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Research Note

Investigating the Economic Effects and the Roadmap of Developing Geothermal Systems to Generate Electricity

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ABSTRACT

Geothermal energy is a non-carbon renewable source from the earth's internal energy. This energy is considered reliable today and has a high potential to reduce the threat of climate change. The main factor that any investor wants to invest in any natural energy source is the resulting economy. In the case of geothermal energy, factors that increase the risk of investing in this sector include higher investment costs, longer payback times than other renewable power plants, and the uncertainty of the size and quality of the resources before the completion of the well drilling operation. The average payback time in geothermal energy systems is 5.7 years, longer than wind and solar energy. According to these factors, the risk of investing in geothermal technology increases. On the other hand, due to its independence from oil and gas, it increases a country's energy security, helps to create direct, indirect, and induced employment, and affects other economic sectors. Also, unlike renewable wind and solar energies, it is not dependent on climate change; therefore, it has higher reliability than other renewable energies. Also, by combining this energy with other renewable energies, its performance can be optimized. For example, in an optimal geothermal-solar hybrid power plant, solar energy provides 48 % of the total energy. In this case, the Levelized Cost of Energy (LCOE) is reduced from 225 $ per MWh (only with geothermal source) to 165 $ per MWh. In this study, while studying the economic effects of geothermal systems, an attempt has been made to address the challenges in this field and present the policies implemented in some countries. It is implied that by providing incentive policies and an appropriate roadmap, it is possible to help attract investment in the operation of geothermal systems.

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1. INTRODUCTION

To increase human well-being, humans need much more energy. By 2040, population growth and economic expansion will be expected to increase the global energy demand by 37 % compared to the year 2013 [1, 2]. The use of fossil fuel energy leads to threats such as Greenhouse Gas (GHG) emissions, hence global climate change and local climate pollution [3-6]. Renewable energy is one of the key technologies to reduce CO_2 emissions [7,8]. This energy includes wind, solar, and geothermal energies. Meanwhile, geothermal energy is a well-known and reliable energy source with high potential [9-12]. For example, deep geothermal sources are based on hot fluids that are widely used to generate electricity. Figure 1 shows a deep geothermal system. Figure 1a shows the cross-section, and Figure 1b shows the heat source and its interactions with the water cycle [13]. The system has three main components: "magma", which provides heat, "precipitation", which provides geothermal fluid, and "permeable zone", which acts as a fluid transfer medium from deep to near the surface. In this system, the heat stored in the ground is used for the intended purpose, while the shallow heat pump systems provide heating and ventilation without using the heat stored in the ground.

Geothermal energy is generated by a systematic approach that begins with surface surveys followed by subsurface explorations and experiments to investigate and study the geothermal source or reservoir. This process usually takes between 2 and 3 years. It will take another 3 to 5 years for the well field to be built and installed in the power plant. Meanwhile, high investment risk can slow down geothermal development and sometimes, prevent the project from continuing. However, the growing human need for energy has caused greater investment in renewable energy, especially geothermal energy. By 2040, with population growth and economic expansion, global energy demand is expected to increase by 37 % compared to the year 2013 [1]. This study, while studying the economic effects of geothermal systems, has been made to address the challenges in this field and the policies implemented in some countries. The roadmap of some European and Asian countries in this field has also been reviewed.

2. ECONOMIC ASPECTS

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The financial results of exploiting an energy source can be a significant factor in investing in this sector. Factors increasing the investment risk in the field of geothermal energy are given below [14]:

1- Higher investment cost than other renewable power plants;
2- Longer payback time; and
3- Greater uncertainty in the size and quality of resources before completing well drilling operations.

On the other hand, due to its independence from oil and gas, increases a country's energy security, helps create direct, indirect, and induced employment, and affects other economic sectors. Some different economic aspects of geothermal energy are given below:

2.1. Economic sustainability of geothermal power plants

Economic feasibility must be studied for the development of sustainable geothermal systems. There are various methods designed for the economic evaluation of geothermal power plants. One of the most popular methods is the Levelized Cost of Energy (LCOE). This algorithm is used to recover the investment, maintenance, and operation costs of a particular power plant over its lifetime and is defined as the price of electricity. Factors affecting LCOE include investment costs, average power generation rate, power plant life, cost reduction rate, and availability of facilities [15].

A mathematical relation for LCOE is provided by Sheu et al. for hybrid fossil fuel-solar thermal systems [16]:

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{(I_t+M_t+F_t+H_t)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{1}$$

where
I_t: Investment expenditures in the year t
M_t: Operations and maintenance expenditures in the year t
F_t : Fuel expenditures in the year t
H_t: Avoided heat production costs in the year t
E_t: Electricity generation in the year t
r: Discount rate
t : Year
n: An assumed lifetime of the system (integer, in years)

Investment costs represent the main factor in the economic viability of a geothermal power plant. This cost includes surface and subsurface costs. Initial costs and surface exploration, infrastructure design, construction, and operation and site maintenance are part of the surface costs. At the same time, the drilling costs of wells are classified as subsurface costs [17]. Figure 2 analyzes the surface and subsurface costs for the five geothermal power plants installed in Iceland. According to this figure, surface costs are linearly related to the size of the power plant. In addition, the investment costs for unknown fields are higher than the investment costs for known and more informed fields.

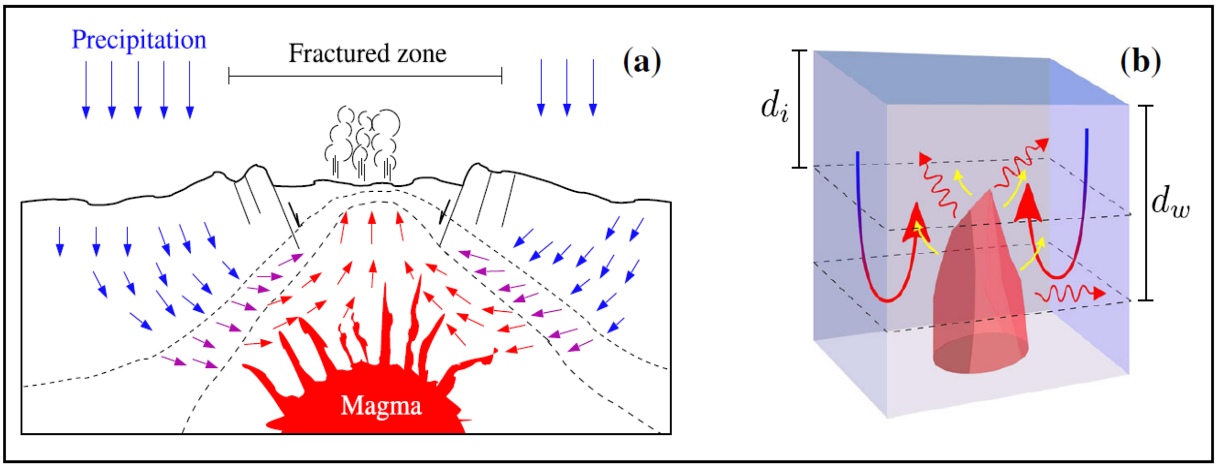


Figure 1. Origin of the geothermal system (a: the components required to form a geothermal system; b: the depth range and heat transfer. d_i (source depth) and d_w (water cycle depth range)) [13]

