ORKUSTOFNUN
National Energy Authority

Geothermal Policy Options and Instruments for the Andean Region

Based on Icelandic and International Geothermal Experience

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Publisher:
Orkustofnun, Grensásvegi 9, 108 Reykjavík
Tel: 569 6000, Fax, 568 8896
Email: os@os.is
Website: http://www.nea.is/

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Geothermal Policy Options and Instruments for the Andean Region, is published on the Orkustofnun website.

OS-2015-06

ISBN 978-9979-68-503-6

July 2015

Table of Contents

Introduction

This report was done in cooperation with the Ministry for Foreign Affairs and based on information from International Renewable Energy Agency (IRENA), workshop held 4-5 March 2013 in Reykjavík, Iceland. The task of this work was to prepare a geothermal strategy document on how Peru, Chile, Bolivia, Ecuador and Colombia, herewith referred to as the Andean Region, could overcome the identified barriers to the development of geothermal energy in specific areas, in cooperation and with support from international organisation in this field.

During the workshop the country-specific geothermal background studies were reviewed and country representatives provided additional input. Subsequently, geothermal development barriers were identified and country-specific roadmaps developed by country representatives. There is broad consensus on the general strategy for geothermal development but the implementation must be adapted to the natural and social environment in each country. The World Bank has issued a thorough geothermal handbook on planning and financing power generation. The main objective of that handbook is to provide decision makers and project developers with practical advice on how to set up, design, and implement a geothermal development program. Geothermal projects are risky and capital intensive, and the key elements of geothermal development are: (ESMAP, 2012)

- ✓ availability of sufficiently accurate geothermal resource data,
- ✓ effective and dedicated institutions,
- ✓ supportive policies and regulations and
- ✓ access to suitable financing for the project developer.

On a global level, diverse types of renewable and geothermal policy tools, implementations and incentives have been used, individually or in parallel, and the policies have also changed during time both in developed and developing countries. The report focuses also on geothermal global development. In most countries geothermal development has taken a long time. The methodology is well known but must be adapted to circumstances in each country. Generally, the first projects must be publicly or donor-supported to prove their viability and reduce the risk to a level that attracts new investors.

Countries considering development of geothermal resources can learn from the experience of other countries which have been applying this methodology in their development strategy over decades. This report uses examples from global and Icelandic geothermal lessons learned for development of geothermal projects. The first attempts of direct use of geothermal heat in Iceland for district heating, date some 80 years back, but generation of electricity with geothermal steam has been escalating over the last 40 years. The report focuses on 3 main areas and subchapters:

I. GLOBAL GEOTHERMAL EXPERIENCE

1. The development of the geothermal sector worldwide.
2. The development, competitiveness and risk of geothermal projects.
3. The international development and financing of geothermal projects.

II. GEOTHERMAL RESOURCES IN THE ANDEAN REGION

4. An overview of geothermal prospects in the Andean Region.

III. GEOTHERMAL DEVELOPMENT AND EXPERIENCE IN ICELAND

5. Development of district heating in Iceland.
6. Development of geothermal electricity generation.
7. The legal, institutional frameworks experience in Iceland.
8. Competitiveness, internationalisation and clusters of the Icelandic geothermal sector.
9. Important capacity building factors in the geothermal sector.
10. Conclusion on the development in Iceland and lessons learned.

Executive Summary

There is no simple formula for success for any country, neither in the area of geothermal development, or in other area of industrial activity. However, through the history of experience, failures and success within countries and regions, lessons learned can be used as valuable milestones and steps towards successful geothermal policy and implementations, energy security, economic savings, growth, jobs and quality of life. The report focuses on three subjects:

i. Global Geothermal Experience,
ii. Geothermal Resources in the Andean Region
iii. Geothermal Development in Iceland.

The geothermal resources in the Andean countries are evaluated against a criterion of geothermal competitiveness to highlight the main challenges and opportunities of the geothermal sector. The results can be used in combination with lessons learned from global and Icelandic experience, to develop policy for the Andean countries from early to late stage of geothermal development. The key conclusions and recommendations are as follows:

I. Global Geothermal Experience

The main lessons learned on global level are:

1. **The policy on geothermal development must be based on assessment of the conditions in each country.**
2. **A properly structured policy system is critical for success.**
3. **Volume is not the same as efficiency.**
4. **Policy tools should be well coordinated and harmonised.**
5. **Policy and regulatory design are dynamic processes.**
6. **Key factors for competitive geothermal policy and renewables must be identified.**
7. **Support schemes for geothermal development are important and valuable.**

II. Geothermal Resources in the Andean Region

The geothermal resources in Andean countries should be examined in the light of these seven criteria:

1. **Authorities and Regulatory Factors.**
2. **Industry, Companies – Projects.**
3. **Scientific and Technical Factors.**
4. **Educational and Human Factors.**
5. **Access to, and cost of Capital.**
6. **Infrastructure, Access to Markets, Sectors and Clusters.**
7. **Access to International Markets and Services.**

Improvement in each country within the sectors of these criteria is essential for a successful geothermal development. It is also important to link the challenges and opportunities in these countries to global lessons learned and cooperation with international geothermal and financial experts.

III. Geothermal Development and Experience in Iceland

Following elements of policy priority have been valuable and important regarding the geothermal development:

1. **Awareness raising among policymakers, stakeholders and municipalities.**
2. **Education and capacity building.**
3. **Evaluation of geothermal resources.**
4. **Promotion of geothermal power generation and district heating projects.**
5. **Development of legal and regulatory framework.**
6. **Financial support to early stage development and exploration.**
7. **International cooperation, geothermal and financial expertise.**

Iceland has more than 80 years' experience of geothermal development adapted to these priorities and has reached a share of renewables in total primary energy use of 85%.

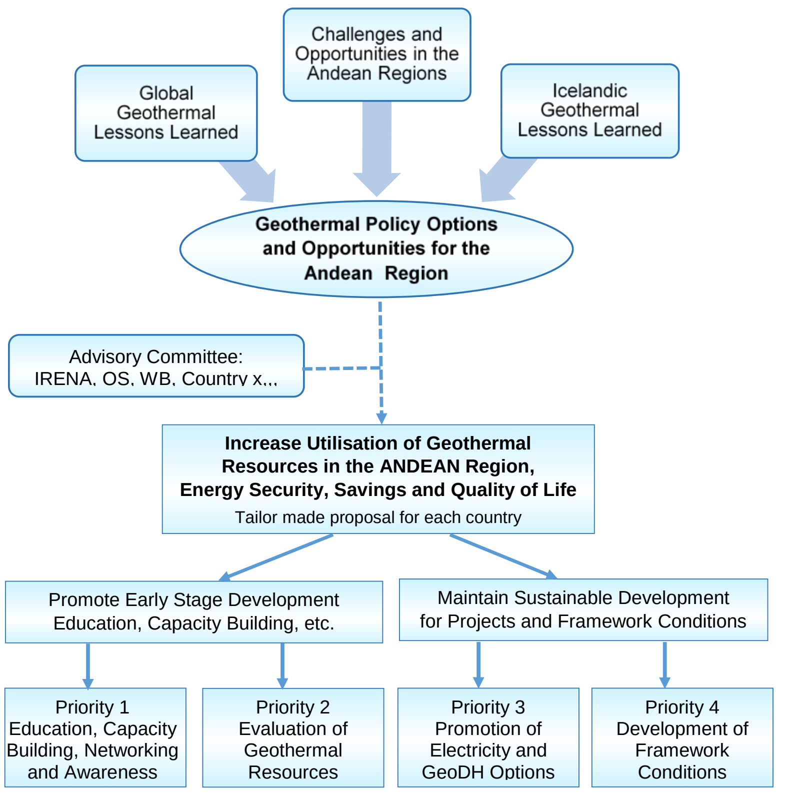
IV. Opportunities and Policy Options for the Andean Regions

Key elements in the development of geothermal energy and financing of renewable energy projects throughout the Andean region, depend on international cooperation of these countries with the most experienced geothermal countries, stakeholders, internationals financial institutions and donors. Successful country projects depend also on global lessons learned, and challenges and opportunities in the Andean region, as well as tailor made policy priorities for each country. The general recommendation for the Andean region is as follows:

1. **An independent policy based on assessment and conditions in each country.**
2. **Awareness raising among policymakers, stakeholders and municipalities.**
3. **Support schemes for the geothermal development.**
4. **A properly structured policy system, is critical for success.**
   a. **Education capacity building, networking and awareness.**
   b. **Evaluation of geothermal resources.**
   c. **Promotion of geothermal power generation and district heating.**
   d. **Development of framework conditions and possibilities.**
   e. **International cooperation, geothermal and financial expertise.**

In this report, Icelandic and international lessons learned have been highlighted in combination with geothermal challenges and opportunities in the Andean region. Figure 1 illustrates how additional work and planning could be organised in cooperation with relevant stakeholders.

