Success rates of petroleum and geothermal wells and their impact on the European geothermal industry

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Abstract

Geothermal energy, as a renewable resource is already used since more than 2000 years. Hence the rapidly increasing experience with this energy resource, new deep geothermal applications are still under debate in politics and public, especially in European countries. Investments are often missing or investors retract their financial support due to the unsecure political situation. Despite all debates, the quantity of geothermal applications is steadily increasing in e. g. Germany over the last three decades.

Taking only German deep geothermal applications into account, a total of 31 systems were running, 34 more were still in the planning phase and a total of 34 were canceled due to various reasons. Of the canceled ones, the majority was shut down for missing investments, uneconomic operation or political reasons. Engineering issues and low discharge only summed up to approx. 21% of the canceled operations, which leads to the assumption, that neither drilling nor geological exploration and planning is a main failure reason for such projects.

Furthermore in this study shows, that the success rate of geothermal drillings is remarkably high and also exceeds success rates published by the petroleum industry. Also, success rate is not bound to the geology of the explored reservoir, nor to the drilling depth needed for exploitation and indeed was improved significantly over the past decades.

In fact, most internationally available data for success rates are derived from high enthalpy systems, in which geothermal resources are explored more efficiently than for low enthalpy systems e.g. in European countries.

By a single deep but slim exploration well prior to any production wells, reservoirs can be investigated and their potential evaluated. Such cheap exploration wells can significantly reduce the project risk due to better understanding of the reservoir and therefore shift main investments to a project phase of significantly lower risk.

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Zusammenfassung

Geothermische Energie, als erneuerbare Energie, wird von der Menschheit bereits seit mehr als 2000 Jahren genutzt. Trotz der schnell wachsenden Erfahrung im Umgang mit dieser Ressource sind tiefengeothermische Anwendungen noch immer unter Diskussion, sowohl auf politischer, als auch gesellschaftlicher Ebene. Dieser Widerstand ist besonders in Europa stark ausgebildet. Investitionen in geothermische Projekte sind selten und oft werden aufgrund der politischen Lage Finanzierungen zurückgezogen. Trotz aller Schwierigkeiten steigt in den letzten 30 Jahren die tiefengeothermische Nutzung in Deutschland stetig.

Allein in Deutschland sind insgesamt 31 tiefengeothermische Projekte in Betrieb, 34 weitere sind in Planung. Stand 2015 wurden jedoch auch insgesamt 34 Projekte aufgrund verschiedenster Gründe gestoppt. Die Mehrzahl dieser Projekte wurde wegen mangelnder Investitionen, einem unwirtschaftlichen Betrieb oder politischen Beweggründen abgebrochen. Ingenieurtechnische Probleme, sowie geringe Schüttungsraten wurden nur bei ca. 21% der Projekte als Abbruchskriterium genannt. Aufgrund dieser geringen Zahl lässt sich die Annahme treffen, dass weder die geologische Exploration noch die ingenieurtechnische Planung Hauptgründe für Misserfolg sind.

Weiterhin zeigt diese Studie, dass die Fündigkeitsquote geothermischer Bohrungen relativ hoch ist und zum Teil die publizierten Fündigkeitsquoten der Erdöl und -gasindustrie übersteigt. Es wird gezeigt, dass das Fündigkeitsrisiko nicht an geologische Gegebenheiten oder der maximalen Endteufe geothermischer Bohrungen gebunden ist und sich über die letzten Jahrzehnte deutlich verbessert hat.

Allerdings stammen die meisten der verfügbaren Daten aus Hochenthalpiesystemen, in denen ein der Erdölindustrie ähnelndes Explorationskonzept angewendet wird und die Erschließung neuer geothermischer Reservoire im Vergleich zu europäischen Niedrigenthalpiesystemen vergleichsweise einfach ist. In Hochenthalpiesystemen wird die Exploration meist durch eine, oder einige wenige günstige Explorationsbohrungen durchgeführt. Erst bei Fündigkeit dieser Explorationsbohrungen werden die teureren, großkalibrigen Produktionsbohrungen abgeteuft, wodurch das Hauptinvestitionsvolumen in eine Projektphase geringen Risikos verschoben wird.