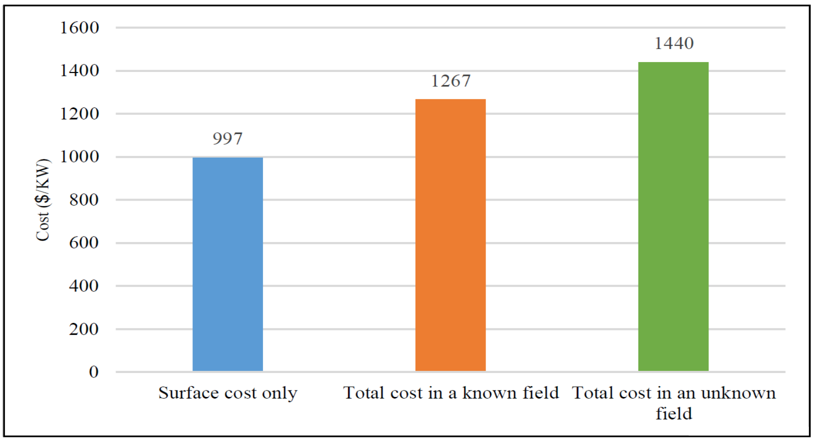


Figure 2. Surface and subsurface costs for five geothermal power plants installed in Iceland [17]

Table 1 also shows the total cost of exploration for the geothermal power plant. This cost varies from one to ten million US dollars.

Table 1. The total cost of exploration for two geothermal power plants with different capacities

Type of cost	Size of power plant (MWs)	Cost	Reference
Total cost	5	1×10^6 €	[18]
	50	9×10^6 $	[19]

The second phase of building a geothermal power plant is drilling several wells to obtain energy stored underground to generate electricity. At this stage, the geothermal power plant infrastructure must be designed and built; in addition, the reinjection and production system and the power plant installation and connection to the power transmission network must be developed. These cases are the three primary parameters at this phase of development. The cost of the reinjection and production system at this stage is between 2.5 and 50 million US dollars depending on the size of the plant [20]. The temperature and chemistry of geothermal reservoirs are also effective in the cost of designing and building the infrastructure of each geothermal power plant [21]. The geothermal reservoir temperature determines the size and price of the geothermal power plant components. Temperature also determines the type of power plant. For reservoirs with a temperature of less than 176.6 °C, a binary power plant, and a geothermal reservoir with a temperature higher than the mentioned one, a single flash power plant will be economical. In this regard, it is necessary to install high-quality materials and apply corrosion resistance, which increases the cost of infrastructure [22]. In geothermal power plants, the mass flow rate and the temperature of the reinjected water decrease over time. This reduction affects the performance of the power plant and economic profitability, which should be considered in its better design and more accurate economic analysis. Also, the ambient temperature of the power plant is constantly changing, which affects the performance of the power plant. It is better to take these changes into account in the design of the power plant.

2.2. Comparison of renewable energies

The International Renewable Energy Agency has compared the costs of different power generation technology with installed areas of different colors in Figure 3 [23]. For example, pale blue belongs to the continent of Asia, while dark blue belongs to the continent of Europe. On the horizontal axis, all types of renewable energy given; and on the vertical axis, their prices in 2016 in $/kWh are provided. As can be seen, the cost of geothermal energy production technology is comparable to those of other renewable energy technologies, and even the equivalent energy cost of South America is lower than those of other renewables.

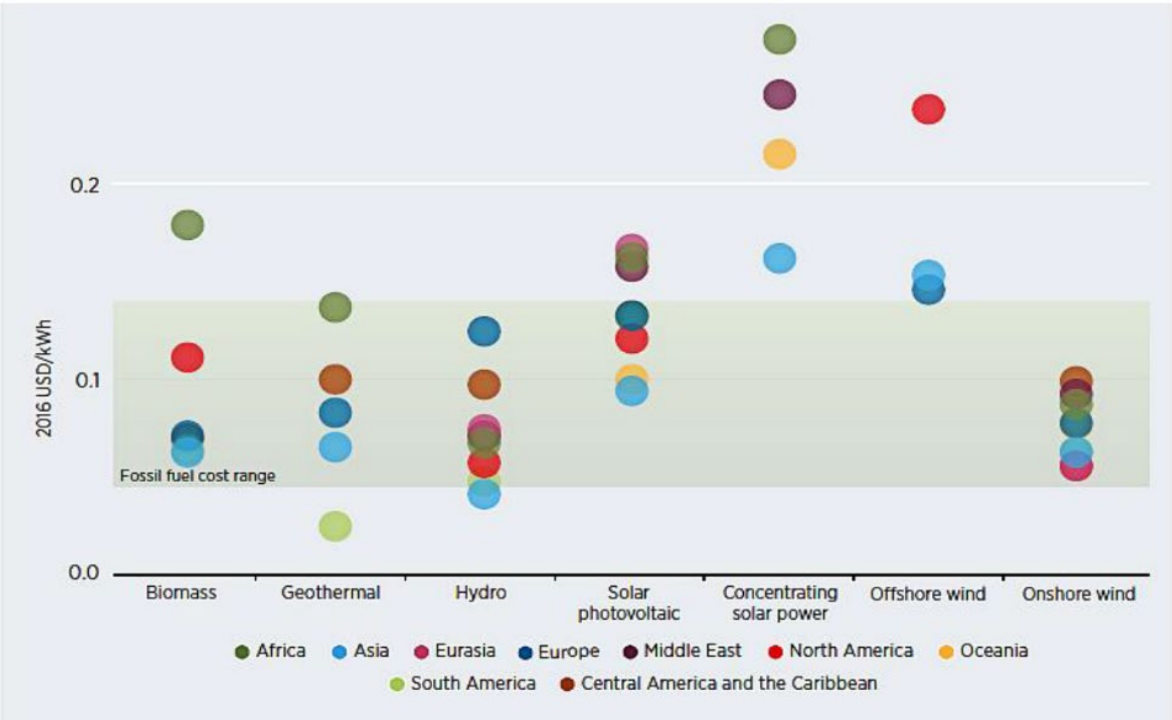


Figure 3. Average levelized costs of different power generation technologies with installed areas [24]

Table 2 shows the payback time and cost of different types of energy [25]. The cost per kilowatt-hour for geothermal energy is very close to the wind, and the costs of the two are higher than water, coal, and gas. However, these costs are significantly lower than photovoltaic (PV) solar power plants.