Figure 1. **Geothermal Policy Options and Opportunities for the Andean Region**



Source: Orkustofnun (OS) (National Energy Authority), Iceland

Iceland has utilised renewable resources to improve the standard of living with success, by improving energy security and providing substantial economic savings, for the economy and consumers for more than 80 years. Hopefully Iceland can assist others to benefit from that experience in one way or another, including in cooperation with IRENA.

However, for more detailed policy recommendation and implementation for each country, more consultations and a planning process is needed in cooperation with the concerning countries, and international bodies, (WB), to establish geothermal and financial resources and expertise, see also chapter, 4.7, and 8.1.

Iceland has benefitted from utilising geothermal resources, both for district heating and electricity. The savings from geothermal district heating alone from 1982 – 2013 is equal to 64 billion Isk. (412.000.000 €) per year, or 800.000 Isk (5.160 €) per family (4 persons), or about 70.000 Isk. (450 €) per month per family, after taxes. Furthermore, the CO_2 savings by using GeoDH have been around 1.5 million tons per year from 1990 – 2010 or 20 tons per family (4 persons). Cumulative savings during 1990 – 2010 are about 35 million tons, or 440 tons per family. This example demonstrates that there are opportunities of substantial benefits for countries by implementing a successful geothermal policy. For more summary information see chapters, 1, 4, 4.7, 8.1, 9 and 10.

I Global Geothermal Experience

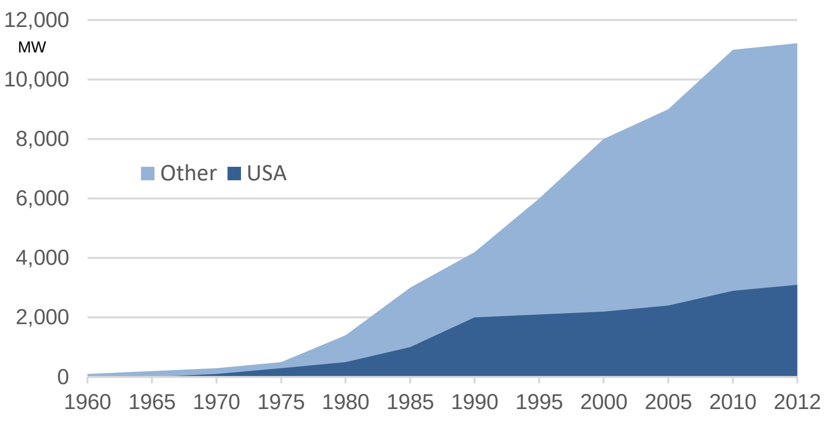
1 Development of the Geothermal Sector Worldwide

1.1 Overview and Challenges of the Geothermal Sector

International Trend in the Geothermal Sector
Since 1990 the global geothermal power market has continued to grow substantially and much more than the US geothermal market. Geothermal energy generated twice the amount of electricity as solar energy did worldwide in 2010 and approximately 11.224 MW of installed geothermal power capacity was online globally in May 2012.

Growth of the geothermal market is driven by a number of factors such as: economic growth, especially in developing markets; the electrification of low-income and rural communities; increasing concerns regarding energy security and its impact on economic security, reducing greenhouse gas emissions, harnessing natural resources and improving quality of life.

Figure 1.1.1. **Installed Geothermal Electric Capacity in USA and Globally, 1960 – 2012**



Source: International Market Overview Report, GEA,

Furthermore, the majority of the growth in the development of global geothermal resources is occurring in countries with large, untapped, conventional resources. As more countries recognize and understand the economic value of their geothermal resources, their development and utilization becomes a higher priority.

Although South America has enjoyed economic growth for the past decades, due to the development and exportation of its oil and gas resources, economic and diplomatic issues surrounding the flow of energy across borders have had adverse impacts on the economies of South American countries. For example, Argentina cut off the supply of natural gas to Chile in mid-2004; and a transmission line built a few years ago to connect Peru and Ecuador has rarely been used due to disagreement on electricity price. In addition, energy use and demand is growing in South America and is projected to increase by 72 percent through 2035, according to the EIA.

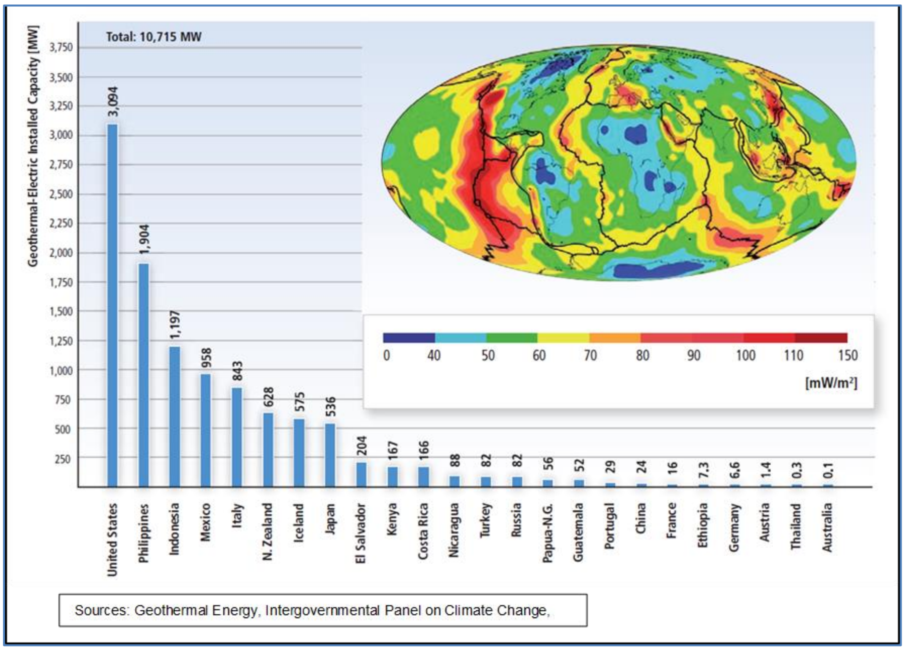
Climate change issues are also an additional factor leading many of these (and other) countries to seek development of renewable resources. The melting of Andean glaciers, changing rain patterns and decreasing water supply have negatively impacted local agriculture and residential patterns. The United Nations expect that Latin American countries will be severely affected by climate change, despite the fact that the region's greenhouse gas emissions represent a small proportion of total global emissions.

To respond to these challenges regarding energy security and its impact on economic security, in addition to increasing demand, many countries including countries in South America have taken steps towards increasing domestic energy security by supporting the development of their renewable energy resources, including geothermal resources.

By utilising geothermal resources, countries in South America are able to use an important and valuable opportunity to meet energy needs with a sustainable form of energy, particularly along the Andean Mountain Range and the Southern Part of the continent.

Experienced international companies in the renewable sector are also showing interest in developing South America’s geothermal resources in cooperation with domestic stakeholders. These companies are partnering with domestic companies, bringing local understanding to the project as well as making development more feasible. (Geothermal: International Market Overview Report, 2012).

Figure 1.1.2. **Geothermal-Electric Installed by Country 2009 and Worldwide Average Heat Flow**



In 2013, the international geothermal sector has been growing at a rate of 4% to 5%, with new plants in United States, Philippines, Africa and Europe, with additional 530 MW of power online around the world, which is the greatest addition in one year since 1997.

There were also about 700 geothermal projects in 76 countries under development globally in 2013. Many countries are expecting that the threat caused by climate change will increase recognition and the awareness of the value and opportunities of geothermal power as a base load and sometimes flexible source of renewable energy. These projects and counties are on every continent and range from small island nations to large economies like China or the United States.

There were approx. 12.000 MW in the pipeline globally in 2014 and about 30.000 MW of geothermal resources under development. Of those 12.000 MW 9evelis. 16% are already under construction in 15 countries, and there seems to be a steady stream of new projects and opportunities emerging. If all geothermal power plants under construction are completed on schedule the global geothermal industry could reach 13.450 MW of nameplate capacity by 2017.