1 Introduction

Geothermal energy is a renewable energy source with continuous natural repowering by the terrestrial heat flow of 50 to 100 $mW{\cdot}m^2$ for the continental crust. The usual working fluid water has an excellent heat capacity and is thus a very efficient medium to extract the heat from the ground. Geothermal springs are used by humanity since more than 2000 years already for heating, medical, spa, health and wellness purposes. This has continuously increased the experience of the treatment of hot and saline waters. Nowadays, geothermal utilization is oriented on the local requirements and the geological conditions and is the only renewable energy source able to deliver power, heating and cooling at once. Depending on the enthalpy of the reservoir either electricity or heat production is in the focus. High enthalpy reservoirs with temperatures of 200 to 350 °C at depths of 1 to 2 km are suitable for power production with dry steam, single, double or triple flash systems of tens to hundreds of MWe capacity, but are mainly restricted to active volcanism or active plate boundaries (e.g. Iceland, Philippines, western USA, Italy etc.). Where no active volcanism or plate boundaries are present mainly low enthalpy reservoirs like deep sedimentary basins or the crystalline crust can be used for geothermal heat or power production by hydrothermal or enhanced geothermal systems (EGS). There the temperatures are usually in the range of 100 to 200 °C at depths of 2 to 6 km and a typical geothermal doublet, consisting of one production and one injection well, rarely exceed thermal capacities of more than 20 to 40 MW_{th} and electrical capacities of binary power plants of more than 5 MW_e.

In central Europe this is represented by small power or heating plants embedded in the landscape and the urban environments. But also by various shallow geothermal utilization for the affordable heating of single houses or small district heating networks. For industrial users geothermally powered district heating is getting more and more interesting as the prices are competitive to conventional heat sources.

On a worldwide scale, the investment costs per installed MW_e geothermal capacity still varies drastically between various geothermal applications and countries (Gehringer & Loksha 2012). For example, the installation of 1 MW_e geothermal capacity (Binary system) in Germany costs more than twice as much as the installation of the same capacity in the USA (Tab. 1). This is mainly due to the availability of large scale drilling rigs, costs of the drill rig personnel and to national regulatory conditions, which have a

Recent Projects	Investment, M€/MWe			Energy Production Costs, €/kWh		
	Flash	Binary	EGS	Flash	Binary	EGS
USA	2.7	3.1	6.2	0.055	0.060	0.100
Indonesia, New Zealand, Philippines	2.3			0.044		
EU		4.5	11.6		0.090	0.200
Germany		6.5			0.100	
Chile	3.6			0.072		
Turkey	2.75			0.063		

Tab. 1: Comparison of investment and energy production costs for different geothermal systems worldwide (after Gehringer & Loksha 2012).

severe impact on the environmental and safety regulations resulting in the application of more costly drilling techniques.

Nonetheless, geothermal applications in European countries are on the verge to reach growth rates competing with international rates. In Germany non-respective of the high investment costs the installed heat capacity generated by deep geothermal applications steadily increases since 1984 with ascending rates since 2004 (Fig. 1). At least for Germany, the installation of thermal capacity for geothermal district heating is growing much faster than the electrical capacity. This is due to the actual development of mainly low enthalpy reservoirs with temperatures of 100 to 150 °C at depths of 2 to 4 km, which still cover a very significant contribution to the energy transition towards renewable resources. Compared to other renewables geothermal energy is still only a fraction of the total installed capacity and it is a critical endeavor to further boost the development of the promising geothermal resources, which will still need a significant amount of time and more important of investments.

Contrary to its potential, in Germany especially deep geothermal applications are often heavily under debate during their planning, construction as well as operational phase in both, politics and public. In consequence of such difficulties, investors are often afraid to invest and retract their investments in deep geothermal projects. On the other hand, it is likely that projects are shut down due to political issues.

The willingness to invest in geothermal projects is directly linked to the promised success rates and to the development of the risk during the project development. It thus has to be a priority of the geothermal scientific community and the project developers to reduce the risk as early as possible for a relative small fraction of the total project cost. A significant reduction of the risk is usually only possible by drilling exploration wells or based on existing wells drilled in the