2.3. Hybrid power plants

Geothermal power plants emit minimal pollution compared to fossil fuels for the same amount of power. Nevertheless, this energy suffers low extraction efficiency. Other energy sources can be combined with geothermal energy to improve its efficiency. This will help reduce operating and investment costs as well as shorten the payback period, thus shortening geothermal energy installations' payback period and tackling high-peak loads [26]. This can be achieved by creating optimal conditions in the composition for each resource. Geothermal energy is usually combined with solar energy. When solar energy provides 48 % of the total energy, system performance is optimized to generate electricity. Considering the LCOE value of 225 $ per MWh only for geothermal sources, this combination is reduced to 165 $ per MWh [25]. Even though many research projects related to geothermal-hybrid systems focus on combining geothermal and solar technologies, there are also a large number of researches on systems using geothermal technology coupled with biomass, wind, biogas, and other technologies. Toselli et al. [27] combined biogas Waste Heat Recovery (WHR) with a geothermal power plant and designed a new hybrid binary plant. They considered the Oberhaching geothermal reservoir in Germany with a total electric power of 4.3 MWel. One of the main objectives of their research was the techno-economic assessment of this hybrid system compared to the conventional geothermal systems. In addition, financial results were provided for the power-only, and power and heat configurations were combined. The lowest LCOE value was equal to 15.42 €ct/kWh and was provided by the hybrid power-only model, while the highest LCOE value was equal to 19.13 €ct/kWh and was found in the geothermal CHP case study [27].

Table 2. Payback period and cost of different types of energy [25]

Type of power plant	Cost ($/kWh)	Payback period (year)
PV	0.24	1-7.2
Wind	0.07	0.4-1.4
Hydro	0.05	11.8 (small), 0.5 (large)
Geothermal energy	0.07	5.7
Coal	0.04	3.18
Gas	0.05	7

2.4. Investment risk

Figure 4 shows an overview of the different phases of geothermal power plant development, project risk level changes, and the cumulative investment cost [28]. As can be seen, at the early stages of surface surveys and exploratory drilling, there is the most significant risk in a new geothermal project. There is considerable uncertainty in the early stages of power plant development regarding temperature and source flow capacity. After drilling and testing the source, this uncertainty is significantly reduced, which provides financial feasibility of investing at later stages of the development.

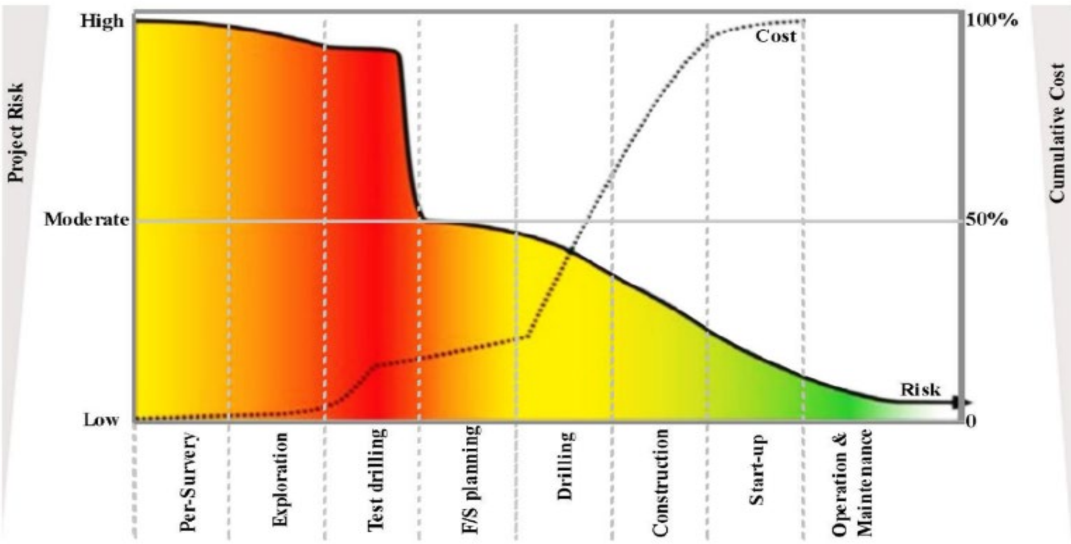


Figure 4. An overview of the different phases of geothermal power plant development and changes in the level of risk and investment cost [28]

3. POLICIES

Geothermal energy enhances a country's energy security, helps create direct, indirect, and induced employment, and affects other sectors of the economy. This energy can improve this security due to its independence from oil and gas, as oil and gas prices are constantly changing. Also, unlike wind and solar energies, it is not dependent on climate change; thus, it has higher reliability than other renewable energies. This reliability will also improve the energy security of countries. Adverse effects of the development of this energy include damage to local lands and grasslands, negative impact on tourist attractions in historical regions and national parks, and the decline of geysers and hot springs. Therefore, it is necessary to consider and manage all cases in implementing and constructing geothermal power plants.

Although geothermal technology has many advantages over other power generation technologies, only about 15 % of the known geothermal resources are currently exploited for electricity production. Two main obstacles that slow down the pace of geothermal development are (1) considerable up-front capital investment required before earning money through electricity sales; (2) the high resource risk at the early steps of the multi-step geothermal project**.** A review of global experience shows that government support in this area contributes to the success of geothermal development. This section discusses some of the approaches and economic policies implemented in different countries to support geothermal development.

3.1. Program of loan guarantee

This policy guarantees the loan given by a third party and is referred to as the guarantor. In this case, if the borrower does not repay the loan on time, the guarantor will pledge to pay the debt. One such policy in the United States is the section 1705 loan program, which was initially financed by 6 billion dolors; however, after the reallocation, that amount was reduced to 2.5 billion dolors. In Germany, there is a program called "Risk of Non-Discovery of Deep Geothermal Energy", according to which, in case of exploration failures, a maximum of 100 % of the loan money is given [29].

3.2. Drilling operation insurance

This type of policy is an insurance policy. By ensuring drilling operations, the risk of drilling failure is paid from the "insurer" to the "insured". Insurance is supported by a reputable investor organization. In this case, the probability of financing by insurers increases. In France, for example, a program called the Geothermal Risk Guarantee System covers 90 % of the cost of drilling the first well. The GeoFund, launched by the World Bank, is designed to facilitate geothermal development in Central Asia and Eastern Europe [29].

3.3. Loan support mechanism

In this case, unlike the previous two cases, loan support directly reduces the cost of investment. In this mechanism, like the loan guarantee mechanism, three parties share the borrower's support: the supporter, the borrower, and the lender. For example, under the Deep Geothermal Discovery Risk Scheme in Germany, loans of 16,800 million euros, or 80 % of eligible drilling costs, are paid to developers to accept exploratory drilling. In Indonesia, a government loan program for exploration operations has been proposed to state-owned companies, private sector, and municipalities [29].

