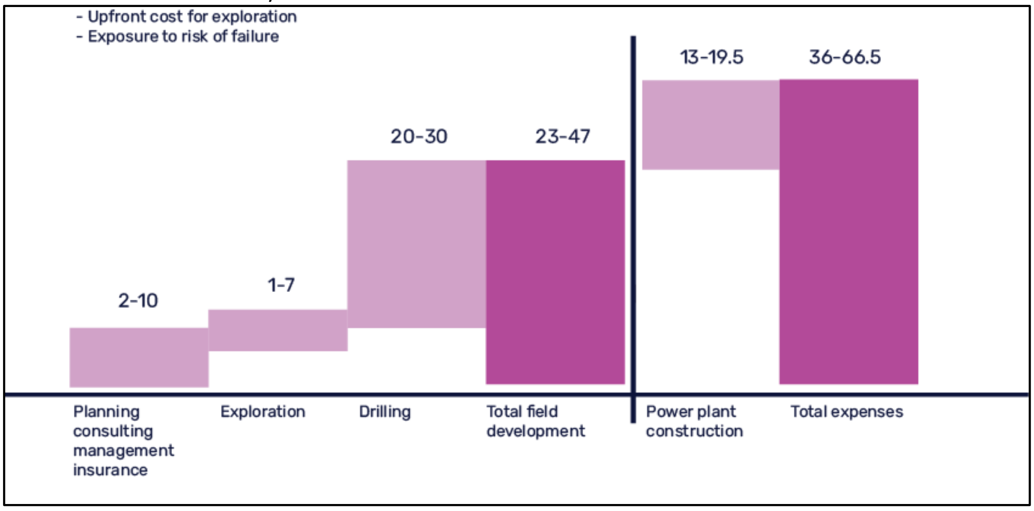


Figure 7*: Cost range for the development of a 20 MW_e conventional high temperature plant with a flash turbine. The graph shows the cost range for the different steps in field deveolopment and the construction of the power plant.*

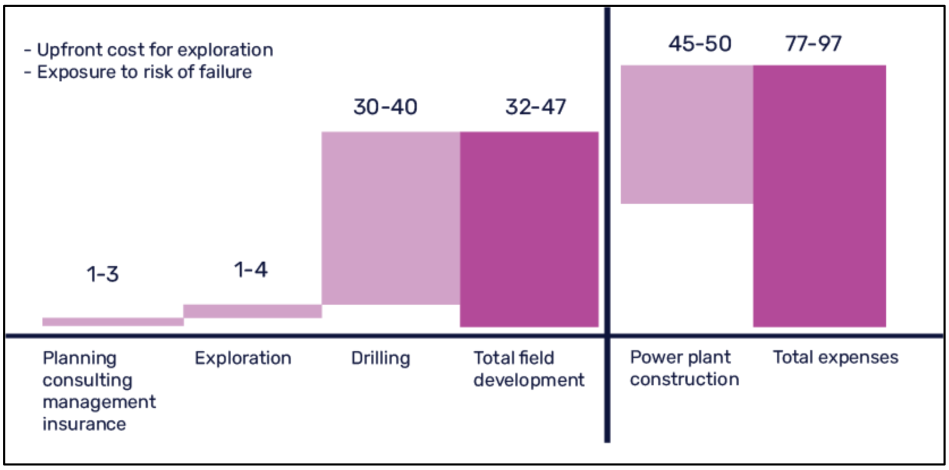


Figure 8*: Cost range for the development of a 10 MW_e medium temperature plant with a binary turbine. The graph shows the cost range for the different steps in field development and the construction of the power plant.*

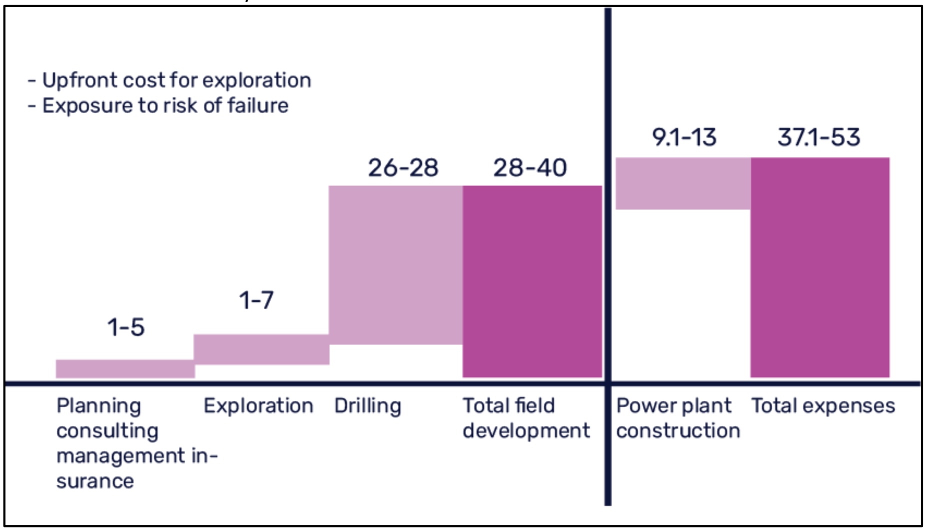


Figure 9*: Cost range for the development of a 5 MW_e (or thermal 25 MW_{th}) EGS plant. The graph shows the cost range for the different steps in field development and the construction of the power plant with a turbo-generator.*

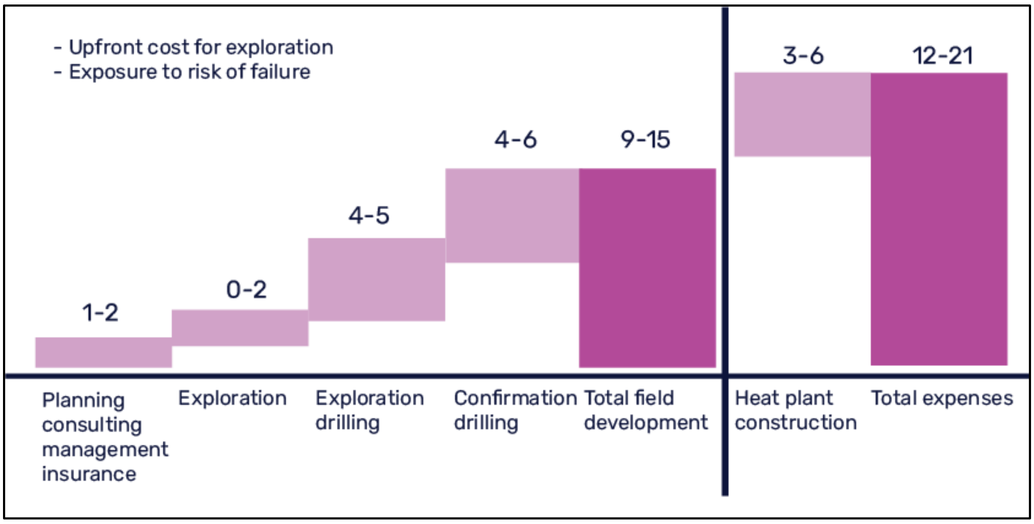


Figure 10*: Cost range for the development of a 10 MW_{th} geothermal DH (doublet) systems, producing 40.000 MWh/year (investment cost = €1.3-1.8 million/ MW_{th}). Capital costs do not include costs for the installation of the district heating grid (about €1 million/km).*

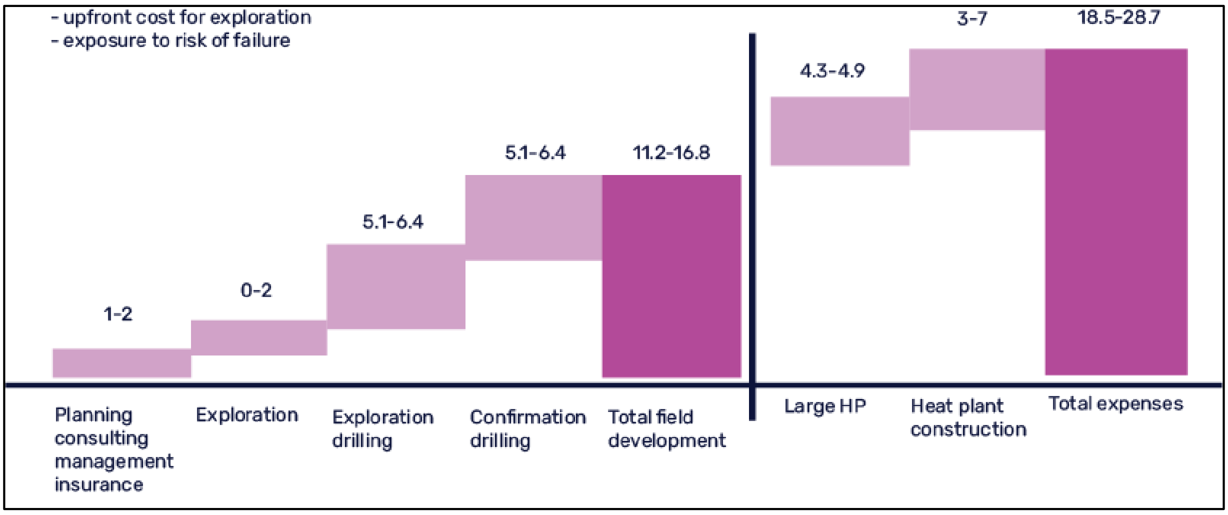


Figure 11 :*Cost range for the development of a 10 MW_{th} geothermal DH (doublet) systems, assisted with two large heat pumps of 4 MW_{th}.*

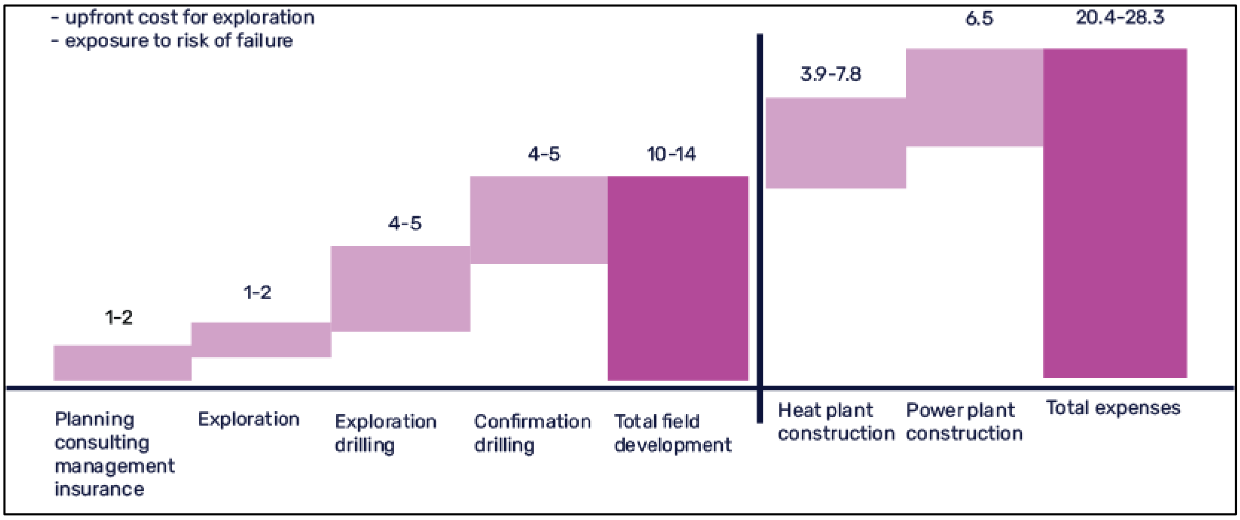


Figure 12*: Cost range for the development of a 5 MW_e and 20 MW_{th} CHP plant (including a turbo-generator)*

Typically, operators begin with screening of a potential resource, obtaining permits, extensive and detailed planning, and obtaining finance for the project; these costs vary from €1 to 10 million.