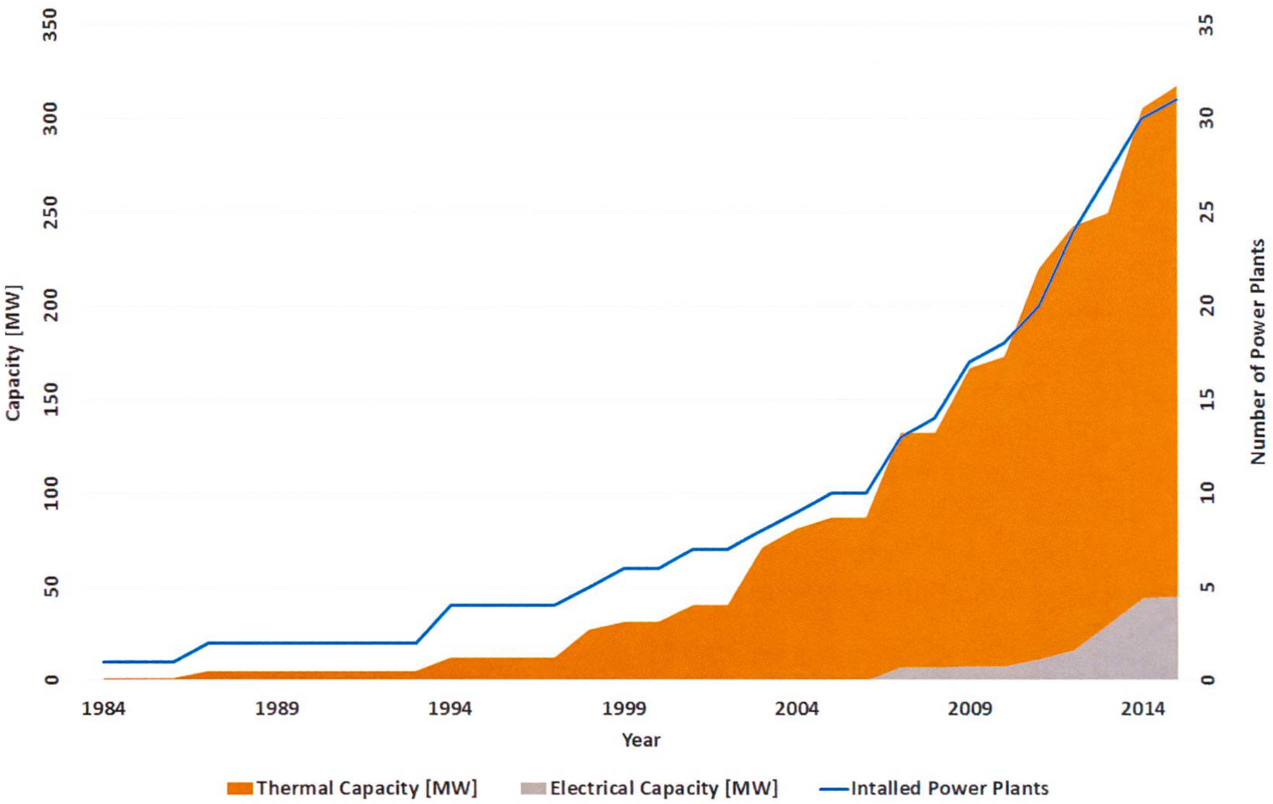

Fig. 1: Installed geothermal capacity generated for heat and power generation by geothermal power plants in Germany, data from GTV (2015), WFG (2015).

same reservoir, whose results allow for a sound evaluation of the geothermal reservoir potential.

2 Geothermal Systems Worldwide

Compared to petroleum reservoirs geothermal systems are, as described above, much more diverse. A classification is thereby made by reservoir temperature, depth and reservoir permeabilities. Depending on the system (high enthalpy hydrothermal system (flash or dry steam), low enthalpy hydrothermal system (binary or district heating) or enhanced geothermal systems in originally impermeable bedrock (EGS)), the amount of exploration necessary and the actual development of exploitation of different reservoir types highly varies in e.g. engineering effort, investment and exploration risk.

In an international comparison of 2613 geothermal wells (IFC 2013), which represent more than 70% of 2011th installed worldwide capacity, it is shown that the majority of geothermal wells do not reach more than 3 km in depth with a slight peak for system depths of 1.5 to 2 km. In case of German geothermal applications, which are not covered by the IFC-study, the average depth of operating systems and systems under construction is approximately 2.8 km, whereas the newly planned systems reach an average depth of 3.6 km (data of GTV 2015, constituted until April 2015). At this point, one legitimate assumption is, that success rates of drillings decline the deeper the drilling is. That assumption could be based on the higher effort needed for exploration or just the increasing technical difficulties in deeper drillings.