3.4. Grant

Grants are also one of incentive policies that are subject to lower risk than lending and insurance mechanisms. This grant can directly cover a certain amount of project costs or include a share of exploration costs. In the United States, for example, 20 % to 90 % of the costs of exploratory drilling operations for geothermal projects are covered by this policy. In Iceland, up to 50 % of exploration costs are covered by this policy [29].

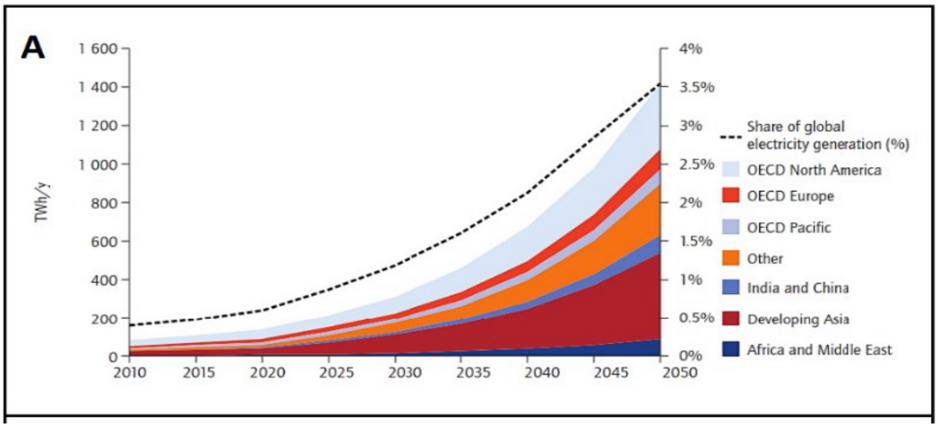
3.5. Exploration under government supervision

In this type of policy, part or all of the exploration costs may be paid by the government under a government-supervised exploration program. In Iran, for example, the Renewable Energy and Energy Efficiency Organization (SATBA) has contracted or directly conducted with several private companies to identify and explore several geothermal sources. There are several reasons for government involvement in identifying and exploring geothermal resources. One of these reasons is the government's willingness to work on a profitable project or investment. Creating energy diversity and reducing barriers to private investment can also be other reasons. Countries such as Japan, New Zealand, and Indonesia have presented various programs in this field [29].

4. GEOTHERMAL ENERGY ROADMAP

A roadmap is an essential tool for the development and maintenance of research activities, as well as an ideal, integrated, and beneficial mechanism for geothermal resources. The roadmap is usually used by DOE technology agencies to create investment, research, and development strategies [30]. DOE's Energy Efficiency and Renewable Energy Office (EERE) emphasizes the improvement of the performance of renewable technologies. The basics of the EERE road map have been modified according to the needs and limitations that geothermal has raised. Given that the ultimate goal of EERE is investment through commercialization in a competitive market, the roadmap is usually based on cost reduction strategies, which define "waterfall" charts to determine key development areas. In particular, this document identifies technological advances that can play an essential role in optimizing and commercializing geothermal. This roadmap builds and evaluates operational techniques/techniques and routes that are relevant to future developments [30].

According to the Hi-RENS BLUE scenario released by International Energy Agency (IEA) in 2011, it is projected that about 3.5 % of the total electricity generation (equivalent to 1,400 TWh) worldwide will be provided by geothermal. More than 50 % of these methods are used for hot dry rock EGS (Figure 5A) [31]. The result of the predictions is that EGS technology and low-temperature sources are the future of geothermal energy. EGS is also expected to play an important role, focusing on research activities [31]. The heat and energy from geothermal in the cold regions are vital. In tropical areas, this energy is also used for industrial applications and spatial cooling using adsorption chillers [31]. Non-electrical applications, or direct use of geothermal energy in northern Europe, are increasing because of the increasing number of geothermal power plants as well as the dual Combination of Heat and Power (CHP) [31]. The use of heat and power is an economical and reliable mix with a clear perspective for the future of geothermal. Figure 5B extrapolates the growth of geothermal heat in various regions by 2050 (total direct use of 5.8 EJ) by removing geothermal heat pumps. CHP and direct use are appropriate for North America, China, and Europe due to their large population; therefore, the most significant developments in geothermal plants are expected to occur in these areas. In general, hot rock EGS technology is expected to be acceptable by 2030 [31].



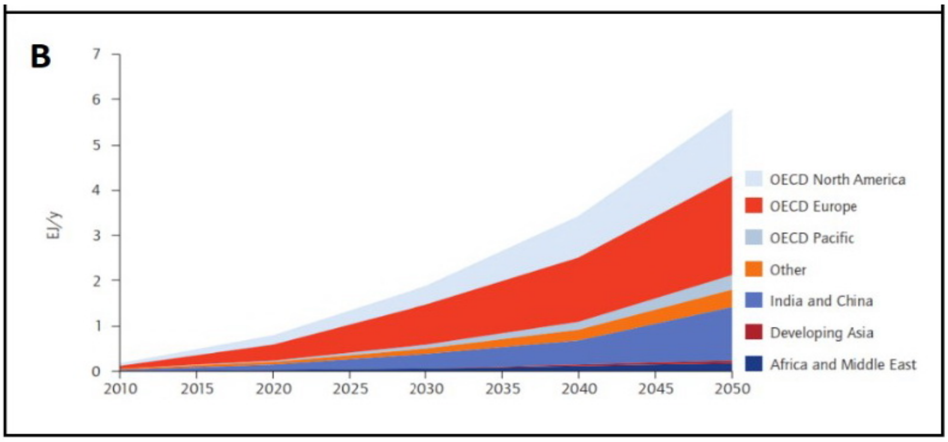


Figure 5. (A) IEA roadmap's vision for geothermal power production until 2050; (B) Future of direct-use geothermal energy until 2050 [31]

In the following, the geothermal energy roadmap for some countries in continents of Europe and Asia is discussed.

4.1. Europe

A pilot study was concluded in 2010 for long-term scenarios and renewable energy development strategies in Germany (BMU 2010 [32]). One of the achievements of this study for the development of geothermal energy was the definition of a scenario for developing the installed geothermal capacity of nearly 300 megawatts by 2020 and 1 GW in 2030. The estimated geothermal heat will reach 8,000 GWh in 2020 (29 PJ) and will be approximately 25,000 GWh (89 PJ) by 2030 [32]. Figure 6 summarizes research and development efforts directed at exploiting geothermal resources for electricity production over ten years for Switzerland, in other words, a geothermal roadmap. Wide exploitation of geothermal energy was achieved by solving two questions: (1) How can an efficient heat exchanger underground generate energy for decades? Moreover, (2) At the same time, is it acceptable to maintain the interference and the risks of earthquakes on the surface? While the public agrees with the possibility of controlling underground resources, these goals are endorsed. The answer to these questions as soon as possible creates three initiatives and innovations:

(A) Advance the ability to model the stimulation process and reservoir operation quantitatively;

(B) Advance process understanding and validation in underground lab experiments;

(C) Perform a petrothermal P&D project, supported by a central scientific monitoring and assessment initiative [34].