The next step encompasses exploration to better quantify the size of the resource and to define targets for (exploration) drilling. Exploration typically encompasses investigating surface manifestations, geophysical surveys and subsurface modelling, but may also include drilling of exploration well(s). Exploration costs range from €0 to 7 million (cost of drilling an exploration well is included within the drilling costs in the following stage) and are linked with the planning phase.

Once the resource has been outlined, the well field is designed and developed, adding another €20 to 40 million to the development (drilling) costs of a power project and €8 to 12.8 million on average for a geothermal heat project. Investing in exploration generally leads to a reduction of the subsurface unit technical cost because of higher certainty regarding the resource, its location/depth, spatial extent, location of inflow and outflow zones and so on. Hence, there is a relationship between exploration and field development phases and their respective costs.

The total subsurface development cost, prior to construction of the power plant amounts to around €23 to 47 million, and €9-16.8 million prior to construction of a heat plant. Until the well field has been developed, there is a risk of failure in connection with the expected subsurface geothermal resource and consequentially a substantial risk for financial loss. Also adding to the time until first power and heat, is the need to first develop the subsurface and obtain data that allows for the appropriate sizing of surface facilities, in particular the power or heat plant.

Depending on the capacity of the plant and the technology used, constructing the power plant will add another €9.1 to 50 million of capital expenditures, and €3 to 7 million for a heat plant. As mentioned, we do not include the cost related to transmission and distribution of, for example, a district heating network (about €1 million per km). Obviously, as both the field and plant have been constructed, the risk is mostly commercial and less governed by resource risks and hence has much more manageable financial consequences.

Costs associated with CHP plants have not been included in the above costs since cogeneration plants account for a small percentage of geothermal capacity installed in Europe; 20-25% of the total geothermal electricity generation capacity installed, and about 20% of the geothermal district heating and cooling capacity. The overwhelming majority of this capacity located in Iceland where geothermal is at the core of an integrated strategy for the provision of district heating.

In total, the development of a geothermal power project until first power requires an overall investment ranging from €77- 97 million for a 10 MW_e medium temperature, binary cycle power plant, €37.1 – 53 million for 5 MW_e EGS plant, and €36 – 66.5 million for a 20 MW_e conventional high temperature plant. Note that costs may vary substantially for a large number of reasons.

Although no cost update information was received from stakeholders specific to conventional high temperature plants using flash turbine technology, it was possible to update costs for 2021-2022 based on cost updates from stakeholders that were not stated as being specific to a particular reference plant/technology type, and according to 2021 renewable power generation costs from IRENA[13]. According to IRENA, in 2021 the global weighted average total installed cost was USD 3 991/kW, equivalent to 3.9 million euros/MW. It is now rare to see projects with costs below 2 million euros /MW. This data is based on the global weighted average total installed cost, and therefore includes both binary plants and conventional high temperature plants which vary considerably in cost.

Typically, costs for binary plants designed to exploit lower temperature resources tend to be higher than those for direct steam and flash plants, as extracting the electricity from lower temperature resources is more capital intensive (IRENA, 2022). The updated costs for 2021 - 2022 reflect this relationship.

The development of a geothermal heat project until first heat costs between €12 and 21 million for a 10 MW_{th} plant size supplied by a well-doublet, to which, for reasons of maximizing efficiency of energy recovery one may add between €4.3 – 4.9 million for the large heat pump (of 4 MW_{th} capacity).

Costs for the development of a 5 MW_e and 20 MW_{th} CHP project (including topsides for power generation) range between €20.4 – 28.3 million.

The optimal capital expenditure profile very much depends on trade-offs and probability of success for each of the phases; exploration, development, and power/heat plant construction. One must not add the maximum of each phase to arrive at a cost estimate for a geothermal energy project; each phase influences the cost for the subsequent phase. For example, a more extensive, and hence expensive, exploration phase may pay back

[13] Renewable Power Generation Costs in 2021 (irena.org)

through reduced unit drilling cost because the probability of a successful well increases, planning and design of wells is improved, and the likelihood of costly operational and technical interventions is lowered because of improved knowledge.

The ultimate profitability of geothermal energy projects strongly depends on the weighted average cost of capital. Generally, the cost of capital for investors in risky ventures is higher than for de-risked and predictable ventures. Geothermal energy projects are not only capital intensive, but also require significant up-front investments to de-risk a venture until parameters of the resource, and hence possible revenue streams, can be quantified. Regarding the above figures, the high-risk stage corresponds to expenditures for resource identification and exploration and exploratory drilling. In the case of projects requiring stimulation or reservoir engineering, there is significant uncertainty on the potential capacity and output of the project until this task has been successfully completed. This means that between 40 and 75% of a geothermal project cost must be invested when there is a very high level of uncertainty regarding the success of the development. This usually translates in higher costs of capital and challenges to find investors with an appropriate risk appetite; typical investors in subsurface energy projects (such as oil and gas) are used to high returns on risky investments.

4. CHAPTER 3 - RESULTS FROM THE CONSULTATION OF KEY STAKEHOLDERS SUCH AS UTILITY MANAGERS AND POLICY MAKERS FOR WIDER DISSEMINATION.

Türkiye

On 22 March 2023, the GeoSmart project team hosted a webinar dealing with the 'Opportunities and Challenges for Hybridization of Geothermal'. Dr Derek K. Baker, professor for Mechanical Engineering at the Middle East Technical University (METU) talked about the hybridisation of geothermal with concentrated solar thermal (CST) or biomass for electricity production and about finding synergies between different renewable energy technologies.

While geothermal energy is available all year-round output is higher in winter than during summer months due to lower outside temperatures. Output from geothermal sources also starts to decline with time or might not be the same as expected during planning. A combination with CST or biomass can compensate these shortcomings, especially solar thermal which has the highest output in summer at the same time as geothermal energy production reaches its lowest point. This hybridisation opens up new opportunities for the use of geothermal energy going beyond the production of baseload electricity by making geothermal plants more flexible and responsive to demand opening up the potential to generate electricity during peak hours, i.e. in the evening and complementing PV electricity which is cheap but only available during daytime.

The webinar also covered the specific opportunities and challenges related to hybridisation. Combining multiple technologies has several advantages such as the sharing of land, personnel, grid infrastructure, power block components and can extend the lifetime of geothermal resources. On the other hand, geothermal has relatively low source temperatures of up to 200 degrees compared to CST and biomass which leads to differences in power generation technologies representing the biggest challenge for hybridisation. In Europe, high temperature geothermal reservoirs overlap with areas with high solar potential especially in Italy and Türkiye, but with the development of new technologies like deep and dry rock geothermal or CST emerging in new locations further north such as Norway there may be more overlaps and a higher potential for hybrid plants in the future. As for biomass in Türkiye, olive oil production, a source for biomass, is co-located with geothermal regions in the south-west of the country. Nevertheless, finding locations suitable for hybridisation is a challenge and conflicts in land use for agriculture have to be taken into account.

The findings from the interviews indicated that Türkiye has a vast potential in geothermal energy that will be developed along with the new technologies and its current know-how. Nonetheless, some political, financial, technical, and social barriers restrain geothermal energy development in the country. Direct utilization of geothermal energy is feasible in many parts of Türkiye, and it can offer significant advantages such as reducing the dependency on natural gas for heating, contributing to regional development, creating local employment, and increasing the social acceptance of geothermal. At this point, new financial incentives or legal obligations to the plant operators can be an effective tool for the prevalence of direct utilization practices in the country. The country can alleviate its foreign dependency on technology by conducting and supporting R&D studies, which can disseminate information between investors and researchers and develop further cooperation among the parties. To minimize bureaucratic processes and conflicts between investors and landowners/local communities, a principal institution's centralized management of geothermal energy seems critical. This can also enable the investors to realize their current projects rapidly and be willing to pursue further ones. As most respondents pointed out, more stringent and systematic monitoring mechanisms can play an essential role in preventing the environmental damages resulting from the improper practices of profit-oriented plant operators and maintaining reservoir sustainability. In line with all the projected developments, the attitude of local people, whose economic and social benefits increase and who do not suffer from environmental damage, towards geothermal may change, and the social resistance to new geothermal projects might remarkably decrease in time. Moreover, stimulating community engagement and continuous dialogue with the locals before realizing a geothermal project and including geothermal energy in the school curriculums can effectively increase awareness, thus, social acceptance of geothermal energy.

The GeoSmart innovations also received valuable feedback from the interviews in Türkiye. Responses to each technology have been evaluated and, for better understanding, have been categorized into four aspects where applicable: legislative, technical, economical, and societal. Overall, the feedback to GeoSmart technologies is positive, with some comments and precautions. The notes are shared below.

Hybridization of Geothermal Power Plants with Concentrated Solar and Biomass

Legislative

- No barrier to hybridization of geothermal and other resources (except the technologies involving natural water sources).
- New legislation on hybrid renewable technologies and their tariffication[14]. Might need more comprehensive legislation for this.

Technical

- Hybridization with solar, including storage, will increase flexibility; hence, the demand will be met better.
- Utilizing the energy from the sun to increase the enthalpy of the geothermal brine also increases the power output.
- Renewable technologies should be used together, utilizing each technology's advantages.
- Using geothermal in other processes such as drilling, or cooling can be beneficial.
- Grid losses should be avoided.

Economical

- With increased flexibility, especially during peak hours, the generated electricity will be sold at higher prices.

Societal

- In greenhouses, women's employment is higher, so utilizing geothermal to heat greenhouses can have a positive impact on society.

Storage & Flexible Use of Geothermal

Legislative

- Geothermal operators will definitely be interested, but the local governments should also be involved and should not expect a unilateral approach from the operators.
- If there will be incentives for these kinds of technologies from the government, most of the plant operators would be glad to implement them. This regulatory support is not present now.

Technical

- Positive feedback since the power output will be increased.

Economical

- With an increase in power output, the payback times will get less.

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[14] http://bit.ly/3mEPMcE

- Operators would consider storing 5-10% of resources to be utilized during peak demand times.
- The scale should be high to make the system feasible.
- There have been concerns regarding the very high cost of the storage systems.
- If geothermal is used in district heating, the natural gas burden will be relaxed to some extent.

Societal

- The storage can be used for the nearby community in the form of district or greenhouse heating.

Silica Retention Tank & Low Reinjection Temperatures

Technical

- Positive feedback concerning lower reinjection temperatures since the power output will be increased.
- A concern. Recirculating the CO_2 back into the system is a better system than the proposed silica retention tank. This system is already patented and used in power plants.
- Operators will be interested if the system is proven to be working properly (either by demonstrating it or by technical modelling). Also, the geothermal brine must be cared for.
- Silica scaling in reinjection wells is a huge problem for geothermal, and operators would be interested.

Economical

- With an increase in power output, the payback times will get less.
- Selling the accumulated silica and lowering the costs for chemical inhibitors are attractive.

Societal

- Lowering the reinjection temperatures makes it possible to utilize the geothermal resource on different technologies (e.g. district heating, greenhouses, etc.), which will have a positive impact on both society and the environment.