3 Geothermal Situation in Germany

In 2015 31 deep geothermal systems were operational, six systems under construction and 34 were in planning (Fig. 2, GTV 2015, WFG 2015). As a result of a literature study, 34 deep geothermal systems were found to be cancelled by various reasons. The data base of reasons for such cancellations is rather rare, but it was found that the majority of such cancelled projects failed due to missing investigations (approx. 30%) as well as political issues (about 15%, including postponing of projects after political elections, angst of bad reputation or expiring concessions). Approx. 18% of the cancellations were due to an uneconomic operation.

As shown in Figure 2 engineering difficulties (like constructional issues or drilling problems) caused only approx. 7% of the cancelled deep geothermal projects in Germany. Low discharge rates are the reason for approx. 15% of the failed applications until 2015. The relatively low fail rates caused by geotechnical or engineering flaws already indicate that the drilling success rate of geothermal wells must be considerably high, which may be caused by the intensive exploration due to the high drilling costs and thereby high investment shares of the drilling (approx. 70% for EGS; EGEC 2011) compared to the project in total. Such high shares of drilling costs are due to the large depth of the drilling operations. In IFC (2013), the international investment share for drilling operations of a geothermal project only averages to 35-40%.

Commonly, citizens' initiatives will form as a geothermal project starts to be planned, not often leading to some of the failure-criterions listed in Figure 2. But not only such initiatives but also the vague financial situation often leads to protracted planning and construction processes as well as obstacles which either need to be solved politically or technically. Nonetheless, every delay hits the political angle of geothermal projects and often also increases the necessary investment.

Furthermore, prospective risk insurances are often either denied or negotiations with various insurance brokers are postponing the drilling operation as happened in i.e. Geltingen (ITG 2015). In some areas where the available exploration data or data from operating projects are just deemed insufficient by the insurance companies, prospective risk insurances are not possible at all, resulting in higher financial risks for the investors.

In Germany, deep geothermal projects comprise of a quite long exploration phase, usually not including exploration drillings, followed by the first and second drilling, which usually have to serve two purposes: exploration on the one hand and exploitation later on (blue curve in Fig. 3). This results in two problems: very high drilling costs due to the large well diameters needed for later production or injection at a project status where the risk is still considerably high due to only indirect exploration methods in the first project phase.

If this multi-purpose first well is not successful, the investor has lost a large amount of money or a high fraction of the estimated total project costs without any significant payback. This high risk, high cost effect significantly reduces the bankability of geothermal projects in Germany. As demonstrated by the petroleum industry, by the geothermal industry and by the small fraction of drilling related issues (7%) as a reason for the cancellation of deep geothermal project, drilling is a manageable, approved and advanced technology. The main project risk is connected to the reservoir-geological knowledge obtained during the exploration phase.

If investors and project developers would be willing to live with slightly higher total project costs and to include a comparatively cheap exploration drilling in the early phase of the project (black curve in Fig. 3), the risk could be significantly reduced at an early stage of the project and more importantly prior to the drilling of the cost-intensive drilling of the injection and production wells. This approach would include the lessons learned by the petroleum industry within the last 50 to 100 hundred years,