Over the next 5 years significant growth is also expected in the global geothermal power industry, due to construction of power plants in Kenya and Ethiopia that have a capacity greater than 100 MW. In comparison the average size of a geothermal power plant in the United States is about 25 MW.

In Central and South America, countries such as Chile, Argentina, Colombia and Honduras, have significant amounts of geothermal potential, but are still in the early stages of exploring and identifying their resources. It is likely (estimated by GEA) that geothermal resources can be identified for electricity generation in these countries in the near future, e.g. Chile is actively developing 50 early-stage projects and prospects and Bolivia two projects. (GEA, 2014).

1.2 Renewable / Geothermal Policy – Options and Instruments

Growing Importance of Geothermal Policy

It is recognised that renewable energy including geothermal energy, plays an important role in the transition towards greater energy security and has impact on economic benefits and safety, reduction of greenhouse gas emissions, enhancing technology diversification hedging against fuel price volatility, strengthening economic growth and employment, promoting rural development and reducing poverty by access to electricity.

Global trend is also indicating growing commitment to renewable energy, in developed and developing countries, both regarding specific policy instruments and flow of investment in that sector. The growth of renewable energy in developing countries has been outstanding in many cases and linked to similar growth in related services and manufacturing industries. As an example, Brazil, China and India are in the top 10 countries in the world 2009 when it comes to investment in sustainable energy with a combined volume of 44.2 billion US$, or 37% of the total investment in the sector. (Bloomberg New energy Finance, 2010)

Price Related, Quota and Auctions Policies

Both developed and developing countries have used different types of policy and implementation tools to support renewable energy development and the renewable energy market is in general, a policy-driven market.

Since the 1970s developed countries have been designing and implementing different types of price- and quota based mechanisms to promote renewable energy development. For example, the United States implemented its first feed-in tariff policy (FITP) in 1978 and a quota mechanism (RPS) from 1983. Germany was the first European country to introduce a feed-in tariff (FIT) 1990, and many European countries have familiarity with either price- or quota-based mechanisms. The United Kingdom, introduced competitive tenders during the 1990s.

Developing countries also have history of designing and implementing policy and instruments to promote renewable policy. India was the first country to introduce some type of special tariff or FIT in 1993, Sri Lanka in 1997, and Brazil and Indonesia in 2002. Quota systems have been less popular in the developing world, and for example an exact RPS, a quota or target[1] has only been introduced by a few countries, including Chile from 2008, Poland from 2005 and Romania from 2004. Competitive schemes or auctions in the developing world are less common, but some countries have or are now testing their effectiveness e.g. Argentina, Brazil, China, Peru, Thailand, and Uruguay. FITPs are now being implemented in 49 countries around the world and are often stated as the most effective policy for attracting private investment in the renewable energy / geothermal sector. Many developed and developing countries, however use quota based systems, including RPSs and auctions e.g. Brazil, Chile, China, France, Poland, Sweden, the United Kingdom, and the United States. (WB, 2012).

Financial related Policy

Financial related policy has also been used, including fiscal and financial incentives and a range of other supplementary measures to stimulate investments in the renewable energy / geothermal sector. All these measured have been adopted in parallel to price- and quantity setting instruments in both developed and developing countries. (WB, 2012).

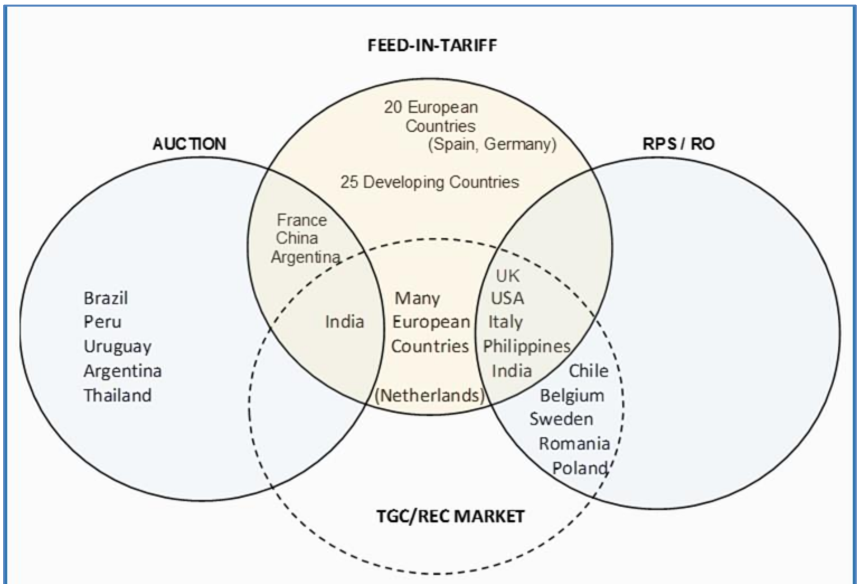
Iceland has used financial incentives to promote geothermal development for about 50 years, and it has been an important policy instrument to increase investments and facilitate the operation of geothermal district heating networks with success, without using other price related policy instruments for the sector. This has been successfully implemented for district heating both in cities and smaller municipalities in Iceland, in areas with both limited and abundant geothermal resources.

[1] A proportional obligation is imposed on utilities or retail companies, and the price is competitively determined by the market.

Emission Certificated / Tax Policy
A growing number of policies that indirectly promote the renewable energy are known as cap-and-trade programs. The system uses a ceiling on the emissions of covered entities, issues allowances or emission certificates, and promotes their trading to generate a market price for emissions and can also be implemented through a tax policy. The cap-and-trade schemes have been implemented in many developed countries, e.g. the United States as the Regional Greenhouse Gas Initiative and as the Emissions Trading System (EU ETS) in 28 European Union countries. Some developed countries have also been applying carbon taxes since the beginning of the 1990s, e.g. the Netherlands and the Scandinavian countries, and others recently like the Canadian Province of British Columbia. In 2012, no developing country has formally implemented a greenhouse gas cap-and-trade scheme or a carbon tax. (WB, 2012).

Trend in Renewable / Geothermal Policy
In 2012 there were 31 developing countries that have introduced some type of price or quantity-setting instrument to increase the share of renewable energy electricity generation, 28 have opted for an FITP, and only a few have introduced an RPS or use auctions e.g. Brazil, Chile, China and Poland. Some countries have also made important policy shifts, and many are now also using both price- and quota-based instruments.

Figure 1.2.1. **Use of Renewable Energy Policy Instruments**



Source: Design and Performance of Policy Instruments to Promote the Development of Renewable Energy, WB, 2012,

The policy structures of choice of various developed and developing countries in 2012 can be seen in figure and table 1.2.1. It shows the increasing acceptance of renewable energy policy tools by some of these countries as well as changes.

Even though, developing countries (middle income) have steadily adopted economic incentives such as FITPs, recent trends point out that upper-middle income countries have started to introduce competitive mechanisms including renewable portfolio standards and auctions. (WB, 2012).

Table 1.2.2. **Trend in Global Renewable / Geothermal Policy**

Year	FITP	RPS / REC	Auction
1970s	**USA (PURPA) 1978**		
1980s		**USA**	
1990s	Germany(90), **Italy (92),** Many EU Countries, India (93), Sir Lanka (97),	**Italy (1999)**	UK (1990)
2000-05	Brazil, Indonesia (2002), Nicaragua (2004), Turkey, Ecuador, China (2005)	UK (2002), Belgium, Austria, Japan, Sweden, Canada, Poland	China (2003)
2006-10	**USA (different states from 2006),** Argentina (2006), **Philippines**, Kenya, S-Africa (2008), 11 developing countries, **Italy (2007-8),** **UK (2010)**	Chile, Romania, **Philippines (2008)**	Brazil (2007), Peru (2008), Uruguay, Thailand, China (2010), India (2010)
Sources: (WB, 2012)			

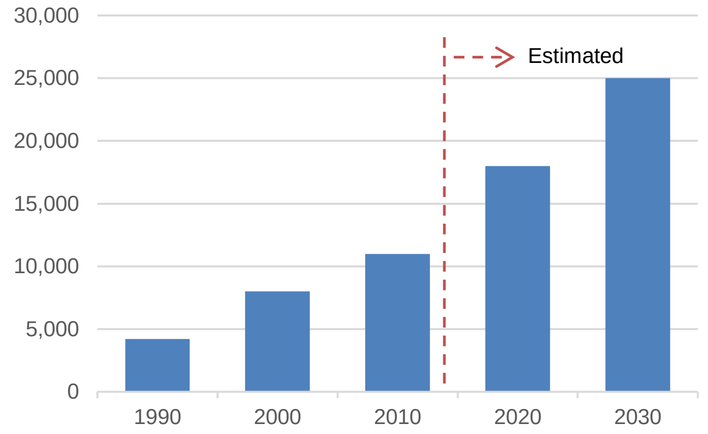
ESMAP, has estimated the global growth of the geothermal sector until 2030. It will continue to grow to cumulated capacity of up to 25.000 MW, as can been seen in figure 1.2.3. It is estimated by ESMAP that based on information on currently planned projects and those that are actually under construction, by the year 2020 worldwide geothermal power generation (from geothermal resources only) is expected to grow to 18.000 MW.