Ground Coupled Cooling

Technical

- A quote: "The water should be designed in such a way that it will never be lost by evaporation or similar mechanisms, and its chemical content will not be touched in a very harmful way, and it should be designed to be sent back again in a way that it will not be changed."
- There may be problems with its implementation in places where water resources are limited, such as Türkiye.
- The system is especially interesting for geothermal operators due to the poor performance of geothermal plants during the summer months in Türkiye.

Economical

- Depending on the techno-economic analyses, the geothermal operators would be interested.

Iceland

Progress – December 2023

The Icelandic stakeholder interviews on geothermal energy outlook, flexibility, and GeoSmart solutions have been ongoing since the fall of 2023. So far, participants from various sectors have attended, been presented with the GeoSmart project, and interviewed on their interest in the project solutions and the geothermal industry in Iceland. 17 stakeholders out of 31 mapped stakeholders have been interviewed. These individuals come from various geothermal-related sectors, such as universities, power plants, electricity providers, cluster management, etc.

The general outlook for the Icelandic industry is positive. All interviewees agreed on the great social acceptance of geothermal energy in Iceland, with only one commenting on minor unhappiness about the disturbance of natural beauty, which results in some resistance to building new power plants among the public. Some commented that the geothermal sector would benefit from increased diversity, especially gender equality and age diversity. Diversity would help to make different marketing approaches to improve social acceptance, as today it seems it is mainly a man-dominated sector. The resources' efficiency was considered very efficient, apart from wasting low-medium temperature water from the power plants. Still, according to some interviewees, this should be addressed and improved in the future. All stakeholders believed geothermal energy was important to Iceland, especially district heating. The stakeholders were mostly happy with the place of geothermal energy in Iceland's energy mix and did not think that things should change in that regard. Still, 30% of electricity is produced using geothermal energy, and over 89% of heat energy. Some stakeholders said that geothermal should have closer to 100% share of heat energy. In contrast, others said it would be inefficient for some countryside parts due to long distances and accompanying energy losses. Instead, the usage of heat pumps, as used in European countries with low enthalpy geothermal areas, should be reviewed.

Some geothermal operators emphasize ensuring the long-term sustainability of the resources. This involves careful monitoring, research on the renewability of geothermal reservoirs, and developing regulations to prevent overexploitation. They also suggest exploring how geothermal energy can be integrated with other renewable sources, like hydro or wind, which could lead to a more robust and stable energy grid.

Many stakeholders said that heat usage promotion and hybridization projects were the solutions that would be followed concerning the future of geothermal energy in Iceland, especially for low- to medium-geothermal water supply. This could, for example, be achieved by promoting more eco-industrial parks and other incentives for such usage. Many are interested in making geothermal flexible to allow for better use of other renewable energy sources, such as wind. In contrast, others point out that another benefit of having more flexibility and storage solutions was to balance the grid from the disturbances that may occur from the large energy consumers, such as aluminium or silicon smelters. Therefore, geothermal energy could be used to stabilize the grid.

A lot of interest was present for the GeoSmart project, and its proposed solution among most interviewees, and most of them would like to hear more about the project and its results. When asked about the project, some interviewees were uncomfortable answering as they would have liked more technical details on proposed solutions and did not think they could answer. Given a positive cost-benefit analysis, the power plant operators were interested in utilizing the proposed solutions. Results such as quantitative data, qualitative feedback, and positive demonstration results are of interest to most stakeholders, especially those from the power plants.

From the interviews, common themes emerge, emphasizing the efficiency and significance of Iceland's geothermal sector, along with identified areas for improvement and shared optimism for the GeoSmart project's positive impact. The discussion underscores the importance of incentives such as increased financing and hybridization projects to enhance flexibility. Recognized stakeholders for project dissemination include energy companies, research institutions, and government agencies. Recommendations encompass continued government support, investment in hybridization, sustained research and development efforts, and educational initiatives to foster public understanding and acceptance. In conclusion, the collective insights depict a positive outlook for Iceland's geothermal sector, underscoring the ongoing need for collaboration, innovation, and stakeholder engagement. The GeoSmart project emerges as an important initiative that could advance the sector's efficiency and impact.

Italy

As part of the GeoSmart project, the main geothermal stakeholders in Italy were identified and interviewed. Following the work carried out in Türkiye, the interviews dealt with the evaluation of the geothermal sector and the innovations proposed by GeoSmart from the point of view of the stakeholders, including technical (such as scaling recovery, efficiency of the plants and flexibility), economic (incentive schemes and support measures) and social topics (communication and social acceptance). As reported in Table 2, no stakeholders from the groups 2 and 5 were interviewed. This is because the solar sector is underdeveloped in Italy and difficulties were experienced in reaching investors available for interviews. It should also be noted that the geothermal sector is experiencing some difficulties in Italy and it has few investors.

A panel meeting titled "Improving Flexibility of Geothermal plants: Challenges and Opportunities" was organized at the end of the interviews series, between the main geothermal stakeholders in Italy and part of the GeoSmart consortium. The aim was to discuss on the topics addressed by the interviews and of main interest for the stakeholders in Italy.

Table 4**:** Italian stakeholders interviewed as part of the GeoSmart project, grouped by categories.

Groups of stakeholders according to the GeoSmart communication plan	Number of Stakeholders
Group 1 – Ultimate end users and beneficiaries: operators and developers	8
Group 2 – Optional End Users: solar thermal power	0
Group 3 – Manufacturers	3
Group 4 – Primary influential bodies/industry association	5
Group 5 – Investors	0
Group 6 – Academia and Public	2

In a ranking of GeoSmart results that can contribute positively to the development of interviewees' products, processes and services, the system to reduce and recover silica aroused great interest. Stakeholders were also interested in flexibility opportunities offered by heat storages to stabilize the grids. However, other subjects wondered how much of the GeoSmart's results could be disseminated, considering intellectual property issues.

About the topics addressed by the questions of interviews, a summary of the findings is provided below:

Topic: Scaling recovery and efficiency improvement in flash plants

Technical aspects for the retention and extraction of silica:

- Silica scaling may result in irreparable damages to the plant;
- A system to retain silica (through delay of polymerization) already exists in ORC plants and it allows to extract silicates.

Technical aspects for the temperature reduction of injection fluids:

- An excessive decrease of the reinjection temperature may impact the aquifer. It is suggested to have also a simulation of the reservoir;
- The reduction of the reinjection temperature maximizes the capacity of geothermal plants and allow to use more heat for direct uses (DH and production processes).

Economical aspects:

- The silica reduction system has been seen as positive, because it may allow to:
    - Improve the business plans of geothermal plants, thanks to the heat and silica recovery;
    - Improve the acceptability, because it allows to create new jobs;
    - Attract more interest from investors, because this system recovers heat with no additional CO_2 emissions. This is important also in case of plant retrofit.
- It is important to deepen economical aspects to assess the profitability of projects and the real sustainability of:

    - The silica reduction system, considering the market value of silica;
    - The heat recovered;
    - Reduced use of scaling inhibitors;
    - Reduced need for new drilling.
- A greater heat recovery is important mainly in Tuscany, where the regional law requires new geothermal plants to use at least 50% of waste heat for direct uses.

Topic: Evaluation of the geothermal sector in Italy

    - Geothermal energy has been at a standstill for 12 years. The last plant was built in 2014, but the decision to build the last plant was taken in 2010. This is mainly due to: the political framework, length of the authorization process, lack of incentives;
- Its role in the Italian energy mix is too low (3%), but the installed capacity can be increased by 50% by 2035.
- It is necessary to consider geothermal as an important energy option because it provides heat and power and it is not aleatory, so it can be used with load factors close to theoretical.
- Lobbies of wind power and photovoltaic are stronger than geothermal
- It is necessary to make policies to plan geothermal at medium-long term
- Geothermal energy should result in more profits to attract investments, but estimations report that the CAPEX is 10 M€/MW in Italy.

Topic: Incentives and support measures

In general:

- The increase of 60MW envisaged by the draft law for incentives are too few
- Geothermal technology is not mature enough and it is necessary to incentivize them to reduce prices increase plants (as done with PV). This should also reduce the Pay back period of geothermal projects. Support the exploration of geothermal resources, through: insurance schemes to cover the mining risk, the exploration can be carried out by public entities, because geothermal resources are state-owned resources.
- Support measures for CHP and renewable heat, for H&C/DH and for industrial process
- A clear and long-lasting legislation is important to support the geothermal sector.
- Speedup and simplify authorization procedures.

Incentives and support measures for flexibility:

- Support and incentives to award renewables that stabilize networks (DH and electricity grids)
- It is necessary to award the capacity market
- To modulate the power produced can be useful, because the new incentive scheme draft limits the power production to 40 GWh/y per geothermal power plant
- Incentives for innovation and storage systems are needed

Topic: Standards

- It is necessary to bring together the entire geothermal supply chain (as in particular technology providers and developers) to promote new standards, as done for the O&G industry
- It is necessary to establish relationships with the O&G industry to adapt their standards to geothermal sector
- It is necessary to promote a standard on performance testing of geothermal plants, both concerning power and heat production.
    - This should help to cover the gap between the project developer and the customer. Indeed, the developer tends to satisfy the customer (the plant operator and investors), proposing nominal performances higher than the real ones

- Performances of plants should be considered also according to the temperature of geothermal fluids and the performance loss in summer, otherwise the business plan of the plant doesn't work.

- Geothermal energy is too site specific and generalization is a futile effort
- Standards for power and heat production and for the extraction of raw materials are necessary
- Standards should help to give as much certainty as possible to investors:
  - The GSAP (Geothermal Sustainability Assessment Protocol) has been an attempt to understand fundability of projects,
  - It is necessary to have standards to optimize plants
- Standards for the evaluation and authorization process of a new geothermal project are required to give certainties on timings of these processes and to avoid the influence of politicians

Topic: Cooling of ORC plants with groundwater

- It is useful for Mediterranean area
- It consumes a lot of water and it is hard to have an authorization, also in light of the drought of recent years
- Authorities don't give the authorization to use groundwater for these purposes
- Maybe it is better to use geothermal water
- The risk is the formation of an aqueous film.
  - This may result in an exchange of heat between the film and the atmosphere and not between the pipe of the adiabatic cooling system and the atmosphere, with a loss of efficiency in the exchange of heat. This risk is particularly high when water is not well atomised and becomes steam (*so some operators suggested to observe its functioning over time*).
- It is interesting to understand how many degrees this system lowers
- This system may face maintenance problems due to the possible formation of fouling
- This system should be customised in different contexts

Topic: Flexibility

Economic issues:

- The flexibility has to be economically sustainable
  - with competitive business plan with respect to baseload and the use of natural gas
  - the payback period should be calculated.
- Flexibility should be rewarded in some way (e.g. with special tariffs) and should be recognized by the market.
- The flexibility is necessary to cover discontinuous consumptions and aleatory renewables. Changes in electricity consumptions and the increase of renewables in the energy mix are causing an increase of turbogas power plants and an increase of system charges in the energy bill

Technical issues

- It has to be demonstrated that the proposed system works
- Flexibility with thermal storages is very important for the management of DH networks
- It is interesting to understand how the storage/flexibility system is managed
- The grid manager should help to better understand the requirements and sizes of plants
- It is interesting to deepen the storage system with PCM

Topic: Acceptance

- It is necessary to improve awareness among citizens and politicians and to develop skills of technicians and utilities
- The public opinion should be aware about the opportunities offered by geothermal, which is able to provide heat and power

- A geothermal project should involve and liaise with territories and local communities before asking permits.
- The acceptability can be achieved also creating new jobs, for example with direct uses
- The lack of acceptability is sometimes the result of NIMBY phenomenon, despite all want to decarbonize

Belgium

A total of 7 experts were interviewed, comprising diverse backgrounds including geology, engineering, business development, and policy advising. They are instrumental in shaping geothermal research, policy, and project development in Belgium. This summary encapsulates the challenges, potential, strategies, and stakeholders contributing to the development of geothermal energy in Belgium.