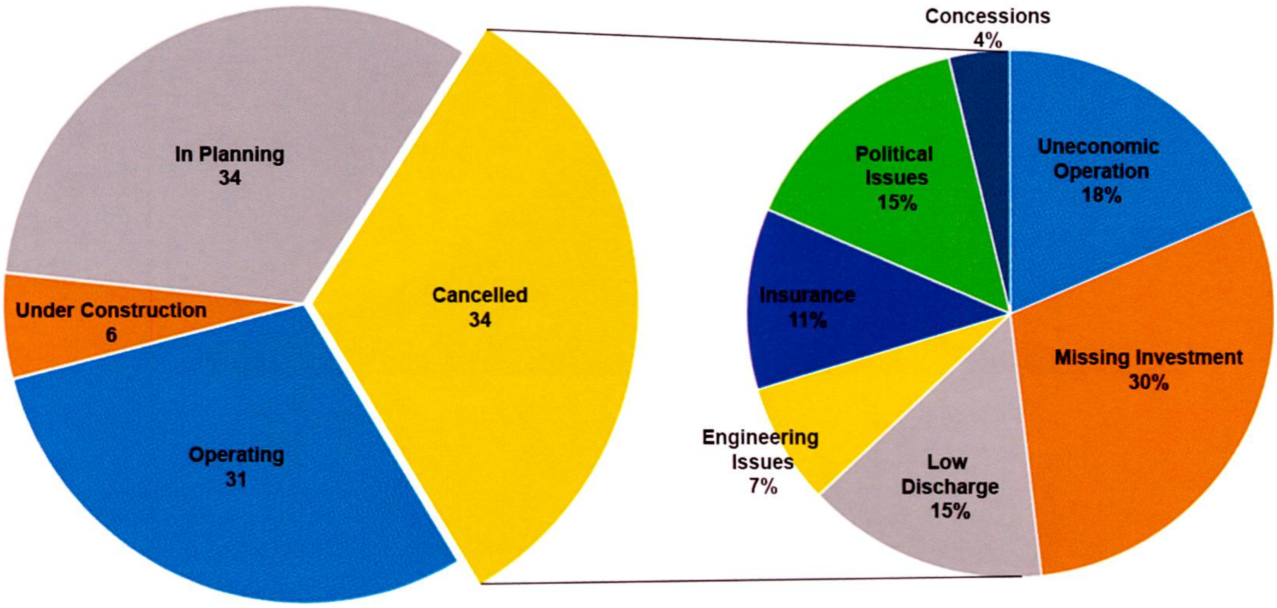

Fig. 2: Status of deep geothermal projects in Germany (left) and reasons for geothermal project cancellations in Germany (right). Data based on literature study with input data of GTV (2015), WFG (2015), Geo-T (2015), IGA (2015), ITG (2015).

where exploration drills are a normal part of the exploration phase and a main requirement for the planning of the actual exploitation.
Anyhow, as shown in the following section success rates of geothermal drillings, both worldwide and in Germany, are quite impressive already and one would expect that the public or investors perception of deep geothermal energy should be quite opposite to what it is nowadays.

4 Success Rates of Geothermal and Petroleum Drillings

Specific data for drilling success rates is rare and not easily accessible. In petroleum industry success rates are often stated as an overall value for their annual exploration and production drillings. This available data is considered in a comparison between geothermal drillings and drillings of the petroleum industry as shown in Figure 4. For geothermal applications such data is even more rare since there are no global players in geothermal power like e.g., in petroleum industry, who operate worldwide and with a high quantity of wells.

As basis of the success rates of geothermal applications, IFC (2013) mined a database of 2613 drilling distributed over 14 countries. Approx. 17% of the investigated wells are constructed in high enthalpy steam fields (230-240°C) and more than 50% in systems