It is also stated in the report that countries in "*Latin America like, Mexico, Costa Rica, Nicaragua, and El Salvador are likely to continue developing new geothermal power projects with a total added capacity of 500 to 1.500 MW by 2020. Other countries (e.g., Peru, Chile, and Argentina) might start developing their first projects before 2020. Guatemala, Honduras, Panama, Colombia, Ecuador, Bolivia, and several Caribbean island states, including Cuba and Haiti and Dominica, also offer good prospects.*

Looking to 2050, significant additions in installed capacity can also be expected in the following countries and regions:

- *Pacific Asia: Malaysia, Papua New Guinea*
- *Africa: Tanzania, Eritrea, Sudan, Somalia, Malawi, Zambia, Burundi, Rwanda, Uganda, Democratic Republic of Congo, Mozambique, Madagascar, Comoros and Mauritius, and several North African countries.*
- *Latin America: Guatemala, Honduras, Panama, Colombia, Ecuador, Bolivia, and several Caribbean island states, including Cuba and Haiti".* (ESMAP, 2012)

Figure 1.2.3. **Estimated Global Geothermal Capacity 1990 – 2030**



Source: ESMAP, 002/2012

As can been seen from ESMAP estimations towards 2020 and 2030, it is estimated that the geothermal sector will grow in Latin America and all the Andean region countries, Peru, Chile, Bolivia, Colombia and Ecuador, based on potential geothermal resources and opportunities within these countries.

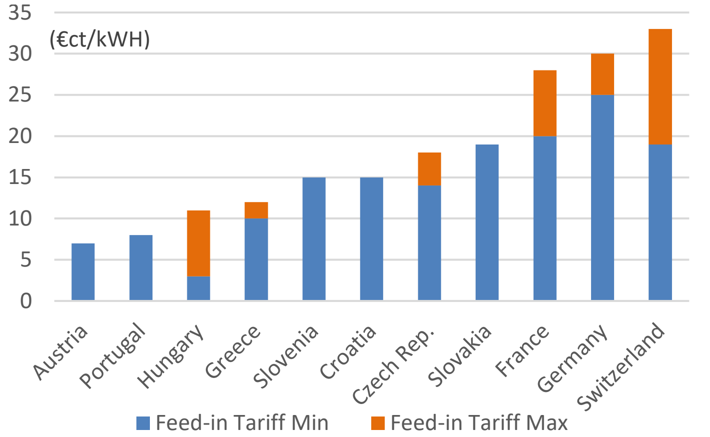
1.3 Support to Renewable Energy in the European Union

1.3.1 Operational Support

Support to geothermal electricity has been given in various forms of public policy mechanisms. Generally the support can be in the form of **1) investment support** (*capital grants, tax exemptions or deductions on the purchase of goods*) or / and **2) operating support** (*price subsidies, renewable energy obligations with green certificates, tender schemes and tax reductions on the production of electricity*). (EGES, 2013)

For more than 10 years a few EU Member States have driven the development of renewable energy and invested in R&D and development, building demonstration plants, and finally in supporting deployment of renewable energy equipment. Some of these EU countries, (e.g. Germany, Denmark, Spain) now have major renewable energy companies, operating globally.

Figure 1.3.1.1. **Feed-in Tariff System in EU Countries**



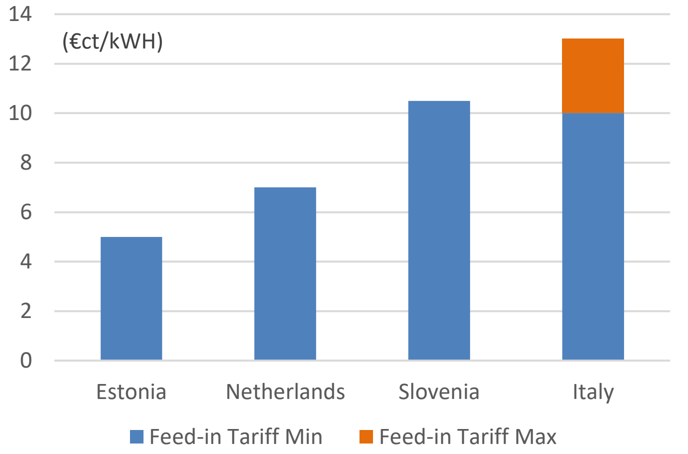
Sources: EGEC, 2013

Growth of these companies was among others based on support to renewable energy, paid by domestic energy consumers paying slightly higher energy bills to cover the extra cost of developing the renewable energy. The policy of the EU is that this kind of growth and commitment must occur across all member States, if they are to reach their targets. (Commission, 2011)

The policy on supporting renewable energy can be found in the report on Review of European and National Financing of Renewable energy where it is stated: "*The Commission finds that the short-term costs of investing in electricity grid infrastructure are far outweighed by the benefits of creating an integrated European electricity market capable of sustaining a future de-carbonized electricity sector. The urgency of the need for action has been highlighted most recently in the IEA's 2010 World Energy Outlook.*

Whilst energy infrastructure has traditionally been funded by the private sector or national governments, European intervention and funding for infrastructure projects of European importance can help create a more efficient energy network and create significant cost savings for Europe. Similarly, European intervention to promote efficiency in the achievement of the renewable energy targets could save billions of Euro". (Commission, 2011).

Figure 1.3.1.2. **Feed-in Tariff Premium System in EU Countries**



Sources: EGEC, 2013

1.3.2. Financial Support

Regarding financial support to geothermal renewables, investment requires capital expenditure to generate production and revenues to cover costs.

Renewable energies have in general lower operating costs but higher capital costs. The financing structure of renewable energy therefore has to take this into account.

To increase the development and use of renewable energy and meet the investment gap, efforts can be directed through direct or indirect support, to

- lowering the cost of capital by reducing technology, plant and construction costs, or
- by raising more revenues through support measures, to cover costs.

Table 1.3.2.1. **Financial Support to Geothermal Heating in EU countries**
Investment Grants France (Fonds chaleur renouvelable) for collective office buildings Germany, Hungary, Greece, Poland, Romania, Slovakia, Slovenia, Spain
Feed-in tariff Italy (Conto termico), Netherlands (SDE+), UK (Renewable heat incentive)
Tax rebate/VAT reduction France: (VAT reduction for DH, rebate on tax on revenues for individual housings), Hungary, Italy, Netherlands
Low or zero interest loans France: (for individual housings), Germany, Hungary, Netherlands, Poland, Slovenia, Spain
CO_2 tax Finland, Sweden, Denmark *Sources:* (EGES, 2013)

The renewable energy sector is in general a capital-intensive sector, meaning it requires a large amount of capital but lower operating costs (no fuel costs for most technologies) and therefore proportionately higher capital costs. Financing of renewable energy has to take this into account.

To expand renewable energy deployment, efforts can therefore be directed via direct or indirect support, to lowering the cost of capital (for technology, plant and construction costs), or by raising more revenues through support measures like FIT, to cover costs.