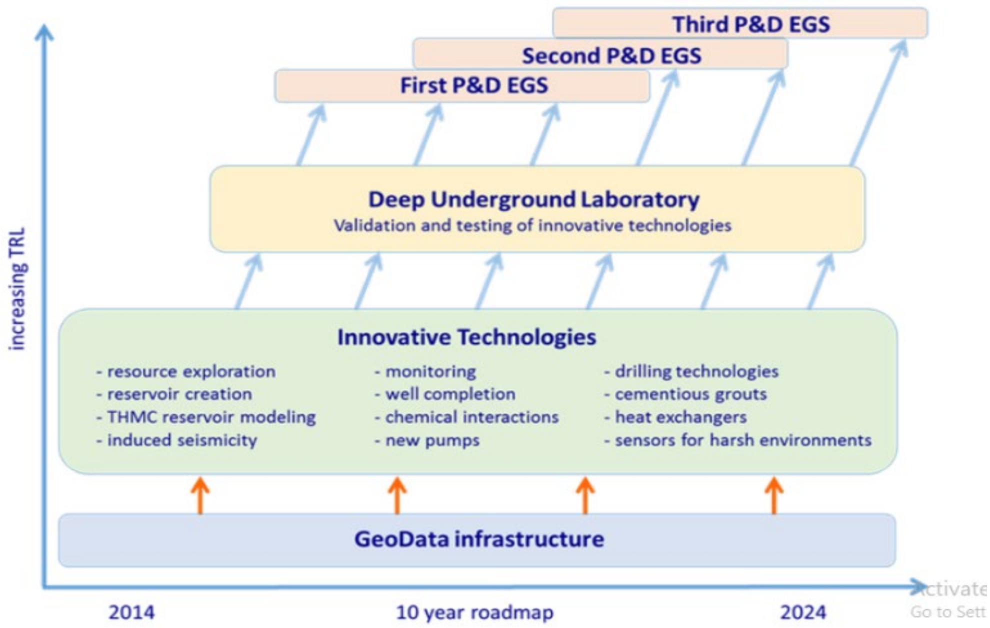


Figure 6. A geothermal roadmap for Switzerland over ten years [34]

A study published by Unione Geotermica Italiana (UGI) in December 2011 concluded that by limiting development to such systems, geothermal electricity of no more than 1,500 MWe and 9 TWh/yr will be obtained in Italy in 2030 (Figure 7); however, if the technology of Unconventional Geothermal Systems (UGS) becomes mature by 2025, it should rise to a maximum of 2000 MW and 12 TWh/yr by 2030 (Figure 8). In such cases, UGS will contribute to the total geothermal energy of Italy in 2030 by more than 25 % [35, 36].

Recent studies by UGI on the possibility of geothermal energy growth in Italy up to the year 2050 have demonstrated that only by using hydrothermal systems in 1500 km^2 above high-temperature areas without the help of the UGS, the projected average increase for the future would disappear by around 2030, after which it would begin to decrease gradually, resulting in a capacity of about 1,200 MW and producing about 7.5 TWh/yr by 2050. On the contrary, the UGS must be technically mature by 2025 and their commercial exploitation begins to generate electricity; they will primarily deal with the reduced production of hydrothermal systems and the production of a combination of hydrothermal systems plus UGS to by 2050, about 3000 MWe and 18 Wh/yr. Of this total, ~ 1800 MWe and ~ 10.5 TWh/yr belong to UGS only. That is thre reason why the long-term increase in geothermal energy in Italy depends mainly on the technical-economic feasibility of exploiting geothermal systems other than traditional hydrothermal systems [35].

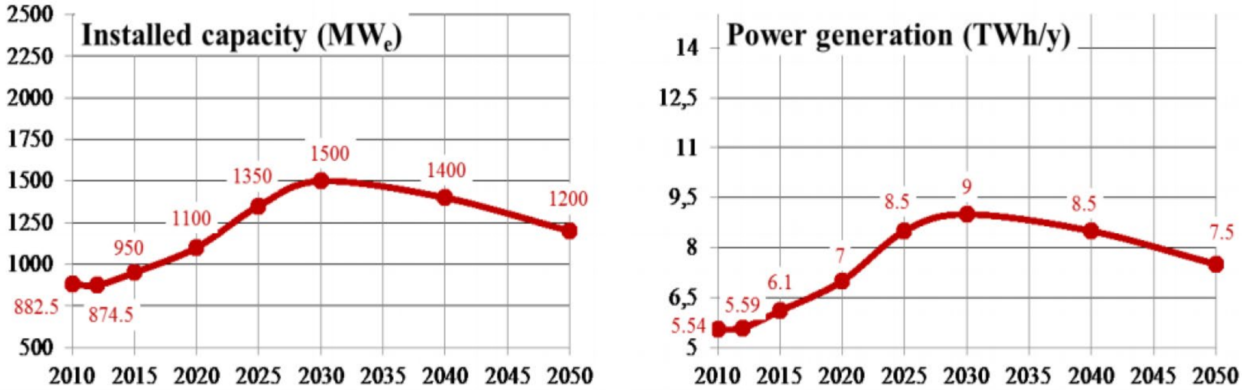


Figure 7. (A), (B). Development of installable capacity and producible energy until 2050 by harnessing hydrothermal systems only according to the best possible growth scenario in Italy [35]

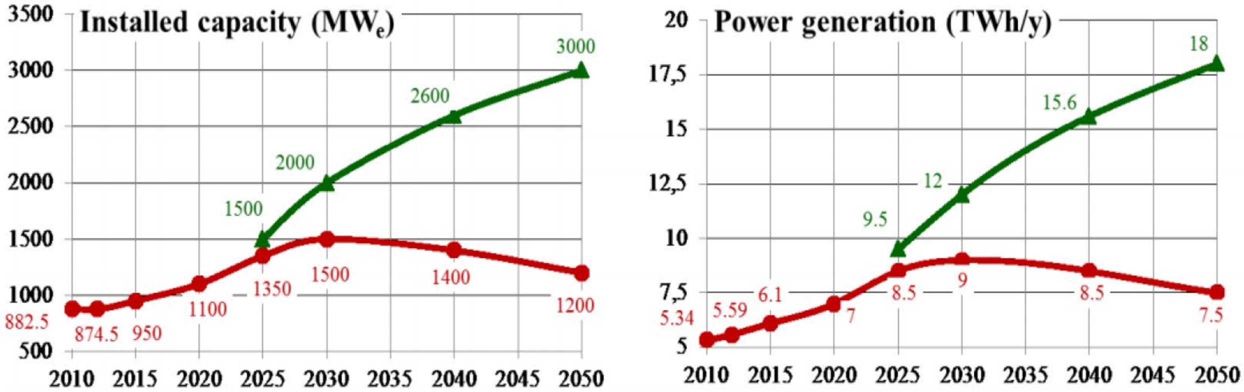


Figure 8. (A), (B). Development of installable capacity and producible energy until 2050 by harnessing hydrothermal systems according to the best possible scenario, jointly with one or more UGS/Unconventional Geothermal systems [35]

The trends in the geothermal market (electricity generation and heating) in 2010-2020 are shown in Table 3 for the European continent. This information is provided by the Member States at the NREAP. The latest update (data for 2015 and 2014) is provided by European Coal and Steel Community (EGEC) [37].