Current State of Geothermal Industry

Belgium's geothermal sector is in its early stages, marked by five operational projects. Challenges persist in technical understanding and regulatory complexities, requiring political and financial support for plant development and future projects.

The role of Geothermal in the Belgium Energy Mix

Geothermal, predominantly suitable for heating, demonstrates potential within the Dinantian limestone. Yet, challenges in funding, regulations, and market demand impede its optimization for electricity generation.

Promoting Geothermal in Belgium

Key strategies include leveraging geothermal as a baseload energy source, integrating it into urban areas through district heating, and focusing on successful projects to inspire new initiatives.

Social Acceptance and Knowledge

Belgians generally view geothermal positively but lack comprehensive understanding. Communication on benefits and safety measures is essential to address concerns around seismicity and ground instability.

Tools for Geothermal Energy Utilization

Essential tools include seismic monitoring, thermal energy distribution networks, technology adaptation, financial support, and transparency materialized by subsurface data sharing.

GeoSmart Project Expectations

To foster job creation, technological advancement, public acceptance, and facilitate operator engagement in utilizing innovative solutions.

Stakeholders and Development of Geothermal Standards

Research institutions, private companies, and governmental bodies are crucial in filling gaps, establishing standards, and balancing safety and sustainability.

Business Models and Flexibility

Flexibility in geothermal operation is contingent on sound business plans, commitment to heat offtake, and leveraging technological advancements to improve project viability.

Innovations in Geothermal

Innovations such as silica retention systems, while impactful in other contexts, might have limited relevance in Belgium due to low silica content and localized geothermal challenges.

5. CHAPTER 4 - DEVELOPMENT OF NEW MODELS FOR PRICING AND TARIFFICATION

5.1 Going Beyond an LCOE approach

The competitiveness of the deep geothermal sector has to be consolidated by:

- Developing a fair basis of cost comparison between energy sources, beyond a unique LCOE approach, taking into actual account system costs and external factors
- Analysing the ability of energy market models to properly remunerate the various benefits of geothermal energy in a industrial context of intensive capital investment (CAPEX) and marginal operational costs (OPEX)
- Establishing fair competition globally with the geothermal stakeholders from across the world

Considering that the rest of the world is moving towards geothermal energy at an accelerated pace, these efforts need to be maintained and made subject to ambitious further expansion in order to maintain Europe's leading position in developing the geothermal industry of the future, both for research and commercial development.

LCOE is one of the criteria most used to compare the competitiveness of different energy sources, notably in policy making. It is a very limited indicator, however, as there is no consideration of system costs such as the cost of transmission, or other network costs such as impact on system balancing, impact on state/system energy security, and the costs of external factors such as government-funded research, residual insurance responsibilities borne by the government, external costs of pollution damage or external benefits (e.g. the value of knowledge for future generations).

Current market models are unable to remunerate energy sources with low operational costs, hence there is a need for 'out-of-market' remuneration (feed-in tariffs, contracts for difference, premiums, capacity remunerations).

Europe has pioneered the exploitation of geothermal resources for power generation for over 100 years in Larderello, and the EU still maintains a leading role in electricity due to the development of new technology in many parts of the EU with the integration of national projects (in France and Germany) into a European Project at Soults-Sous-Forêts (France). In addition, the EU has the first successful commercially funded EGS project in Landau (Germany) and an EGS for industrial use (ECOGI project in France). 15% of the world's installed geothermal power capacity is located in Europe. European companies are often technology leaders.

With more than 400 geothermal DH (District Heating) systems in operation, Europe is also the global leader for geothermal DH. Global competition exists mainly for heat exchangers and pipes. The use of geothermal heat in industry, the agri-food sector and services also started in Europe.

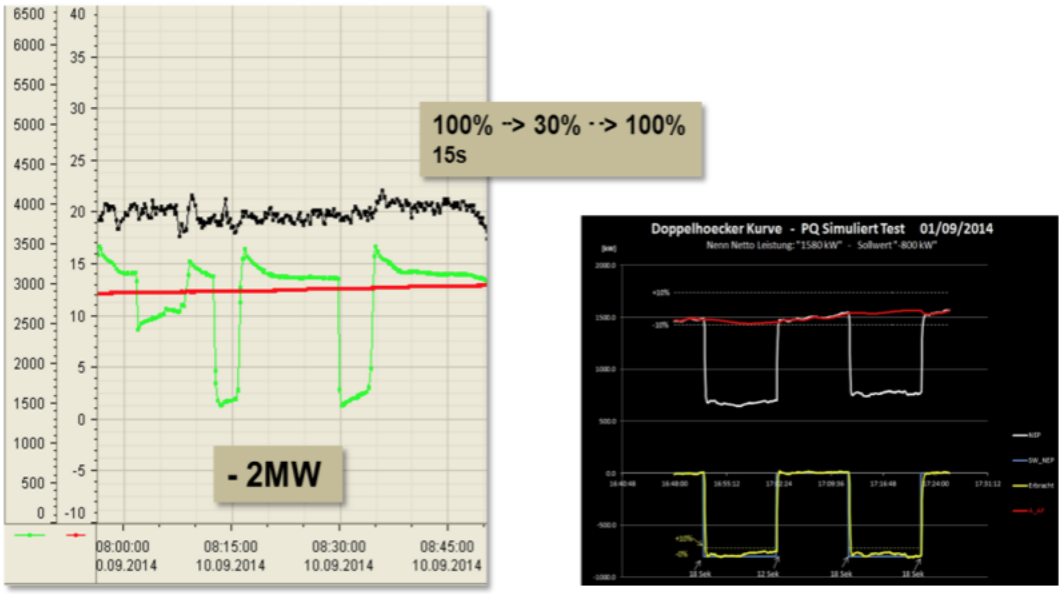
5.2 LCOE+

The **LCOE+** is a new matrix designed to go beyond the conventional LCOE (Levelised Cost of Electricity) measure. LCOE is produced by taking current given costs of producing 1 kWh of electricity in a generic energy system and dividing it by the total number of kilowatt hours generated over the technology's lifetime. This puts geothermal at a disadvantage as it focuses just on the price of electricity rather than additional services to the energy system. For geothermal, these are many and often play a vital role. They include:

- **Resource efficiency:** Geothermal power plants do not consume critical raw materials imported from overseas. For example, the 16.5 MW_e Velika 1 geothermal power plant in Croatia, provided as much electricity as the 309 MW_e installed capacity of solar PV installations in 2020. The 20 MW_e Slatina 2 geothermal plant started construction in 2021 to more than double Croatia's renewable baseload renewable power output and finance has been agreed for the Slatina 3 power plant. Cindrigo Geothermal Ltd, the owner, is securing licenses for an additional 1,000 MW_e capacity.

- **Flexibility:** Geothermal power plants in Germany have demonstrated that they can ramp up and down production in 15 seconds as outlined in Figure 14;

Figure 13 Flexibility of geothermal power plants[15]



Graph showing flexibility of geothermal plants with ORC turbogenerators. In some pilot geothermal plants located in Germany it was proved that power can be reduced from 100% to 30% in 15 seconds and brought back to 100% in 15 seconds. Courtesy of Turboden.

- **Storage:** Geothermal provides two types of storage solutions – Underground Thermal Energy Storage (UTES) and
- **sustainable lithium extraction**.

None of these essential energy services are covered by the conventional LCOE.

The problems with the LCOE matrix are well documented. The IEAGHG Technical Report – Beyond LOCE: Value of technologies in different generation and grid scenarios (2020)[16] introduced a *"Modified Screening Curve"* (MSC) which incorporates additional measures outlined in Figure 16 below.

[15] EGEC, Factsheet Flexible power generation from geothermal: A valuable solution for grid stability

[16] See https://documents.ieaghg.org/index.php/s/02aVgHm8HZdUQOQ

***Table 1:** Comparison between an LCOE approach and the proposed screening curve method*

Data Requirement	LCOE	Screening Curve
Capital cost	✓	✓
Fixed O&M	✓	✓
Variable O&M	✓	✓
Load duration curve	–	✓
Technology availability	✓	✓
Hourly iRES availability	–	✓
Analytical solution	✓	✓
Suitable for systems analysis	–	✓

Figure 14 Comparison between LCOE approach and the proposed screening curve method

Non-price services were also further developed by the European wind industry. They focused on three aspects - Sustainability & Biodiversity; System integration & Innovation; and European supply chain development & benefits to communities.[17]

The LCOE+ concept incorporates the features of the wind industry and the MSC with the additional criteria:

- Grid stability
- Flexibility
- Least land impact for storage
- Resource efficiency

The next step is to add a weighting to all of these criterions and a model to express values to better the outcomes of LCOE+ when assessing power generation technologies.

5.3 New pricing methodology

EU energy prices have followed a marked increase from July 2021, firstly due to COVID-19 pandemic and then due to Russia's invasion of Ukraine.

The high and volatile prices and serious concerns about security of supply all over the EU imposed a structural reform of the electricity market, with the dual objective of securing European energy sovereignty and achieving climate neutrality.

It aims at making the EU energy market more resilient and making the energy bills of European consumers and companies more independent from the short-term market price of electricity. This can be done by

[17] Wind Europe 2022 – Position on non-price criteria in auctions https://windeurope.org/wp-content/uploads/files/policy/position-papers/20220413-WindEurope-Position-paper-non-price-criteria-in-auctions.pdf?20220520b

reforming the Energy Market Design by new Electricity market design rules rewarding benefits of geothermal power.

5.3.1 Current functioning of the EU electricity market

As in other sectors, the EU electricity market has a number of different players in the supply chain – from producers (or generators) to suppliers to end-consumers - with wholesale prices at one end and end-user prices at the other. The supply chain is all the companies or entities that play a role in the electricity market. It includes:

- Electricity generation: companies with electricity generation assets, namely power plants. They produce electricity and sell it on the wholesale market
- Transmission system operators or TSOs – entities which manage the transmission networks, i.e., high-voltage power lines linking generation assets and transformers.
- Distribution system operators or DSOs – entities which operate the distribution network typically medium and low-voltage lines, bringing electricity to customers.
- Electricity Suppliers – companies that sell electricity to consumers.

The electricity market follows the economic principles of demand and supply, aiming at ensuring that demand is served at any moment in time in the most cost-effective way. In very basic terms, electricity generators sell their production on the wholesale market. This is further sold by suppliers to consumers via the retail market.

The wholesale market in the EU is a system of marginal pricing, also known as a pay-as-clear market, where all electricity generators get the same price for the power they are selling at a given moment. Electricity producers (from national utilities to individuals who generate their own renewable energy and sell into the grid) bid into the market: they establish their price according to their production cost. The merit order is the ranking of power plants according to their respective generation costs. It is established based on the variable costs of each power plant, calculated in €/ kwh. Renewable energy sources are produced at zero cost and are therefore by definition always the cheapest. The bidding goes from the cheapest to most the expensive energy source. The merit order therefore ranks renewables first, followed by nuclear, gas, coal, and oil fuel.

The cheapest electricity is bought first, next offers in line follow. Once the full demand is satisfied, everybody obtains the price of the last producer from which electricity was bought.

This model provides costs based only on LCoE. Overall, it is better for consumers to have a transparent model that reveals the true costs of energy.