Table 1.3.2.2. **Types of Financial Support to Geothermal Heating in EU Countries**

Reducing capital costs	**Reducing capital costs through revenues**
Grants: taxpayer funded aid, often for innovative demonstration projects. **R&D grants**: grants, often for research into innovative, immature technologies. **Public loans**: offer cheaper access to capital due to public funds used to bear greater risk. Particularly useful for small and medium sized enterprise (SME) who are less able to access capital. **Equity funds**: private medium risk investors, expecting relatively high returns, for later stage of projects and more mature technologies, and investment periods of 3-5 years. **Venture capital**: private equity investment for financing technology innovation, with active involvement of the fund managers in the project. **Mezzanine funds**: loans that take more risk than normal (“senior”) debt but less risk than equity; expecting relatively short term and variable but high return. **Guarantees**: offer of compensating payment to a lender or an investor in case of payment default by a project developer. **Contingent grants or loans**: support that is converted into a loan when a project turns out to be successful, or treated as a grant if the project encounters financial difficulties.	(starting point: energy prices covering costs) **Regulated prices**: feed in tariffs, (FIT) giving energy producers a fixed financial payment per unit of electricity or heat produced from renewable energy sources. Often fixed for 10-20 years, differentiated by technology and phased out. **Regulated premiums**: feed in premiums, (FIP) giving energy producers a fixed financial payment per unit of electricity or heat produced from renewable energy sources for the green value; the producer receiving the market price for the physical energy. **Quota/certificates**: impose a minimum share or quota of renewables in the electricity, transport fuel or heating fuel mix, which can be met either through physical production (common for biofuels) or through purchasing “green certificates”, virtual, rather than physical energy. The producer of the green energy is paid for the green certificates by the supplier or other facing the obligation. **Fiscal incentives**: tax exemptions or tax credits for investments in renewable energy projects. **Tenders**: A government call for tender for a renewable energy project, often specifying the capacity/ production/ technology/ site. The winner is generally granted a long term power purchasing agreement at a competitive price.

NATIONAL SUPPORT FOR RENEWABLE ENERGY

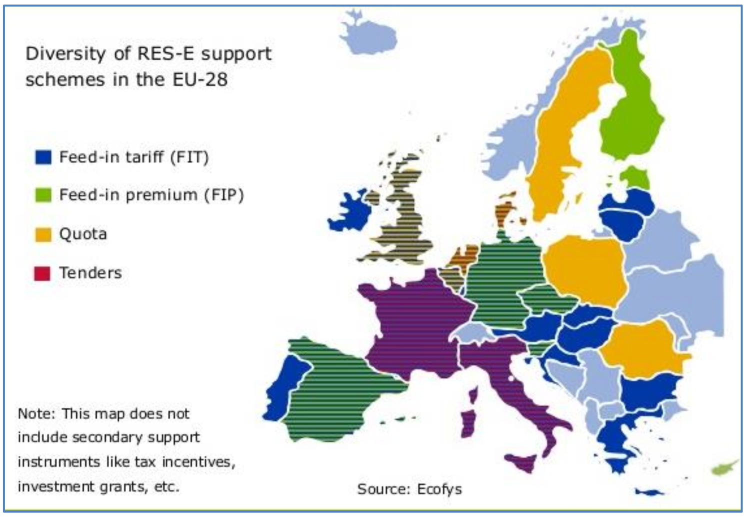
EU Member States' use of different instruments for electricity, heating and transport (biofuels).

		Austria	Belgium	Bulgaria	Cyprus	Czech Rep.	Germany	Denmark	Estonia	Spain	Finland	France	Greece	Hungary	Ireland	Italy	Lithuania	Luxembourg	Latvia	Malta	Netherlands	Poland	Portugal	Romania	Sweden	Slovenia	Slovakia	United Kingdom
Sources:		AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK
Electricity	FIT	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x	x			x			x	x	x
	Premium					x		x	x	x											x					x		
	Quota obligation		x													x						x		x	x			x
	Investm. grants		x		x	x					x		x	x			x	x	x	x								
	Tax exemtions		x							x	x		x						x		x	x			x		x	x
	Fiscal incentives			x			x		x											x	x	x				x		
Heating	Investm. grants	x	x	x	x	x	x		x		x		x	x	x		x	x	x	x	x	x	x		x	x	x	x
	Tax exemtions	x	x					x				x	x			x	x				x				x			x
	Fiscal incentives			x			x		x			x											x					
	Premium											x																
Transport	Quota obligation	x		x	x	x	x	x		x	x	x			x		x	x	x		x	x	x	x		x	x	x
	Tax exemtions	x	x		x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x

Sources: SEC (2011) 131: Review of European and national financing of renewable energy in accordance with Article 23 (7) of Directive 2009/28/EC

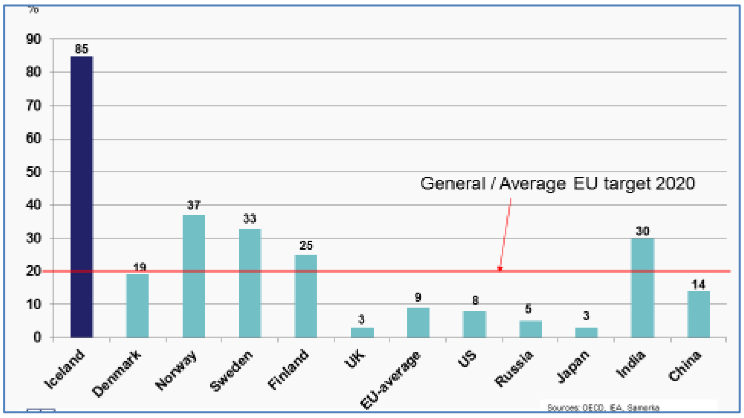
The choice of support measures to help reduce renewable energy costs depends on the technology and project development, and different forms of project risk, technology, construction, regulatory and it depends in particular on the maturity of a project or technology. When technology and projects are capable of being deployed but not yet competitive, support tends to shift from capital support to operating support, but there is a range of tools, depending on circumstances.

Figure 1.3.2.3. **The main RES-E Support Scheme in Europe**



Looking at national support schemes in Europe, it is interesting how EU member states use a range of different instruments. The use of multiple instruments can be appropriate, given the different economic status of all the different technologies, in terms of maturity. (Commission, 2011). When looking at the share of renewables in total primary energy use, it can be seen that Iceland has the highest share, with 85%, and the average for Europe is 9%, USA 8%, Japan 3% and China 14%. The high share of renewables in total primary energy used in Iceland, is not only due to great potential of renewable resources, but also because of long term priority and sustainable policy towards harnessing these renewable resources, through hydro and geothermal programs and projects generating electricity and geothermal district heating. This policy has created savings for businesses and homes, increased energy security and reduced greenhouse gas emissions. It has also created economic opportunities and savings and improved quality of life.

Figure 1.3.2.4. **Share of Renewables in Total Primary Energy use**



1.4 Global Renewable and Geothermal Policy – Lessons Learned

On global level, diverse types of renewable and geothermal policy tools, implementations and incentives have been used, individually or in parallel and the policies have changed over time both in developed and developing countries. (WB, 2012).

1. An independent policy based on assessment and conditions in each country is important.
When designing and choosing policy, administration, regulation and implementation tools, it is important to design this policy based on overall assessments and evaluation of actual conditions challenges and possibilities in each area e.g. type of market, supply, demand, volume, risks, organisational and administrative capabilities, etc.

2. Policy system in right structure is critical for policy success.
Policy success depends on the existence of basic legal and regulatory conditions, as well as organisational and administrative efficiency. Legal framework for grid connection, resources, land use and distribution of licences and rights must be prepared and implemented, so granting permits and implementation of projects will not be stuck in bottlenecks.

3. Volume is not the same as efficiency.
Volume based renewable energy policy may not necessarily be efficient. Even if the policy combination succeeds in prompting investments that achieve capacity targets, the economic efficiency (cost per unit of benefits) may be low.

4. Importance of coordination and harmony of policy tools.
The coordination of policy instruments has the potential to create complex interactions and unforeseen effects. Policy makers have to consider the possibility among policy and regulatory tools that the combined impact may result in various and inefficient outcomes. It is important that individual policies are coordinated with the wider set of framework conditions that impact the energy market.

5. Policy and regulatory design is a dynamic process.
Over the years countries have tried different types of policy tools to support renewable policy and many are now using both price and quantity setting mechanisms. Feed-in tariff policies (FITPs) have required successive adjustments and attracting private investment while at the same time reducing minimal payments. Policy changes should however be organised through systems that allow participants to manage the risks in order to maintain a certain level of regulatory stability and security.

6. Competitive renewable and geothermal policy depends on a number of key factors.
Well-designed policy does not always create a competitive and successful renewable or geothermal sector (effective, efficient) if various critical factors are not carefully included in the system, e.g. integration of renewable energy into the transmission infrastructure and rules on transmission access and connection.