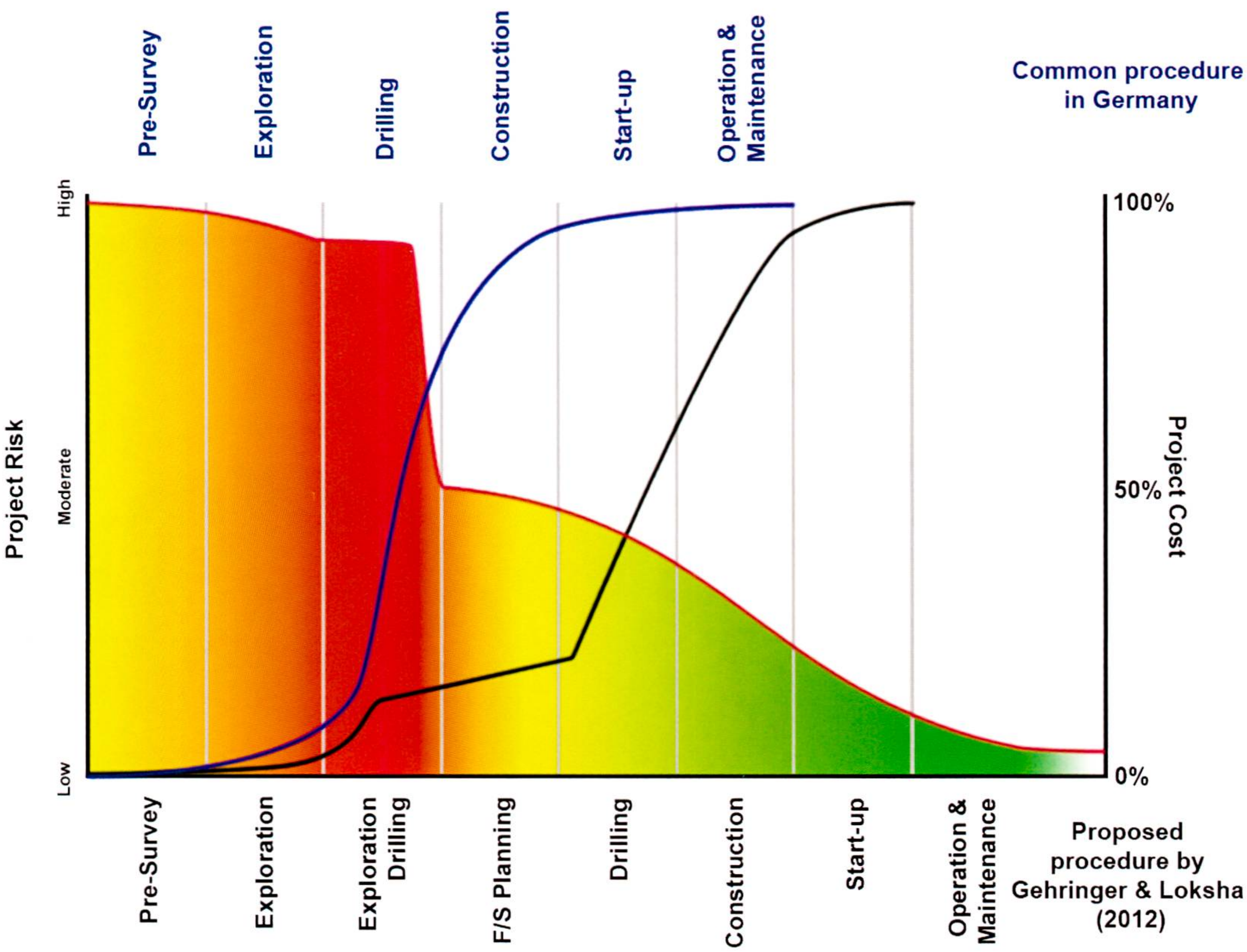

Fig. 3: Comparison of the cost development and project phases of deep geothermal projects as proposed by Gehringer & Loksha (2012) in black font and black curve and the cost development and project phases reflecting the actual common procedure of deep geothermal projects in Germany in blue font and as blue curve in correlation to the development of the project risk. The further the project proceeds the higher the bankability becomes.

with temperatures higher than 230°C. Further, Sanyal and Morrow (2011) studied the success rate of the high enthalpy Kamojang field (approx. 80 wells) in Indonesia and at The Geysers field in California, USA, stating wide ranges of success rates during different project states. In a second study of Sanyal and Morrow (2012), 1112 geothermal wells, distributed over 52 individual geothermal fields, were evaluated according to their success rate, documenting an average success rate of 71%. Further, Sanyal and Morrow (2012) state that the success rate in drillings varies between 33 to 100% with a majority in the range of 60 to 80%. The study of Shevenell (2012) is exclusively focused on geothermal drilling of a total of 16 powerplants in Nevada, USA.

As mentioned in IFC (2013) and Sanyal and Morrow (2011), the term «success rate» for geothermal drillings is not clearly defined whether a drilling is successful when it achieves the engineering aspects or if it is profitable. Success rate should be replaced by a quotient of cost per MW in future.

For the success rate of the petroleum industry, data of several companies were analyzed. Eni for example, drilled 60 exploration wells during 2012 and a total of 351 development wells as 56 exploration wells and 407 production wells were drilled in 2011 (Eni 2011, 2012, 2015). Richmond Energy Partners (REP 2015) states a success rate of 35% for approx. 1100 exploration wells drilled during 2009 to 2013 in 64 different countries. Engie (former GDF Suez, GDF Suez 2015) performed 14 exploration and exploitation drillings in 2014 of which 10 were successful, leading to a success rate of 56% for 2014. Since 2001, a total of 209 wells were drilled, with an average success rate of 60% (for both, exploration and exploitation wells) between 2010 and 2014 (GDZ Suez 2015). No rate for an overall success rate is stated. Nonetheless, for a direct comparison, different geological backgrounds as well as engineering approaches need to be considered such as onshore – offshore systems in petroleum industry.