The retail electricity market in the EU fix the price that customers pay per kWh of electricity used during a certain period of time. The bill includes the electricity price - reflecting the consumption-, the transmission and distribution network tariffs, as well as taxes and levies. In Europe, according to Eurelectric[18], the electricity component represents 31% of the electricity bill, while network tariffs account for 28% and taxes and levies reach 41%. Changes in the wholesale rates have then a direct impact on the retail price.

[18] Power Barometer -2023: https://powerbarometer.eurelectric.org/

5.3.2 Towards new Electricity market design rules

There is a need to reform the electricity market:

- Energy price crisis caused by reduced Russian gas imports, nuclear and hydro shortages. Ukraine invasion exacerbated this.
- Today, About 20% of EU electricity generation comes from flexible gas plant.
- Current price rules doesn't incentives or fiscal rewards for baseload and predictable (geothermal) renewable energy generation, and there is no support for flexibility, storage or energy savings.
- Southern European countries had problems because of the heat wave that added greater pressure on their electricity systems.
- Electricity system also came under pressure from the jump from fossil heating to electric heating. This is highlighted in the Polish government's national roadmap for geothermal energy published in October 2022 "The use of ground source heat pumps is also an important element of energy security. Their high efficiency means that they consume much less electricity than air-source heat pumps, thus avoiding large power draws from the grid (e.g., during heavy frosts, when using air-source heat pumps). When combined with photovoltaics (PV) and thermal energy storage, ground source heat pumps form a complementary and efficient district heating system."

With a pure focus on LCoE, current pricing rules have so far failed to ensure a fair valuation for geothermal-based electricity and heat based on its baseload attribute and consistent local energy supply.

Key considerations for geothermal power and heat plants in the context of an electricity market reform:

- Rewarding reliable renewable power generation capacity: The true value of a geothermal power plants rests on their high availability with capacity factors routinely exceeding 90%, as high as 100% on given years. Permitting and licensing processes must include this significant benefit when considering an application. The timescale for permitting and licensing, as well as the need for a single contact point or a 'geothermal authority', as is used in mature markets such as Iceland, will significantly replace the marginal pricing impacts of fossil gas.

- Adequate reward for grid balancing services: In the current electricity market rules, geothermal plant developers already had to adapt some of their technologies to demonstrate their capacity to respond to increasingly strict balancing requirements. Turboden's plants in Germany have demonstrated their ability to ramp up and down 70% of their load in a matter of seconds, at the grid operator's request . As the electricity market rules expose renewables generators to balancing responsibility and balancing markets are playing an increasingly important role, geothermal operators must be given adequate recognition of their vital grid balancing services they provide.

- An EU framework for underground thermal energy storage: UTES is critical to meeting seasonal demand. However, there is no commercial-scale demonstration programme to aid the design of appropriate regulatory and support mechanisms.

- Pooling financial risk mitigation across the EU: Risk mitigation schemes are essential to addressing the CAPEX aspects of geothermal development .

- Achieving the Internal market for heat: the security of heat supply and the price affordability for heating and cooling of households and for the industry urge to establish the internal market for heat. This requires legislating open and fair retail markets for heat; institutionalising a European Network Transmission System Operators for Heat charged with managing infrastructure for renewable energy sources; fostering cross-border cooperation.

5.3.2.1 Retail electricity market

The price paid by the consumers includes the electricity price - reflecting the consumption-, the transmission and distribution network tariffs, as well as taxes and levies.

So the other costs, typically system costs and externalities, are not included so they are not paid by the consumers but by tax payers.
To ensure a fair energy transition, the retail price must include the full costs for the society:

1) Electricity price: as depicted in the following chapter for the wholesale electricity price, price must include the production cost of the electricity generation and the systems costs and externalities associated
2) System costs must include the real associated to the power technology: transmission and distribution network tariffs linked to their impact reflecting the load factor, and the costs for storage for this technology
3) taxes and levies must be fair for the consumers and the tax payers to reflect all costs for externalities typically reflected in non price criteria

5.3.2.2 Wholesale electricity market

To reform the electricity marker design, the European Commission proposed using more long-term contracts, such as power purchase agreements, and investment support should be structured as two-way contracts for difference: "*The aim is to better protect consumers, accelerate the deployment and better integration of renewables in the energy system, but also to enhance protection against market manipulation stability and predictability of the cost of energy and thereby contribute to the competitiveness of the EU industry*".

Auction systems with non price criteria

Member states are not using tendering schemes to support RES. Auction systems must valorise the electricity and heat generated, taking into account not only the LCoE, but also system costs and externalities. They should not focus on the installed capacity in GW, but rather on the energy supplied to the grid in GWh.
Auctions designed in innovative ways can help to achieve specific country goals, beyond solely procuring electricity and heat at the lowest price but the full cost for the society. Non-price criteria should be at the basis by including, first of all, systems' costs and externalities. Auction systems must:

- Support technologies balancing the grid;
- reward the value of the electricity and/or heat produced (baseload, flexibility etc.);
- use sustainable LCA to help the introduction of socio-economic criteria, adding environmental and social LCA;
- maximise the socio-economic benefits of renewables, such as jobs creation and local economic development;
- reward a made in Europe supply chain
- ensuring greater participation of communities or other new and small players.

The geothermal sector needs non-price criteria in order to have fair comparison to be deployed all over the EU. In particular, it is not taken into account that:

- Geothermal has the best load factor (higher than 90%) and can generate flexible electricity (ramp up and down in 15 seconds).
- It is a local source of renewable energy, producing also heating, cooling and minerals such as geothermal lithium.
- Geothermal contributes to local economic development, especially when supplying energy to the agri-food industry and tourism (hotels & spas etc.).

None of these attributes are rewarded by the market and the auctions based on price. Hence, non-price criteria are needed to reward geothermal. Moreover, another solution is to launch renewable energy auctions by technology.

Some auctions in Europe have failed or were cancelled due to a lack of bidders because of strike prices did not account for inflated cost of materials and labour. Failures such as these must not be an option if we are to protect citizens and industry from fossil powered energy. Hence the need to ensure these variables are also included in the tendering process.

Contracts for Difference (CfDs)

This is the main way in which governments can finance new electricity generation capacity in a few technologies. Two-way CfDs means the generator receives income when the price of electricity collapsed but consumers receive it, to some extent, when prices go above the agreed ceiling. Geothermal producers receive income stability between the strike prices. However, this covers operational costs not production (drilling, etc). Indirectly combined geothermal power and heat projects incentivised.

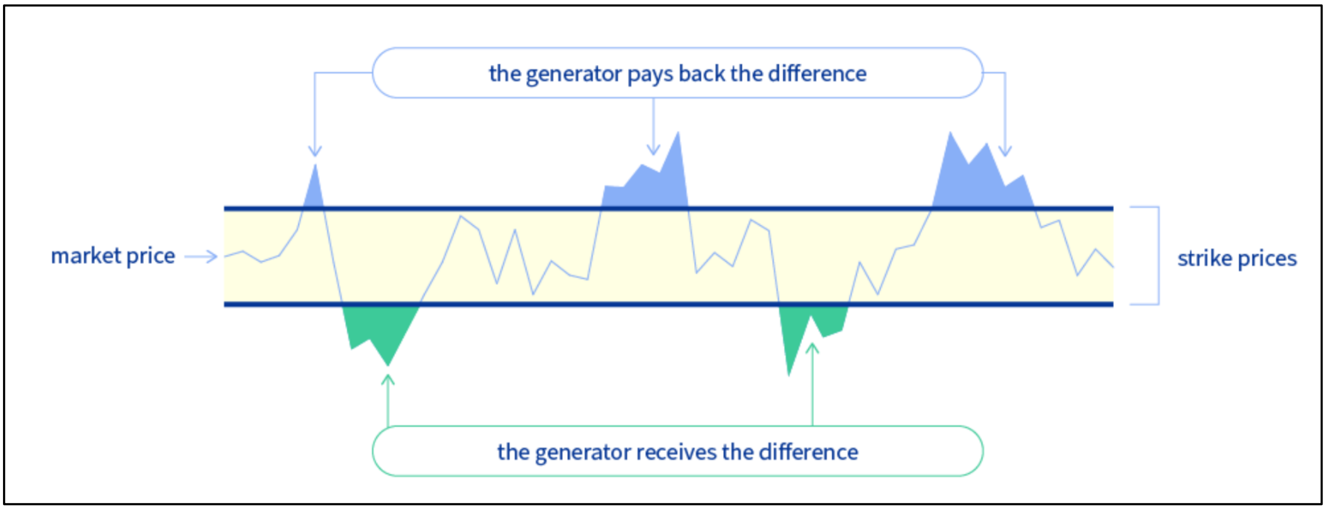


Figure 15: Contracts for Difference

The proposed two-way CfD rules to tender new capacity must include non-price services such as system adequacy, reliability, storage and flexibility as well as additional services such as heating, cooling, sustainable lithium or other raw material extraction into strike prices to sufficiently reward and incentivise investment in geothermal capacity.

It is unlikely that new geothermal electricity capacity will be secured through the proposed two-way CfDs without strike prices including these essential non-price features. New geothermal capacity will not be commissioned solely to provide storage or flexibility alone because the Levelised Cost of Energy (LCOE) for geothermal includes these services, which explains why the upfront CAPEX cost is higher. In Italy, a 15 MWe geothermal plant had a capital cost of €103 million LCOE; compared to €68 million for a 39.6 MWe geothermal plant; whilst 10 and 20 MWe of onshore wind had LCOEs of €59 million and €52 million, according to the IEA's LCOE Calculator.

6. CONCLUSION

As highlighted above, the EU's renewable energy targets and the Green Deal focus on increasing the resilience of the electricity system and on rewarding flexibility which are both aspects geothermal electricity can contribute to if barriers are overcome, and the right incentives are in place. The examples from the different countries presented in Chapter 1 show how energy policy frameworks accelerate or slow down the development of a geothermal projects.

Besides the barriers for geothermal electricity production such as geological data availability, regulation, permitting processes, and skills, the high upfront costs and risks related to the geothermal resource are key factors. For geothermal projects, upfront capital expenditure (CAPEX) is typically high, about 80-90% of total project cost. This is combined with risks related to the geothermal resource which may require additional investment such as exploration or development. In the short-term, there is the risk of not finding an economically sustainable geothermal resource after drilling and in the long-term there is the risk of the geothermal resource naturally depleting rendering its exploitation economically unprofitable. For the profitability of a project, mitigating these risks is crucial. On the one hand, risks can be minimised with improved exploration techniques and better data availability. A widely proven solution to facilitate market uptake of geothermal energy is the establishment of financial de-risking schemes such as insurance, grant schemes or Public Private Partnerships. In mature markets they can take the form of private insurance and Public-Private Partnerships, while in less developed markets public and public/private risk instruments are required. Grant schemes are especially suitable for markets where there is little information about the geothermal resource and few projects for reference. Best practice for upfront cost support schemes and risk mitigation exist in France with the SAF Environment Fund and in the Netherlands with the Geothermal Heat Guarantee Scheme. But these frameworks often focus on heat production and therefore need to be extended to geothermal electricity as well.