7. Support schemes are important and valuable
Support schemes are crucial tools of public policy for geothermal to compensate for market failures and to allow the technology to progress along its learning curve. By definition, they are temporary and shall be phased out as this technology reaches full competitiveness;

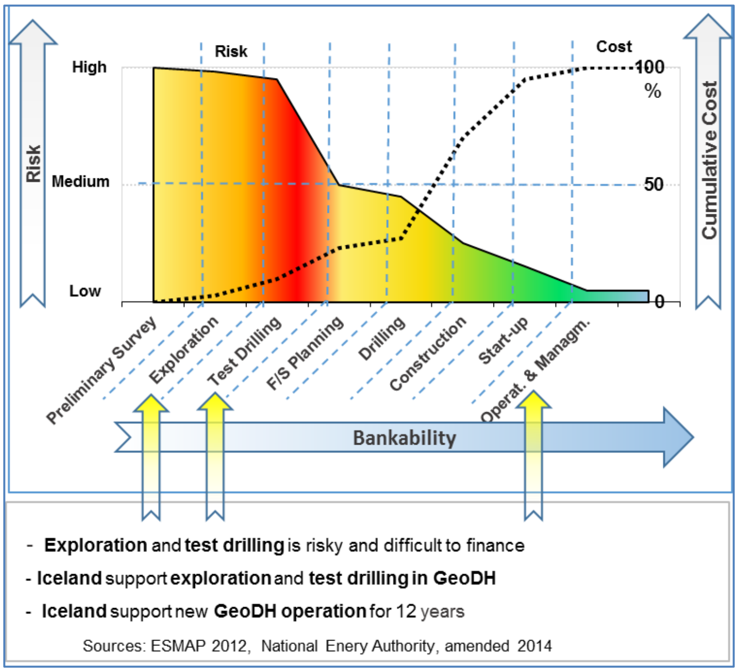
2 Development, Competitiveness and Risks of Geothermal Projects

2.1 Risk and Financing of Geothermal Project

It is generally recognized that geothermal exploration and development is a high-risk investment, due to uncertainty associated with a natural resource that cannot readily be observed or characterized without relatively large expenditures for drilling.

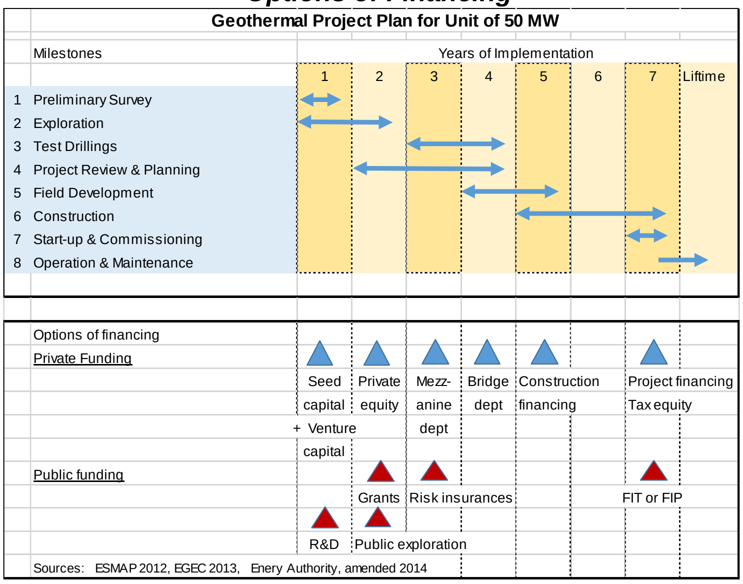
The long development time typically required to move a project from preliminary exploration through development to construction is an additional risk factor and many large geothermal projects (50 MW_e) have taken close to 10 years to develop and even more. This is a long development and construction time for investment, with the added risk in the early phases of the project. From figure 2.1.1 it can be seen that the risk profile is greatest during the Preliminary Surveying and Exploration Phases, but in that part of the project the cost is comparatively low.

Fig. 2.1.1 ***Risk, Bankability and Cost of a Geothermal Project***



The test drilling phase requires a greater level of expenditure although there is still a high level of uncertainty and risk involved and this step is frequently the biggest barrier for further development of the project. Therefore, numerous international aid agencies and governments around the world have recognized this as a barrier to development geothermal projects. Risk mitigation funds (private and public) have been established in some countries to assist projects through this exploration phase. In addition, more capital has also been spent on R&D in geothermal projects in recent years. Generally, funding is only committed to the test drilling part of project development if the investor believes there is an adequate financial return on investment ROI (in terms of a percentage of the committed capital per annum).

Fig. 2.1.2. ***Geothermal Project Plan and Options of Financing***



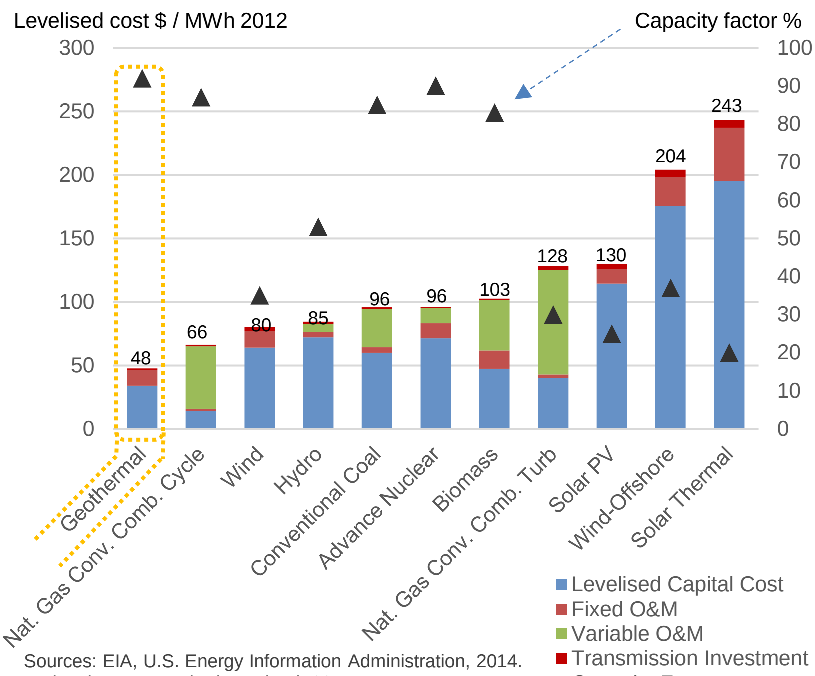
In addition, risk mitigation funds (grant scheme) improve the predicted ROI by reducing the amount of capital invested by investor. Usually, maximum ROI is only achieved if wells produce at or above their predicted outputs, and this result relies on high quality exploration methods and interpretation. Several mechanisms for supporting investments in geothermal energy exist around the world and at a national level. These financial mechanisms (public and private) can address different project stages and can come from different sources. In Iceland, public grants at early stages have helped many projects.

2.2 Competitiveness of Geothermal Technology – Comparison

When comparing total cost of electricity, levelized cost of electricity (LCOE) is often used as a classical summary of the overall competitiveness of different generating technologies. It shows the per-kilowatt-hour cost (in real dollars) of building, maintaining and operating a generating plant over an assumed financial lifetime. Key elements of LCOE include capital cost, fuel cost, fixed and variable operations and maintenance (O&M) cost and an assumed utilization rate for each plant type.

However, cost factors varies between the technologies, as cost structures are different (e.g. wind and solar have no fuel cost, etc.), and across regions, depending on overall framework conditions. This cost can also vary through time as technology changes. Additional items like, projected utilisation rate, resources mix and capacity value, have also impact on decision making in each region.

Figure 2.2.1. **U.S. Average Levelised Cost of Electricity and Capacity Factor for Plants, entering services in 2019**



Sources: EIA, U.S. Energy Information Administration, 2014. National Energy Authority Iceland, 2014

In figure 2.2.1 the LCOE values and capacity factors, are shown as average numbers for each utility-scale generation technology in USA and are calculated based on a 30-year cost recovery period, using a real after tax weighted average cost of capital (WACC) of 6.5%. However, in reality, the cost recovery period and cost of capital can vary by technology and project type. As the numbers are U.S. national average numbers for the electric generation, the numbers can be different between states and regions.

According to figure 2.2.1 the geothermal sector is the most competitive one, in comparison to other sectors as the levelised cost is only 48 $/MWh and the next one is natural gas-fired conventional combined cycle with 66 $/MWh, or 38% higher. Wind is estimated as 80 $/MWh or 67% higher, hydro is estimated on 85 or 77% higher and other options beyond. (NEMS, US National Energy Modelling System, 2014)

From the U.S. comparison of LCOE, the competitiveness and low cost of geothermal generated electricity is further outlined, which is an important and valuable message and opportunity for energy policy formulation and policy makers, in various regions and countries – including the Andean Region.