As shown, provided data is often for specific geothermal fields only or confined to areas and countries of high geothermal activity such as Indonesia, Philippines or New Zealand. In such high enthalpy fields, exploration is commonly comparable to procedures in petroleum industries, which is an exploration phase with less successful drillings for field investigation followed by highly successful production drillings on basis of high exploration effort. Such exploration and exploitation procedures diverge highly from such from most low enthalpy European geothermal projects with only two exploitation wells, as described above.

Exempli gratia in deep geothermal applications in Germany drillings most often subjected to multiple purposes, e.g. the exploration drilling is also the exploitation well, which reduces the success rate of production wells drastically. In IFC (2013) it is also shown, that the success rate increases by the number of drillings in a geothermal field. Majority of provided data is gained on fields with more than 10 single drillings.

5 Conclusion

Drilling success rates of geothermal applications are, in a context of a worldwide consideration, comparable to the overall success rates of petroleum applications. Based on the evaluated data however, the drilling success rate of geothermal drillings is still slightly higher both for exploration and exploitation wells compared to petroleum drillings. For high enthalpy geothermal systems, exploration approaches of both industries are also quite similar, i.e. a geophysical exploration and a couple of exploration wells followed by production wells. Such an approach seems to be fruitful in terms of high success rates, especially for the production wells, but is not considered in low enthalpy systems like present in most European countries yet.

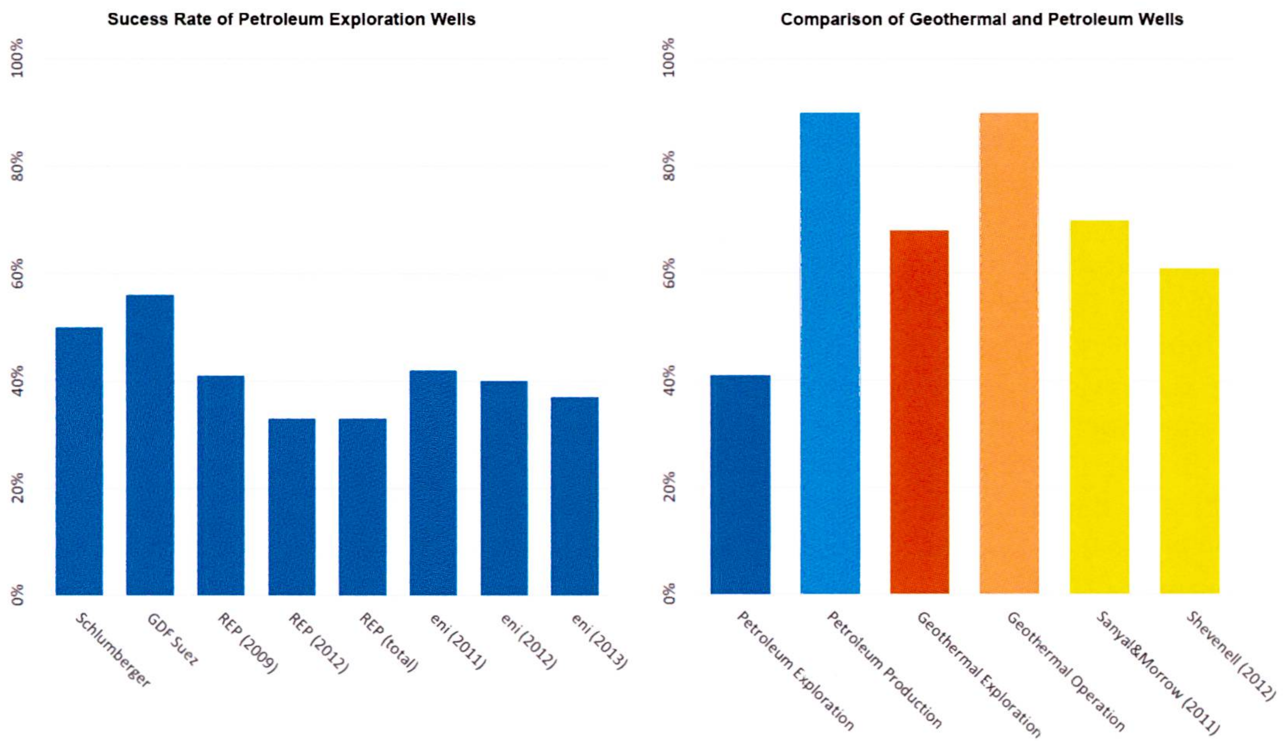

Fig. 4: Success rates of petroleum exploration wells (left) and direct comparison to success rates of geothermal wells (right). Data based on literature study with input data from Alfaro et al. (2007), GDF Suez (2015), REP (2014, 2015), Eni (2011, 2012, 2015), IFC (2013), Sanya & Morrow (2011, 2012) and Shevenell (2012).