The deliverable also proposes a new model for pricing and tariffication that remunerates the flexibility offered by geothermal power by taking into account differences in the production profiles of fluctuating and dispatchable generation technologies as well as the associated large variations in the market value of the electricity they supply. The LCOE+ goes beyond the conventional LCOE measure in that it does not focus just on the price of electricity but also on additional services to the energy system. Geothermal power plants produce more energy throughout the year than other technologies due to less maintenance outages and independence from weather. They are more resource efficient and use no critical raw material. Crucially, geothermal power generation is flexible. Power plants can ramp up and down quickly and can be used for storage. These system costs and external factors have to be taken into account to properly remunerate the various benefits of geothermal energy, to develop a fair basis of cost comparison between energy sources and for a fair competition with the geothermal stakeholders globally. Current market models are unable to remunerate energy sources with low operational costs, hence there is a need for ‘out-of-market’ remuneration (feed-in tariffs, contracts for difference, premiums, capacity remunerations). EU energy policies such as the recent EMD are pointing in this direction as well with a focus on flexibility and autonomy and Contracts for Difference as a key instrument.

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ANNEX 1 – LEGAL TEXTS FOR THE ELECTRICITY MARKET DESIGN

This is a summary of the different legal texts proposed by the European Commission, the European Parliament, Council and EGEC.

The agreement on the reform of the Electricity Market Design (EMD) between EU Parliament and Council was reached on 14 December 2023.[19] The new EMD is to ensure a sustainable, renewables-based and independent energy system and thus protect consumers from high electricity prices, the reform favours long term contracts, demand response and storage. The key instruments to achieve this are Power Purchase Agreements (PPAs) and two-way Contracts for Difference (CfD). PPAs allow for longer term electricity supply contracts with stable, predictable prices.

CfD provide power producers with stable revenues accelerating the deployment of geothermal and other renewables. They are authorised for existing nuclear and renewable assets in the case of investment and for new power plants. A number of provisions govern the conclusion of these contracts, requiring, for example, alignment with State aid rules and monitoring to ensure that there is no negative impact on EU competitiveness. The only real concession made to Parliament on this point is that the CfD will not be the only direct aid scheme authorised for new investments. "Other equivalent schemes with the same effects" may be introduced, adding the final text to the Council version.

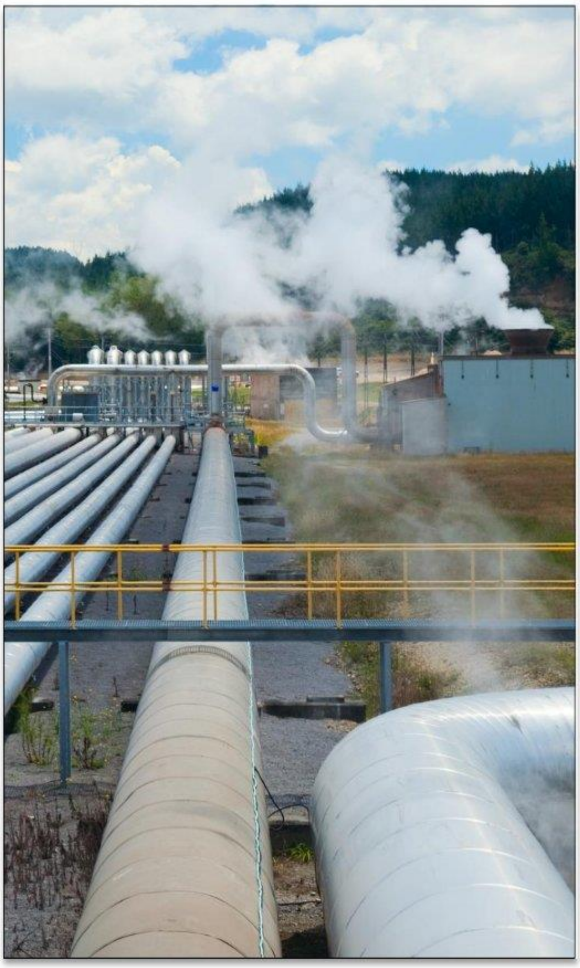
Furthermore, to make power systems more flexible, Member States can introduce support schemes for demand response and storage which can create business cases for geothermal power due to its flexibility and its suitability for storage.

[19] See https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6602

ANNEX 2 – FACTSHEET ORC GEOTHERMAL PLANT FLEXIBILITY 2023

This project has received funding from the **European Union's Horizon 2020 research and innovation programme.** *Grant agreement 818576*

1/ Geothermal, an overlooked solution for global warming mitigation



Geothermal Energy
... The art of the strategic move

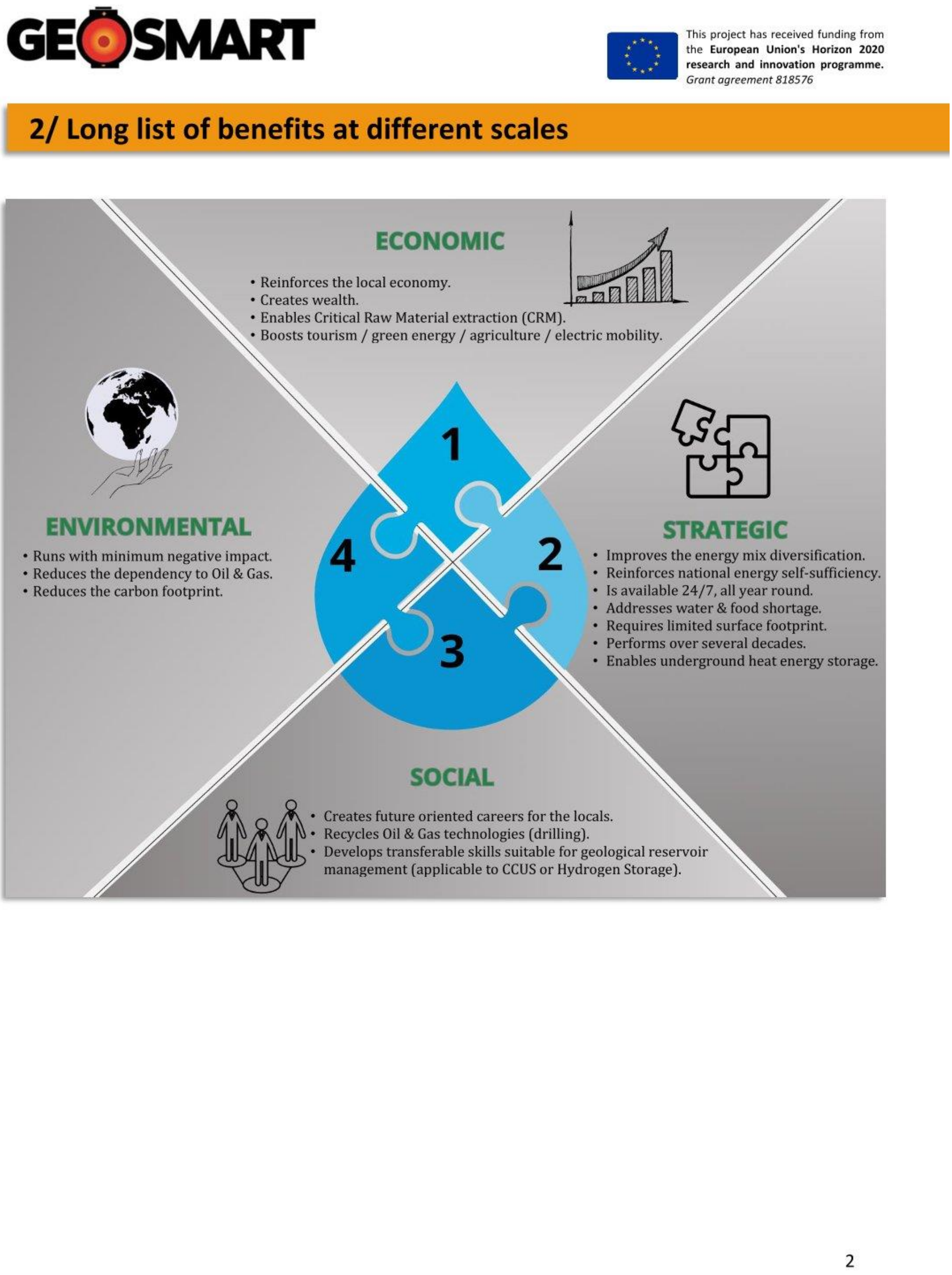
Geothermal stands as a sustainable energy source, derived from the Earth's subsurface heat. This deep-seated warmth is harnessed via cutting-edge technologies including **Organic Rankine Cycle (ORC)** geothermal power plants for electricity production initiating a smart residual heat valorization chain.

Geothermal has been generally **overlooked**. Yet, its benefits are extensive, spanning from the reduction of greenhouse gas emissions to the provision of an **unwavering energy supply**, available round the clock. The latter characteristic set this low-carbon energy source as a **serious baseload candidate** to fill in the gap faced by EU countries since the end of the Russian gas supply under the current geopolitical context. Additionally, the supply may also be adjusted to match intraday fluctuation energy demand, as tests run in German Geothermal plants have shown that output can be ramped up or down within seconds.

Capital expenditure investments often challenge geothermal projects. However, the unrivaled binary system power plant's flexibility can counterbalance this obstacle. Diversified applications enable projects' **financial de-risking** by **securing off-take agreements**, which enhances the attractiveness of geothermal initiatives. In this **factsheet**, we delve into the versatile spectrum of applications that geothermal plants with binary systems can serve.

Let's explore the key facets that makes geothermal a pivotal player to **decarbonize the industry** and address **climate change**.

1


GEOSMART
This project has received funding from the European Union's Horizon 2020 research and innovation programme. Grant agreement 818576
2/ Long list of benefits at different scales
ECONOMIC
• Reinforces the local economy.
• Creates wealth.
• Enables Critical Raw Material extraction (CRM).
• Boosts tourism / green energy / agriculture / electric mobility.
1
2
3
4
ENVIRONMENTAL
• Runs with minimum negative impact.
• Reduces the dependency to Oil & Gas.
• Reduces the carbon footprint.
STRATEGIC
• Improves the energy mix diversification.
• Reinforces national energy self-sufficiency.
• Is available 24/7, all year round.
• Addresses water & food shortage.
• Requires limited surface footprint.
• Performs over several decades.
• Enables underground heat energy storage.
SOCIAL
• Creates future oriented careers for the locals.
• Recycles Oil & Gas technologies (drilling).
• Develops transferable skills suitable for geological reservoir management (applicable to CCUS or Hydrogen Storage).
2

GEOSMART

This project has received funding from the **European Union's Horizon 2020 research and innovation programme.** *Grant agreement 818576*

3/ Geothermal energy production systems

Geothermal energy depending on the local geology

1 Dry Steam Power Plants

Part of the first technologies applied in the geothermal industry. Exploiting naturally occurring underground high-pressure steam to run turbines that generate electricity.

2 Flash Steam Power Plants

Widely used across the globe. Extracting high-pressure hot water from the subsurface. The rapid steam expansion from the hot water is exploited to run the turbine to generate electricity.

3 Binary Cycle Plants / ORC Power Plants

For lower reservoir temperatures. Use of a working fluid with lower boiling point (e.g., organic fluid (pentane); CO2 or N2/water mixtures). The latter gets heated up in a Heat Exchanger by the geothermal brine. Past its boiling temperature point, the working fluid runs the turbine for power production.

Current technologies under development to support the power generation systems

Cutting-edge technologies: (EGS) Enhance Geothermal Systems; (AGS) Advance Geothermal Systems; Innovative drilling for Ultra-Deep Geothermal (UDG)

- **EGS** aiming at engineering an artificial reservoir in which water is injected and retrieved after being heated in the subsurface. Requires rock permeability enhancement (by the means of rock fracking or existing faults and fractures reopening via chemical dissolutions).
- **AGS** emerging technologies, aiming at engineering innovative systems such as closed-loops with no reservoir rock nor natural geothermal brine required.
- **UDG** reaching targets up to 5 times deeper than reservoirs regularly exploited in today's geothermal projects. It requires robust equipment able to withstand extreme conditions with high pressure (HP) & temperature (HT). A better understanding of risks, inherent to deep targets, is also needed (wellbore stability; corrosion; Normally Occurring Radioactive Material; induced seismicity). R&D remains crucial, not only to reduce drilling costs, but also to ensure safe and responsible technology deployment.