Table 3. 2010-2020 Trends in geothermal power installed capacity (GPIC) (MWe), geothermal heat production (GHP) (ktoe), and geothermal heat pumps (G-HP) (ktoe) in the EU. Countries not reported in the figure have not reported [38]

Item / Country	Year	GPIC	Year	GHP	G-HP	Item / Country	Year	GPIC	GHP	G-HP
France	2010	26.5	2010	98.2	271.1	**United Kingdom**	2010	N.A.	0.8	21.7
	2017	17.1	2014	125.7	261.6		2014	N.A.	0.8	56.6
	2020	80	2020	500	570		2020	N.A.	0	95.3
Spain	2010	0	2010	16	N.A.	**Bulgaria**	2010	N.A.	32.7	N.A.
	2017	0	2014	18.8	16.4		2014	N.A.	33.4	N.A.
	2020	50	2020	9.5	40.5		2020	N.A.	9	N.A.
Germany	2010	10	2010	51.7	246.2	**Romania**	2010	N.A.	21.1	N.A.
	2017	38.19	2014	91	334		2014	N.A.	25.1	N.A.
	2020	298	2020	686	521		2020	N.A.	80	8
Italy	2010	754	2010	139.3	44.2	**Poland**	2010	N.A.	13.4	3.1
	2017	915.5	2014	129.6	70.18		2014	N.A.	20.2	8.4
	2020	920	2020	300	522		2020	N.A.	178	N.A.

Austria	2010	1	2010	20.5	N.A.	**Sweden**	2010	N.A.	N.A.	N.A.
	2017	1.2	2014	19.4	N.A.		2014	N.A.	N.A.	8.03.3
	2020	1	2020	40	26		2020	N.A.	N.A.	815
Greece	2010	0	2010	16	N.A.	**Finland**	2010	N.A.	N.A.	N.A.
	2017	0	2014	11.7	N.A.		2014	N.A.	N.A.	133.8
	2020	120	2020	51	50		2020	N.A.	N.A.	N.A.
Croatia	2010	N.A.	2010	6.8	N.A.	**Ireland**	2010	0	N.A.	N.A.
	2017	N.A.	2014	10.7	N.A.		2017	0	N.A.	N.A.
	2020	10	2020	15.7	N.A.		2020	5	N.A.	N.A.

4.2. Asia

The distribution of low-temperature geothermal resources in China is more than other sources. Therefore, it is essential that energy be generated at a low cost and on a large scale. In the five-year Chinese geothermal plan, a significant progress has been made in low-temperature geothermal technology. The next step, which is vital to this five-year program, is improving system performance and expansion. In addition, the cost of construction and operations is reduced [39]. The geothermal energy roadmap for the 15 years in China is depicted in Figure 9.

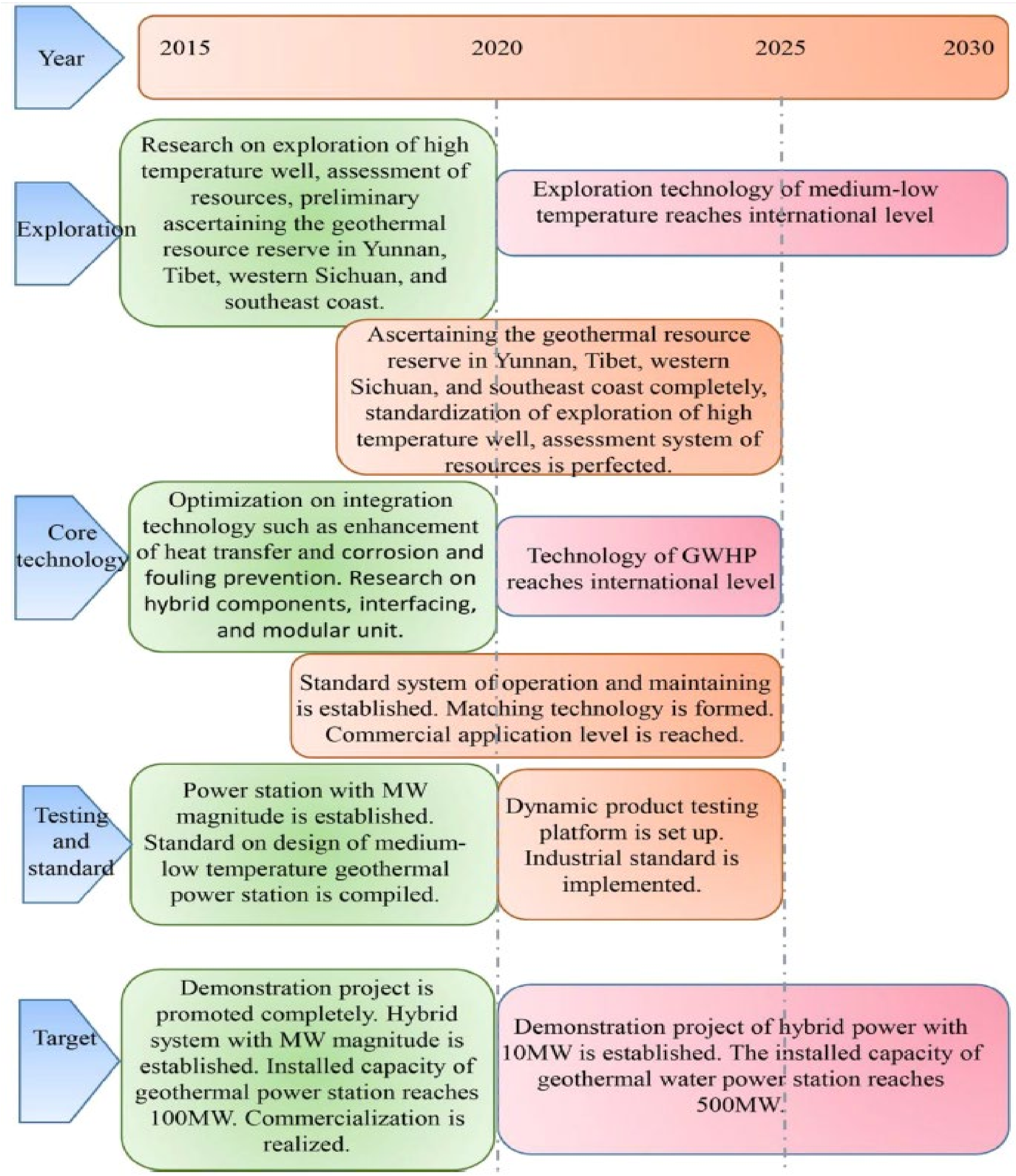


Figure 9. Geothermal power generation roadmap in China [39]