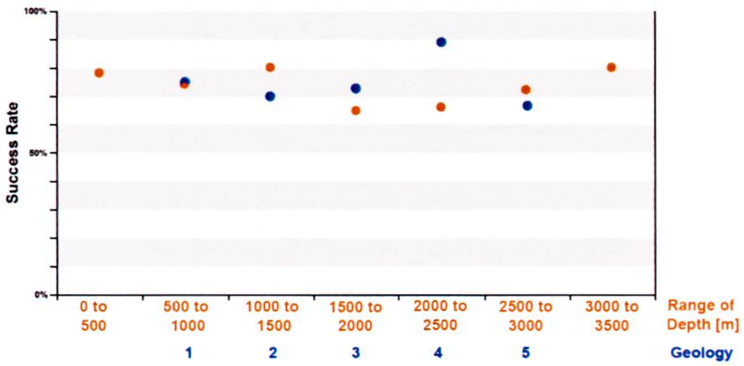

Fig. 5: Success rates compared to depth ranges (orange) and geology (blue; 1 = Granitic/higher-grade metamorphic, 2 = Tertiary and older volcanic/volcaniclastic (large-scale volcanic structures absent), 3 = Younger volcanic/volcaniclastic (large-scale volcanic structures preserved), 4 = Sedimentary basin (clastic, drilled above basement), 5 = Sedimentary basin (clastic, wells drilled into basement)). Data and classification according to IFC (2013), modified after IFC (2013).

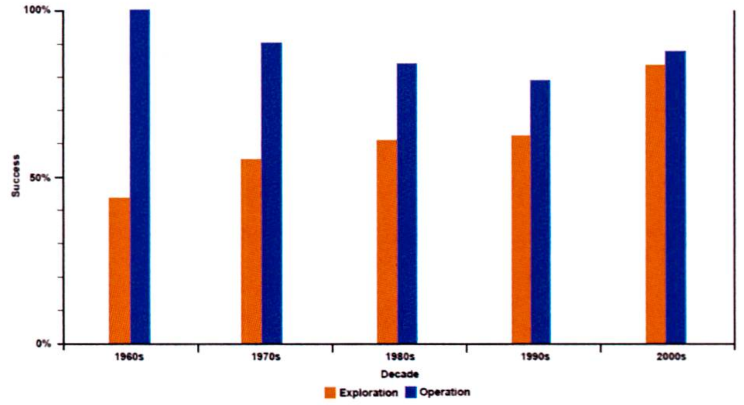

Fig. 6: Success rates of geothermal drillings over the past decades. Modified after IFC (2013).

Nonetheless, for European countries, no comprehensive data set that could be analyzed is available yet, but the data set provided for worldwide geothermal applications shows, that the success rate does not strongly react to either drilling depth or geology (IFC 2013, Fig. 5).
As shown in Figure 6 the success rate also increased over the past decades, at least for exploration wells, which is an expression of progressing drilling technology and the impact of advanced geophysical exploration methods.

Altogether, geothermal wells are compatible with success rates of petroleum industries and most often even excel them with excellent success rates of 80% and more. Besides that, geothermal applications still lack financial background to compensate dry production wells and the willingness to include exploration drillings reaching same depths as the planned production well at early project phases. Reflecting that to the European geothermal situation, it is highly recommend to treat geothermal power as a resource distributed in larger volumes or fields, which then need to be explored by a couple of exploration drillings. This requires the cooperation of the different concession holders in a certain geological environment (e.g. the Upper Rhine Graben in France, Germany and Switzerland). As shown in this study, such exploration wells massively increase the success rates of production wells. Therefore, geothermal fields need to be explored in a larger scale, like some of the high enthalpy systems in e.g. New Zealand or Indonesia, to finally be systematically exploited.

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