GEOSMART

This project has received funding from the **European Union's Horizon 2020 research and innovation programme.** *Grant agreement 818576*

4/ Binary geothermal plant using ORC

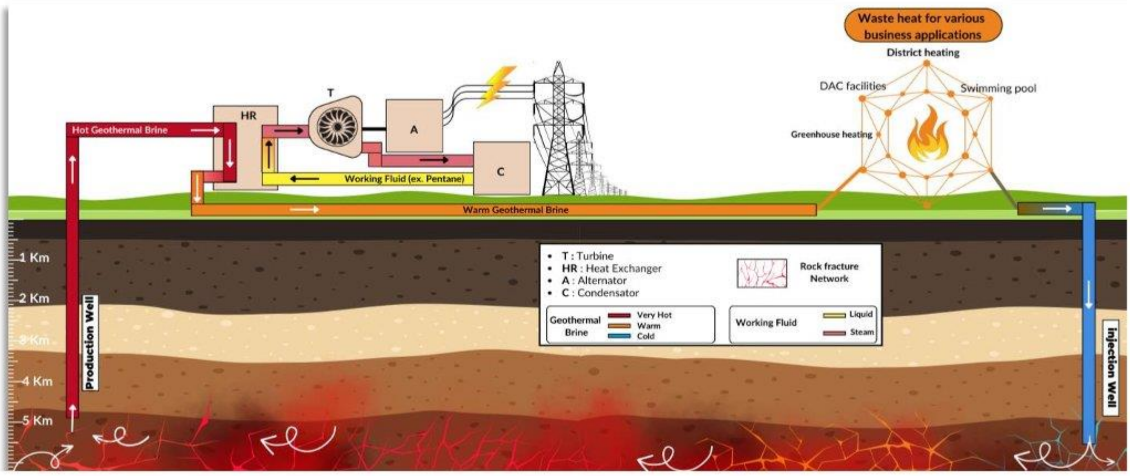
Why focusing on binary geothermal power plants?

- **Flexibility:** Different type of working fluids may be used according to the exploitable heat in place. Binary systems enable using the heat for electricity generation, while still being able to repurpose the waste heat for other business applications. For maximum heat exploitation, with the brine returning to the subsurface at lowest temperatures possible, solution must be implemented against mineral precipitation such as scale retention systems. The latter technology currently being developed by **Geosmart***. It is worth noting the inherent duality in these processes, as they necessitate not just technical feasibility but also economic viability.

- **Efficiency:** Lower subsurface temperature requirements for power generation. Thanks to its low boiling point, the working fluid can expand and drive a turbine for electricity production, even with temperatures around 100°C.

- **Scalability:** Unless located on a tectonic plate boundary with volcanic activity, most countries are not gifted with a high geothermal gradient. Most places present a geothermal gradient of ~30°C/Km. As being efficient at medium to low temperatures, binary systems are very scalable worldwide. Unlike Flash or Dry Steam technologies requiring specific contexts with high brine temperatures.

- **Sustainable:** Binary systems reduce the geothermal brine contact with the environment to a bare minimum. The environmental footprint is small, in comparison to other power plant systems inclined to release Carbone Dioxide. Binary plants are more inclined to preserve environments with a sensitive eco-system.



*__Click here to access R&D on silica scaling__
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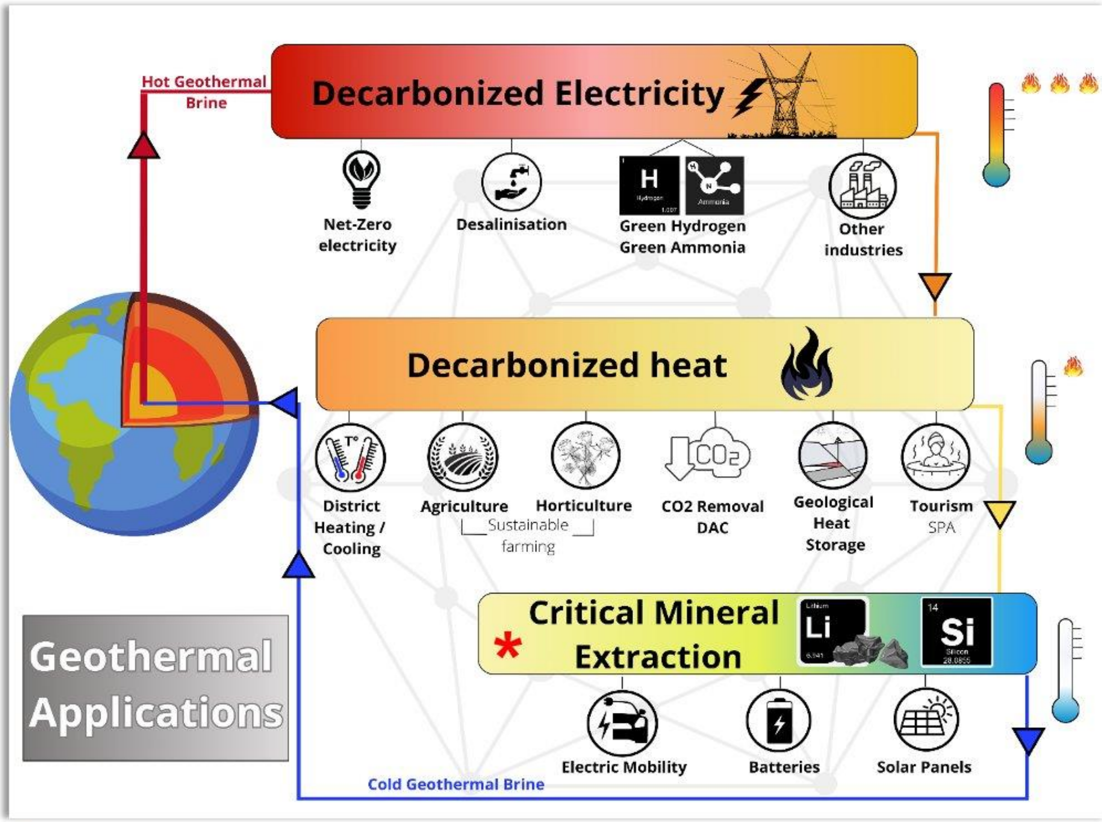
5/ Geothermal applications, cascade utilization



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Technologies are currently under development for brine critical mineral extraction (CME). The minerals can be extracted at different temperatures according to their inherent nature conditioning, their solubility or precipitation behavior. In other terms, CME can take place at different temperatures in the waste heat value chain – not per say at low temperatures.

5

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Geothermal energy, available **24/7**, offers a **versatile** and **sustainable** solution for building a cleaner, greener future. Its **diverse applications** and **adaptability** make it a crucial player in the transition to decarbonized energy sources.

Decarbonized Electricity

The **high-temperature** brine extracted from the subsurface can be harnessed to produce **electricity** using **ORC technologies** where the working fluid runs turbines. Such a low carbon power source can positively. impact various sectors targeting a net-zero supply chain (from **district** to **heavy industry electricity supply**) committed to combating climate change. It can also power water electrolysis for **Green Hydrogen** or **Ammonia production,** the latter being more inclined for transportation.

Decarbonized heat

Once the hot water is used for electricity generation, the residual heat can still be exploited for other applications. It can provide a **sustainable and efficient heat source** for residential, commercial, and industrial needs. For example, sectors like **agriculture**, **aquaculture**, and **horticulture** have heating requirements that need to be met. **Leisure activities**, such as **Spas**, can offer guests a relaxing experience thanks to the exploited brine, which brings Geothermal in the eco-tourism arena. Geothermal heat can support **carbon negative technologies** such as **Carbon Dioxide Removal (CDR)** via **Direct Air Capture (DAC) facilities**.

Critical Mineral Extraction

The brine, in some geological settings, can hold **silica** and **metallic minerals like Manganese, Zinc** or **Lithium.** The latter being essential for the energy transition, as it is a key feedstock serving the **booming electric mobility industry.** Albeit such valuable materials can be present in the scaling compound, the latter is a challenge for geothermal projects longevity. Scaling causes reduction in flow rates, and damages equipment such as pipes, pumps and heat exchangers leading to higher maintenance costs. Technologies are currently under development for brine critical mineral extraction (CME). The minerals can be extracted at different temperatures according to their inherent nature conditioning their solubility or precipitation behavior. In other terms, CME can take place at different temperatures in the waste heat value chain – not per say at low temperatures.

6

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6/ Challenges to overcome to achieve success

Flexibility

A booster to maximize interest for geothermal energy & ease the process!

7

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Right Geological Setting

Not all geological settings are suitable for conventional geothermal energy production systems. Tectonic plate boundaries with volcanic activity are generally sweet spots to find heat. Suitable reservoir structure and petrophysics (good porosity, permeability) are also required, as much as good thermal properties. The presence of a geothermal fluid (ideally confined aquifer) to circulate the heat to the surface is also preferable. Less suitable geological settings require cutting edge technologies for viable energy supply.

Technological Maturity

Technologies are currently being developed to exploit the heat from the subsurface, even in less favorable geological context. Among the innovative solutions, there are EGS, AGS including closed loop systems, or new adequate drilling practices for UDG. As such technologies evolve, they make geothermal energy exploitation possible in regions with low geothermal gradient.

Market Business Case

Can the geothermal plant provide different local businesses with energy all year round? The more the flexibility the more business opportunities can be secured. The geothermal plant must be designed according to both the geological context and the local energy demand. Is there a need for electricity and/or heating network? Is the geological setting suitable to meet the local demand? does an adequate funding system subsist to develop the technology required to meet the local demand? These are all question to address before launching a geothermal project.

Financial Support System

High initial expenses are a fundamental aspect of geothermal projects due to geological and technological complexities. Funding can be obtained from both national and international sources, including subsidies, supportive R&D investments, and insurance to counteract financial risks such as lower than expected well productivity. Flexibility can amplify the Return On Investment (ROI) of geothermal plants by supporting a variety of local businesses in reducing their carbon footprint. Government incentives to push private sector investments are also pivotal in advancing towards goals set by international climate agreements.

Oil Price Competition

The competition from established cheaper hydrocarbon technologies hinders emerging geothermal advancements. Yet, with policies promoting fossil fuel phase-out, geothermal shows promise in driving the industry towards a net-zero future.

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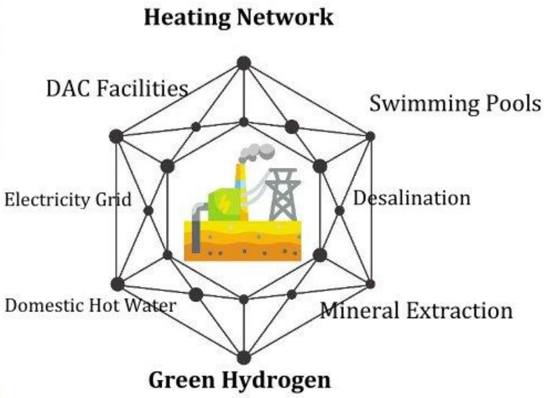
7/ Flexibility: geothermal to shape the local business eco-system

Business eco-system shaped by nature.
Geothermal: Use the geological settings to guide the development of the local region.