In Iran, since 1995, several promising areas (Figure 10) have been identified by SUNA (Center for Renewable Energy Research and Application) throughout the country [40, 41]. The country's national electricity grid is close to 85 GW, of which about 95 % is due to the burning of fossil fuels. Given this level, it will not be easy to achieve a significant share of the country's total energy production by geothermal energy. The Iranian government welcomes the development of renewable energy and geothermal resources to offset the solid economic dependence on the export of fossil fuels. Given that geothermal resources can be adjusted and developed, they can play an essential role in the future of Iranian energy.

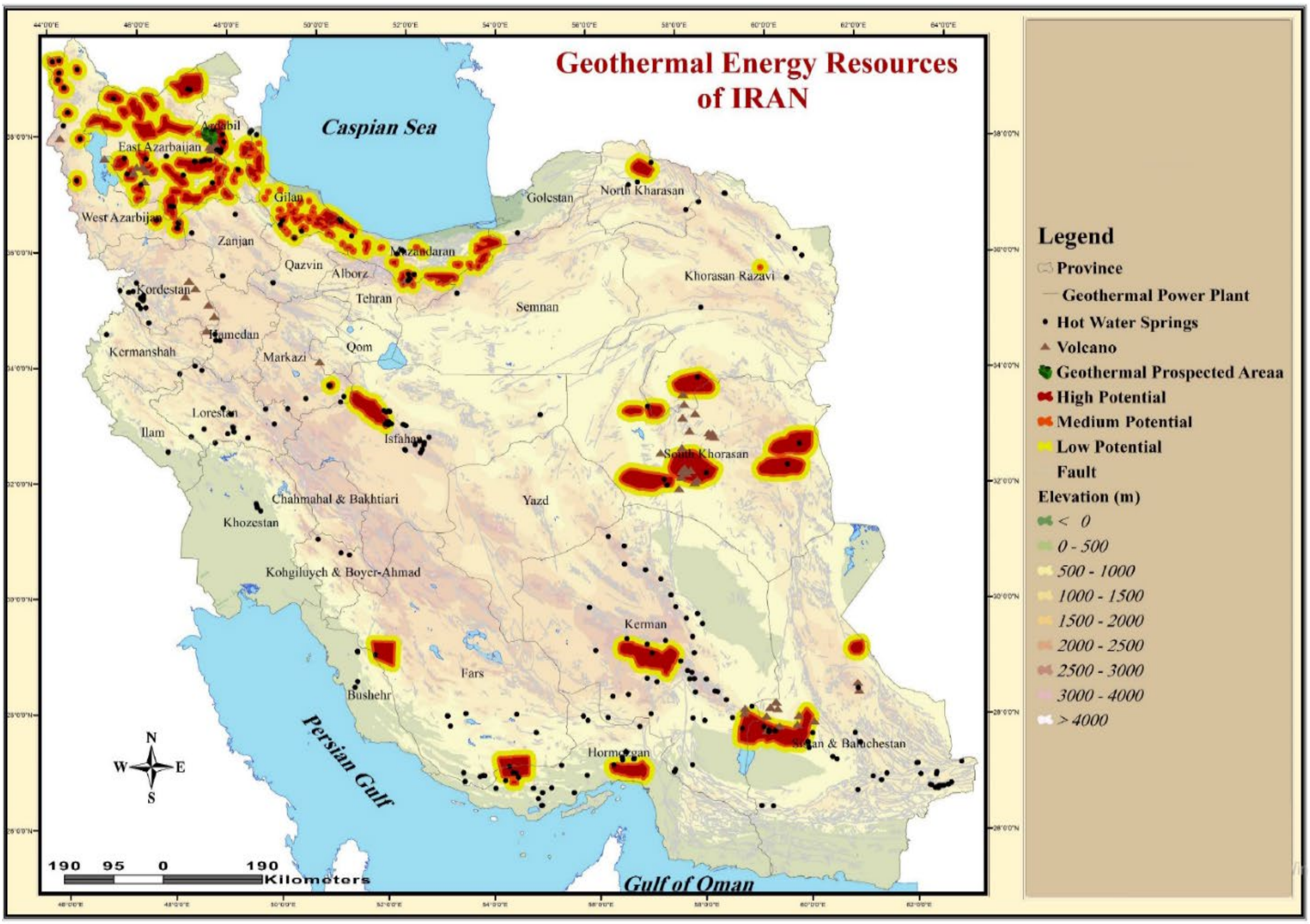


Figure 10. Map of the geothermal prospected area in Iran [55]

According to the above description, due to the geological conditions and the presence of many potentialities of geothermal energy, the lack of high-tech equipment inhibits the growth of this energy source. The association studies in northwestern Iran point to the ability of Meshkinshahr to install a geothermal power plant. The main objective of the project is the discovery and construction of a 55 MW geothermal power plant, which is expected to be operational in the coming years and will produce 410 GW by using high technology [42-50]. The latest information shows that the construction of the first pilot plant is now running with a capacity of 5 MWe, the produced fluid temperature of 86 °C, and a maximum flow rate of 58 l/s (average flow rate: 46 L/s) in the NW Sabalan Site [51-54].

The active subsidy program and special mandatory law in Korea allow geothermal applications and GHP utilization to increase to over 100 megawatts a year in the next few years [56]. Geothermal power generation is expected to increase by EGS over five years. The active participation of industries and commercialization is on the rise. However, it is currently under the influence of the lack of a legal framework to support the production of geothermal power. The regulatory framework of the Renewable Portfolio Standard (RPS) with Renewable Energy Certificates (RECs) monitors geothermal activities. A technical solution to reducing GHGs in Korea will produce 200 megawatts of geothermal capacity by 2030, one percent of the technical capacity [57]. The result of the EGS project, if successful, is a milestone to building a roadmap which is expected to increase from 5 to 10 MW over the next few years. 2000 MW is the estimated geothermal resource potential of Japan. Currently, the total power generation is 500 MW. Experts have provided a roadmap for various ways to overcome the barriers to geothermal energy development [58]. Technologies expected to reach over 1,000 MW of geothermal power in Japan by 2050 include commercialization of magma power generation and hot dry rock (HDR) power generation. It is necessary to increase the number of researchers for enhancing electricity production. Technical development and road mapping can help secure geothermal energy and prevent accidents (Figure 11) [58].