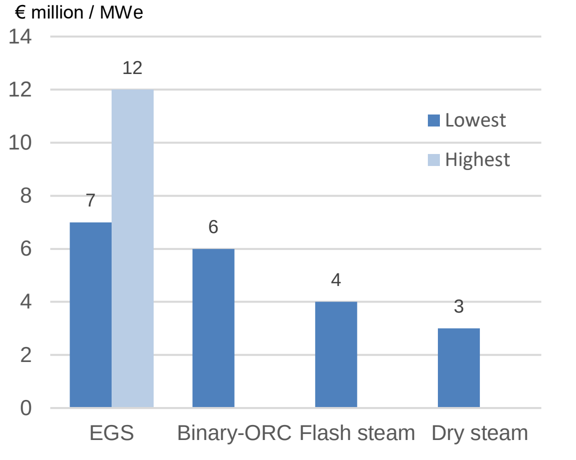
2.3 Cost and Structure of Geothermal Projects

Geothermal Electricity

In Europe it is estimated that the capital costs for geothermal generation per MW_e range between 3 and 12 million euro and it can vary depending on environment and technology. The capital costs are also dependent on drilling, e.g. the number of wells required, the depth of drilling and the geological risk.

Figure 2.3.1. **Capital Cost of Geothermal Electricity**

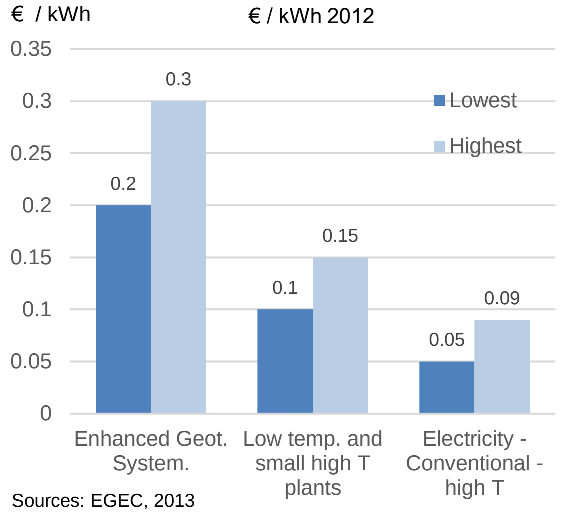
€ million / MWe installed



Sources: EGEC 2013

Figure 2.3.2. **Levelised Cost of Geothermal Electricity**

€ / kWh 2012

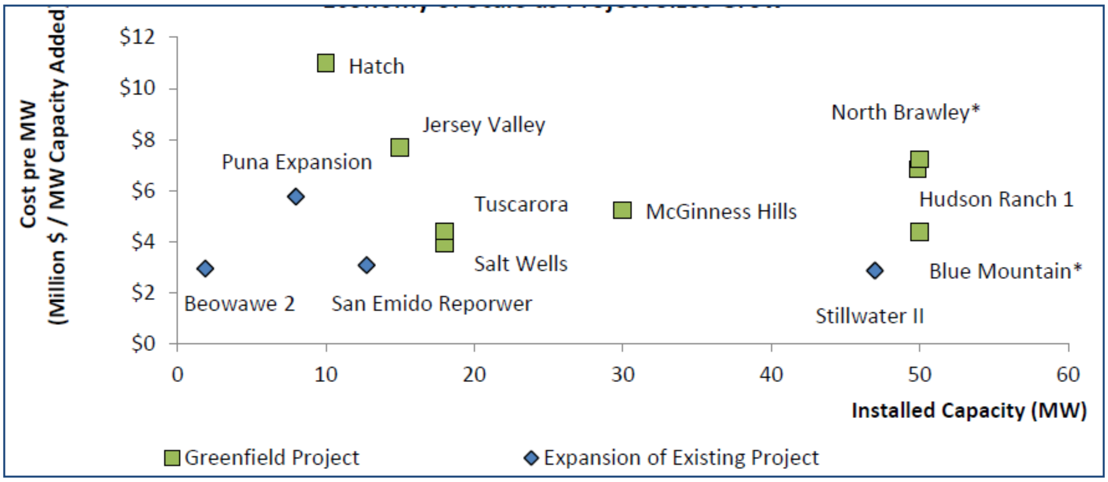


Sources: EGEC, 2013

The geothermal electricity is competitive, with newly built conventional power plants in Europe, where high-temperature hydrothermal resources are available. However, there are barriers for both geothermal electricity and heating sectors, sometimes in the form of unfair competition with gas, coal, nuclear and oil, in the form of prices, taxes or support, which is the reason for support schemes for geothermal.

Figure 2.3.3. **Recent US Geothermal Cost Trends**

Installed Cost per MW for US Utility-Scale Geothermal Projects (2009-2012)



This figure shows cost per MW ($/MW) of recent U.S. geothermal installations with each project's overall capacity, based on publicly available data from the U.S. Treasury's, grant database as of February 19, 2013, based on approved total "cost basis" under the Internal Revenue Code (IRC). As this is the cost base, some other elements are excluded such as transmission line upgrades, but this is the only publicly available data that can be compared across projects. As can be seen from the figure, there is a similar cost structure per MW for some of the projects but different for others, due to different external factors e.g. geothermal resources, and different for greenfield and expansion[2] project, etc. (Energy, 2014)

[2] Greenfield project = new project. Expansion Project = extension of existing project.

2.4 Geothermal District Heating

2.4.1 Cost Structure of Geothermal District Heating

Geothermal District Heating

In most cases, geothermal district heating projects face the same issues as geothermal power plants. Furthermore, geothermal heat pumps can also be considered as a capital intensive technology in comparison with other small scale applications. (EGES, 2013) Geothermal heat is also important and competitive for district heating, where a resource is available, especially where a district heating system is in place. Geothermal heat can also be competitive for industrial and agriculture applications. Geothermal heat pumps can also be profitable, in comparison with fossil fuel heating systems.

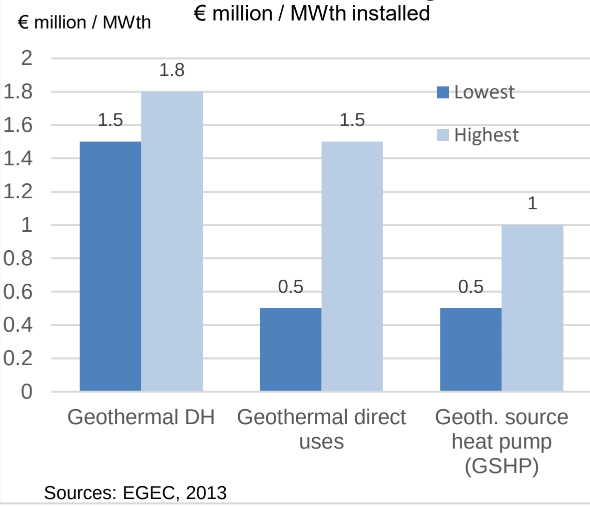


Figure 2.4.1.1. **Capital Cost of Geothermal Heating**

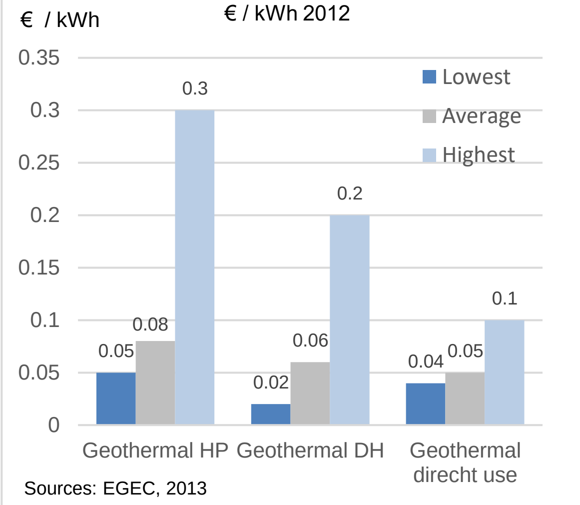


Figure 2.4.1.2. **Levelised Cost of Geothermal Heating**

The levelised costs of geothermal power plants vary greatly. New plant costs in some countries are highly competitive (e.g. € 50/MWh for high-temperature resources). This cost is largely depending on the main cost components such as drilling which can be 30% for high-temperature plants 50% for low temperature and even 70% for EGS. Additionally, the high capacity factor for geothermal (>90%, the highest of all energy technologies including nuclear) mitigates the capital intensity to make geothermal technologies competitive.