Combined geothermal heat & power represents a natural resource that can serve as a catalyst for local economic growth. It stands as a potential metric to drive the development of a business ecosystem, aligning with the specific challenges of the region. This versatile energy source can be harnessed to address a range of needs, from powering desalination plants to combat drought, to supplying heat for swimming pools and enhancing crop yields.



Business ecosystem driven by the geothermal potential available

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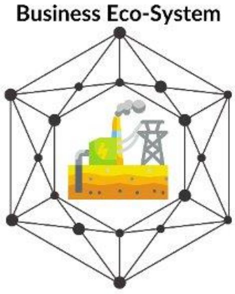
Example:
Location: European country, region with geothermal gradient of 32°C/km (no volcanic activity).
Power generation system: Binary power plant, engaging a working fluid.
Temperature, flow rate: brine temperature **(120 to 130°C)** with good production flow rate **(>300 m3/hr)**

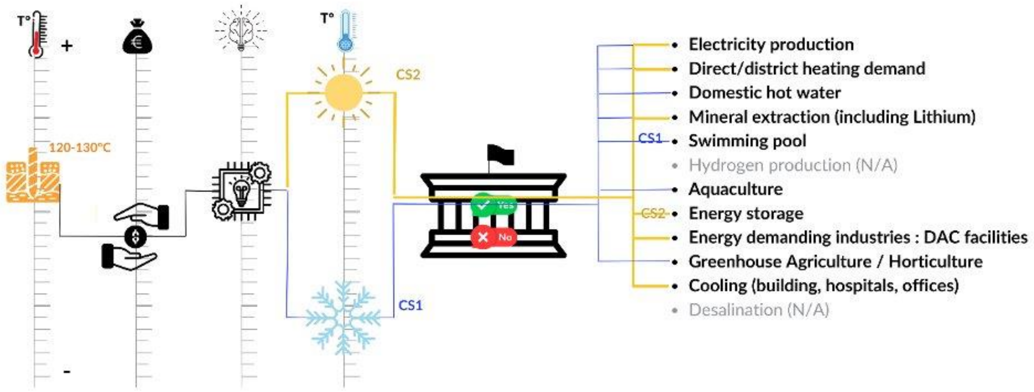
Case Scenario 1 (CS1) Vs Case Scenario 2 (CS2). Single variable applied: seasonal (Winter Vs Summer). Same geological context, CAPEX, used technology, validation by the authorities.

CS1: in the winter, the offtake is secured by:
Electricity and heat demand, mineral extraction, aquaculture, greenhouse agriculture, domestic hot water.

CS2: in the summer, off-take secured by:
Mineral extraction. The demand for direct heat is reduced but can still be stored or used for cooling.

Business Eco-System





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8/ Geothermal applications: flexibility in the Belgian context

Successful deep geothermal energy projects in Belgium send a resounding message to the global stage. Like most countries in the world located away from tectonic plates boundaries, Belgium has no volcanic activity, nor is it gifted with an above average geothermal gradient. Throughout the country, the geothermal gradient is about 32°C per kilometer depth. In Belgium, current deep geothermal projects are exploiting reservoirs at depths ranging from 2 to 4 kilometers (Dinantian, carboniferous limestone) with associated temperatures that could reach 140°C. If such thermal characteristics are relevant for some business applications, other criteria such as the presence of an aquifer, ideally confided in a reservoir rock with a good porosity network, is also required for standard doublet systems. Belgian deep geothermal projects are focusing on heat delivery, as the combination of the above-mentioned factors has not enabled the production of power yet.

The convergence of evolving policies promoting a transition away from fossil fuels and Belgium's current geopolitical situation, experiencing disruptions in the steady supply of Russian gas, highlights geothermal energy's role in heat delivery. This presents an opportunity to address the challenge while advancing toward a net-zero industry.

The below illustration shows the versatile role of geothermal energy in the current Belgian context. It presents a sequential usage of a single geothermal source, starting from the point of extraction until the brine gets reinjected into the subsurface reservoir where it came from. As the brine's temperature drops, the conveyed heat can serve different businesses. From district heating to swimming pools, greenhouses or simply to maintain an above zero temperature in warehouses in the winter. The baseload characteristics of this energy source not only helps companies to score better at their Environment Social & Governance scheme (ESG), but it also protects their economy from unpredictable gas price fluctuations.

Also, highlighted in the diagram is the pressing need for technological advancement, particularly to achieve higher temperatures to increase energy production (including electricity). UDG, or techniques like AGS, EGS could potentially elevate Belgium's geothermal capabilities to match the success of regions benefiting from volcanic activity. Finally, the social acceptance is also a crucial factor to consider.

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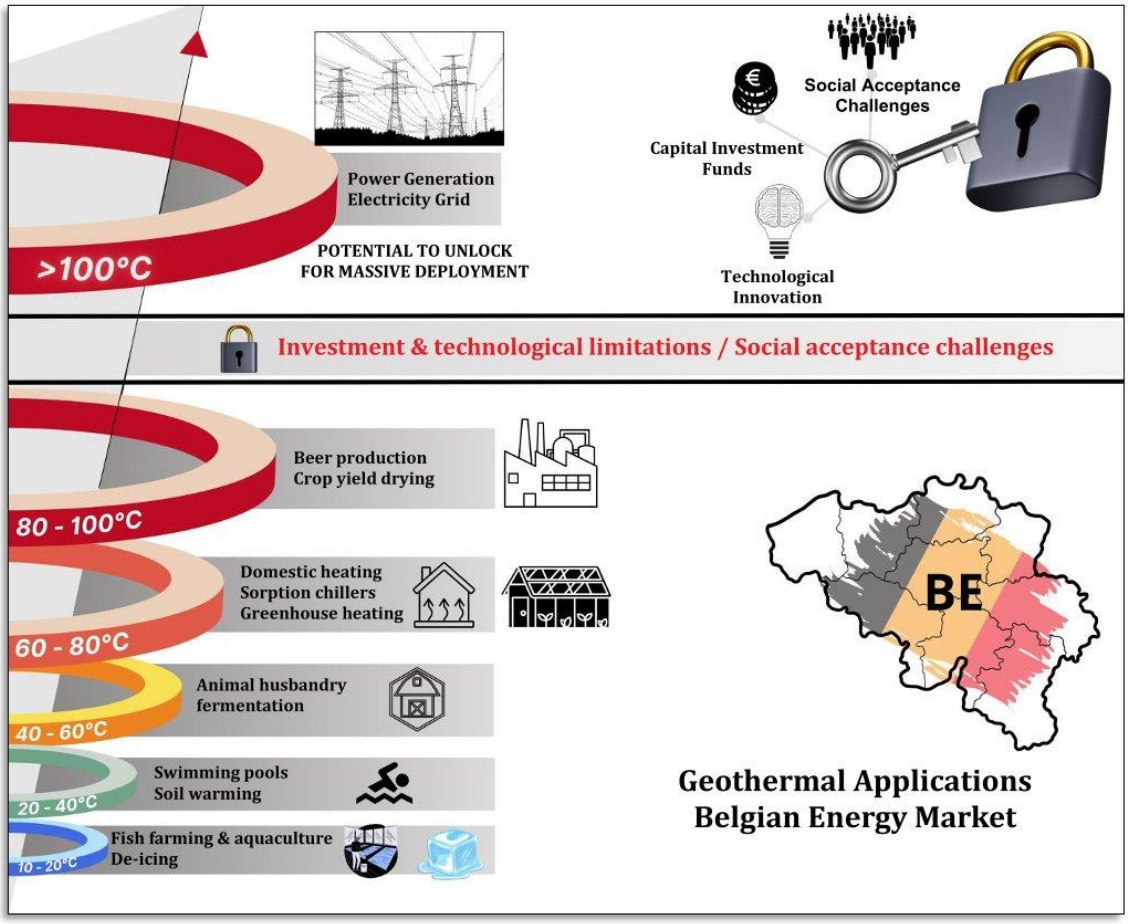

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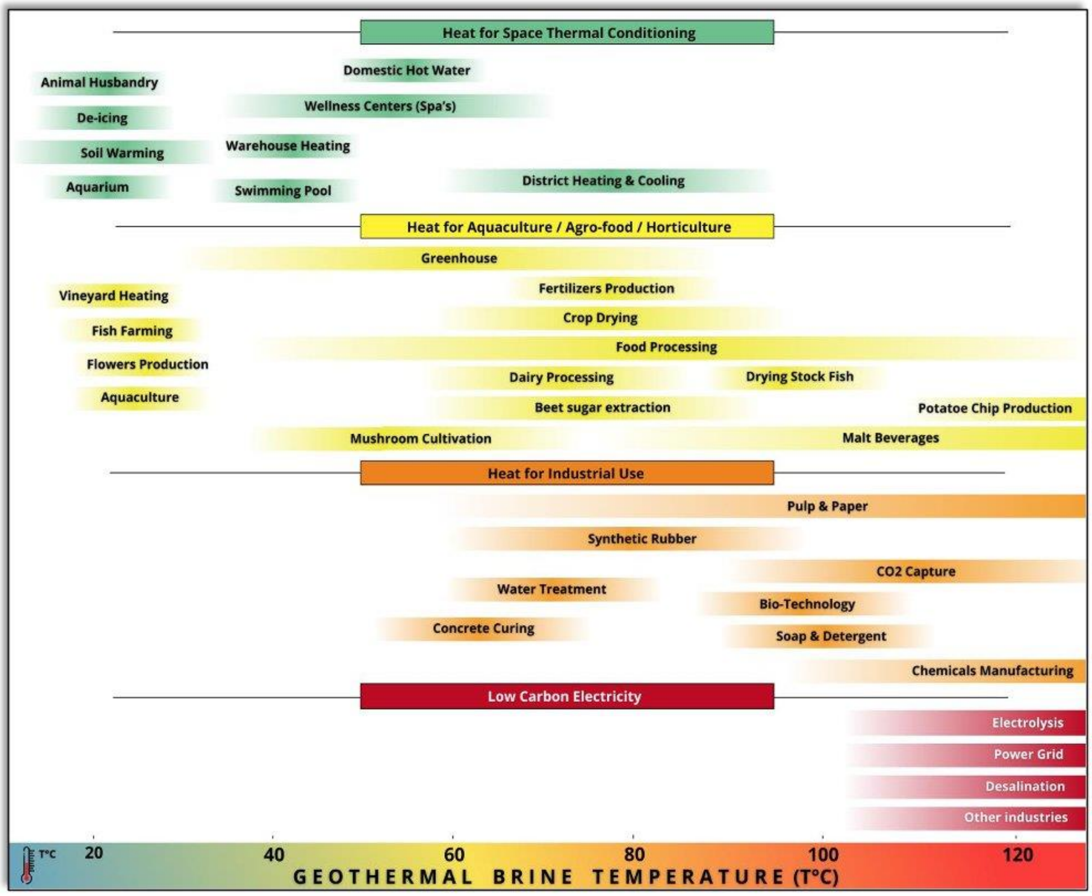
9/ Amongst the industries to decarbonize

Below is a comprehensive list of business applications that stand to gain from the utilization of geothermal energy (geothermal brine temperature below 130°C). The thermal energy extracted from the geothermal brine holds multifaceted advantages that extend beyond addressing power demands, catering to various industries.



References

Inspired by the Lindal's Diagram of geothermal production temperatures and direct uses (from Kurnai et al. 2022) & Jóhannesson, Th., Chatenay, C. "Industrial Applications of Geothermal Resources" (2014)