The MEMR (Ministry of Energy and Mineral Resources, 2012) of Indonesia has established a geothermal development roadmap from 2006 to 2025. Its goal is to develop 9,500 MW in total by 2025. The government has issued EMR No. 21/2013 administrative regulations as an incentive for the development of geothermal energy based on geothermal power plants projects [59].

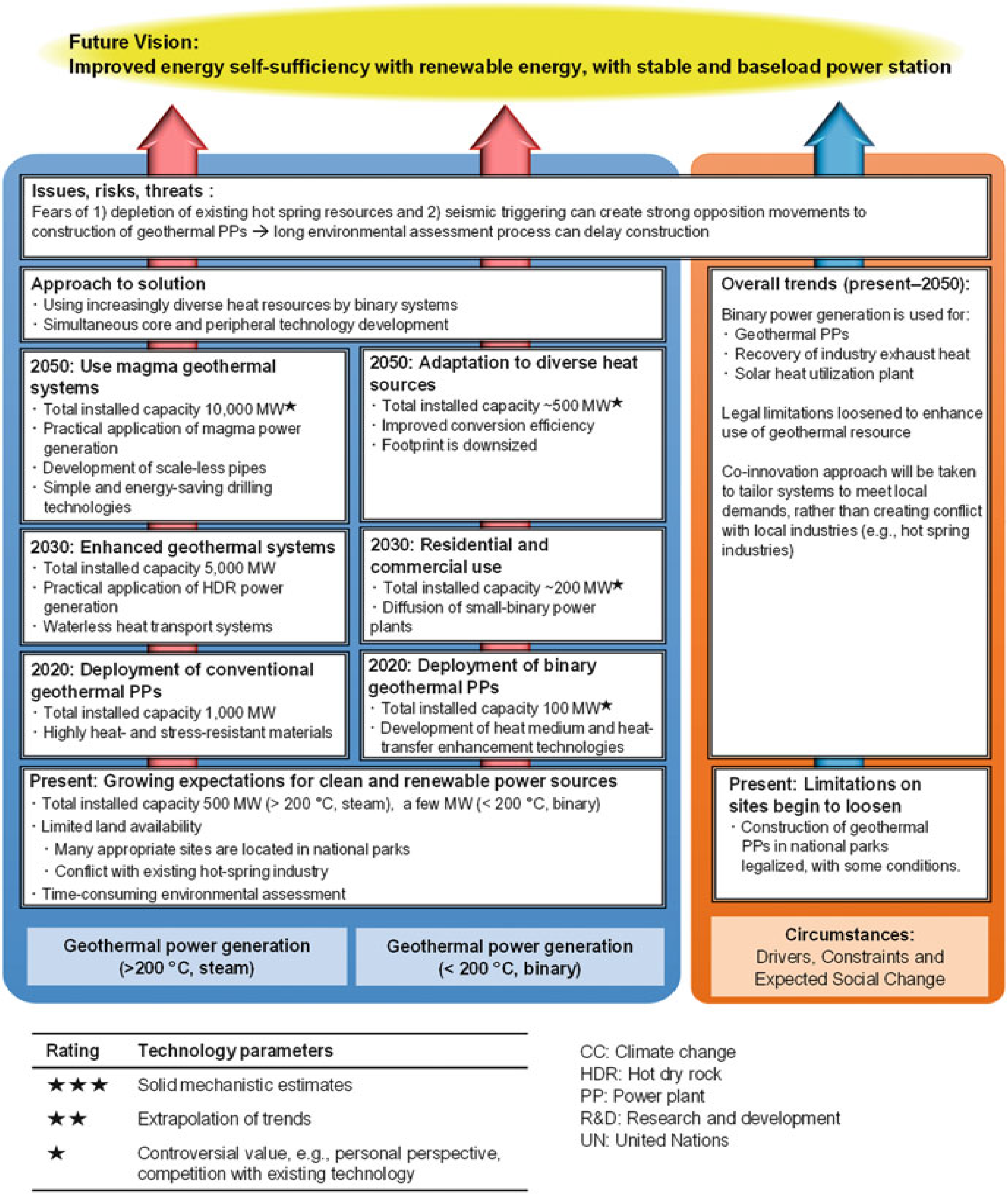


Figure 11. Technical development and road mapping for geothermal energy in Japan [58]

5. CONCLUSIONS AND FUTURE RECOMMENDATION

Various studies related to the economic analysis of geothermal systems were reviewed in this study. Geothermal power plant construction consists of several phases, each with different costs. The highest cost is related to the well drilling operation phase, while the lowest is related to the prospecting and exploration phases. There are two main barriers for slowing the development of the geothermal resources: 1. significant pre-earnings investment; 2. high resource risk at the early stages of a geothermal project. While the environmental damage caused by fossil fuels has not been accounted for, geothermal and other renewables such as bioenergy, onshore wind, and hydroelectric power are able to compete with fossil fuels. Furthermore, geothermal energy has a more extended payback period than wind, PV, hydro (large), and coal. Geothermal energy projects have positive and negative effects. They can positively affect energy security as well as direct, indirect, and induced employment. They can also have adverse effects by altering local lands used for grazing or hunting, damaging local historical areas or national parks, and destroying natural features such as hot springs and geysers. Considerable up-front capital investment, high drilling costs, and high resource risk are the main obstacles that slow down the pace of geothermal development.

By providing incentive policies to investors and researchers in this field, the development of geothermal resources can be promoted. Some of the most crucial incentive policies that currently exist in some countries and international forums include "Loan Guarantee Program", "Drilling Operations Insurance", "Loan Support Mechanisms", "Grant", and "Exploration under government supervision". It seems that by presenting other encouraging and profound policies in this field, it is possible to help attract investment in the operation of geothermal systems. A roadmap is an essential tool for the development and maintenance of research activities. Also, it is an ideal, integrated, and beneficial mechanism for geothermal resources. The roadmap is usually used by DOE technology agencies to create investment, research, and development strategies. In this study, the roadmaps of several countries from Europe and Asia, including Switzerland, Italy, China, and Japan, were presented schematically, and an overview of the geothermal potentials of several countries from these two continents was presented. Along with proper management, it is necessary to prepare a proper roadmap to illuminate the future of geothermal energy so that appropriate decisions can be made. The roadmap provides a strategy for advancing geothermal systems and sets goals for optimizing energy with the technical advancement required. The development of geothermal energy with current technologies shows that technological advances are associated with improving the economic sector of the geothermal project and reducing risk. Consideration of cost reduction, technical development of geothermal projects, and sustainable production of geothermal reservoirs are all essential to achieving sustainable development in geothermal energy. Exploring geothermal resources, global investment, and feasibility of projects depends on technology development in the next few years. Using the suggestions of other researchers active in this field and investing in Research and Development (R&D) in the next few years can pave the way for the development and progress of geothermal projects. Geothermal energy technology is expected to be economically competitive with other energy sources by 2050.

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