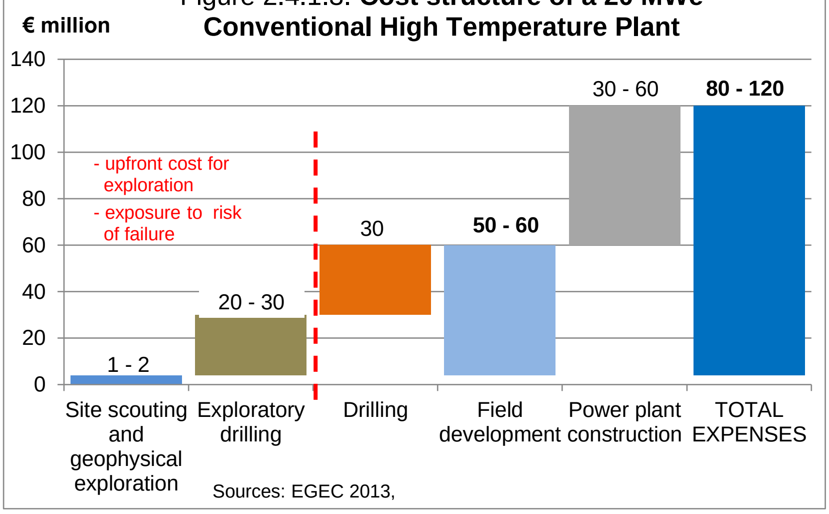


Figure 2.4.1.3. **Cost structure of a 20 MWe Conventional High Temperature Plant**

On average in Europe, the capital cost for geothermal power generation range between 4 and 7 million euros per MW_e, but is also dependent upon the specific site such as number and depth of geothermal wells and technology. Deployment of geothermal energy will require contribution and cooperation of private and public funding – but the engagement of the private sector is crucial. Nevertheless, there are financial barriers to develop geothermal power projects in many places of the world – which need to be overcome through public support at the beginning of geothermal development.

2.4.2 Policy towards Geothermal District Heating, Savings and Security

AEBIOM, EGEC and ESTIF, organizations representing the biomass, geothermal and solar thermal sectors respectively, addressed an open letter to the Heads of State and Government, ahead of their spring meeting in Brussels 19th of March 2014. The letter states that *"...Investing in renewables for heating and cooling will bring security of supply and more competitiveness, and could save EUR 11.5 billion per year, announces the industry. Over recent years, the lack of awareness and political support to renewables for heating and cooling has meant only modest market development in the sector. However, in view of the upcoming discussion of the European Council on EU climate and energy policies beyond 2020, there is a great opportunity to invert this trend."*

Dr. Guðni A. Jóhannesson Director General of the National Energy Authority of Iceland, also stated in the ERA NET Newsletter in May 2014 that, *"It is therefore important for policymakers and others to recognize the great opportunity regarding geothermal heating for savings for countries, as it is estimated that geothermal heating in Iceland is saving equal to 7% of GDP or 3000 US$ per capita or close to 1 billion US$ for the economy only for 2012. It has also been estimated that renewables for heating and cooling could save EUR 11.5 billion per year within EU, improve the energy security and mitigate climate change*."

"Geothermal district heating has the potential to alleviate Europe's energy security crisis" – is stated in a press release from Geothermal District Heating (GeoDH)[3] in Brussels, 15th May 2014. (National Energy Authority Iceland, 2014) It is estimated that over 25% of the EU population lives in areas directly suitable for Geothermal District Heating, in 22 European countries with GeoDH systems in operation, where existing heat networks are well developed. The main benefits of geothermal heating and cooling are economic benefits and opportunities of resource utilisation, provision of local baseload and flexible renewable energy, diversification of the energy mix and protection against volatile and rising fossil fuels prices. In addition, the harnessing of geothermal resources can provide economic development opportunities for countries in the form of taxes, royalties, technology export, and jobs.

According to Eurostat, about one third of the EU's total crude oil (34.5%) and natural gas (31.5%) in 2010 was imported and, 75% of that gas was used for heating (2/3 in households and 1/3 in the industry). Geothermal DH technology has therefore potential possibilities to replace a significant part of imported oil and gas for heating households and industry. It has been estimated by GeoDH, that Geothermal DH technology has the potential to replace a significant part of that fuel. However, in order to enable such a development the GeoDH consortium has proposed enclosed policy priorities which are: (GeoDH, 2014)

1. Simplify the administrative procedures in order to create market conditions, which would facilitate development;

2. Develop innovative financial models for GeoDH, including a risk insurance scheme, and the intensive use of structural funds;

3. Establish a level playing field, by liberalizing the gas price and taxing GHG emissions in the heat sector appropriately;

4. Train technicians and decision-makers from regional and local authorities in order to provide the technical background necessary to approve and support projects.

5. Increase the awareness of regional and local decision-makers on deep geothermal potential and its advantages.

3 Geothermal District Heating (GeoDH) is the use of geothermal energy (i.e. the energy stored in form of heat below the earth's surface) to heat individual and commercial buildings, as well as for industry, through a distribution network.

2.4.3 Legal, Financial and Cost Structure of Geothermal District Heating Projects

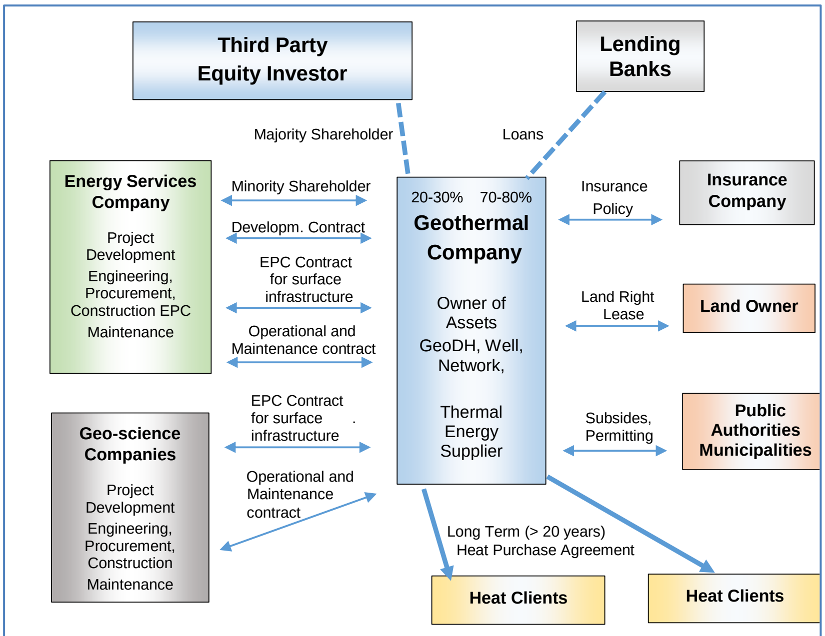
Legal and Framework Structure

Legal and financial structure and planning are main elements of GeoDH planning and risk assessment. However, risk assessments depend on each type of project which can be different based on location, regulation, technology, management, finance etc.

Nevertheless there are also general similarities for such projects regarding legal and financial frameworks for Geothermal District Heating – as can be seen in enclosed figure 2.4.3.1.

A Geothermal Company (GC) financed by the equity investor (20-30%) and by bank by loans (70-80 %), is established to centralise the assets, rights and operational agreements. This company signs a long term agreement (>20 years), heat purchase agreements with end users with a fixed charge (capacity charge) linked to kW of capacity subscribed, and a variable charge ("consumption charge") proportional to kWh supplied.

Figure. 2.4.3.1. **Legal and Financial Framework for GeoDH**



Sources: GeoDH 2014, National Energy Authority, amended 2014

The company should also sign key contracts regarding engineering, procurement and construction and operating and maintenance, for both the geothermal well and the district heating network. The company also has to have insurance policies (civil liability, damage, geothermal resource risk if possible, etc.). Finally, the company has to secure land rights, permitting and subsidies with the land owners and public authorities or municipalities. (GeoDH, 2014)

Cost structure for Geothermal Heating

The risk characteristics of a geothermal heating project are different depending on the three stages of the projects, which are: 1. Exploration, 2. Drilling, 3. Building which is much less risky.

In a calculation presented in GeoDH paper 2014, it is estimated that, *"a private investor who would be given the opportunity to invest 20 million Euros in the building, and receives a feed-in tariff of 90-96 Euros/ MWh would earn around 9-10% per annum on the 20 million € invested. If that investor financed two-thirds of this investment with debt, as it is common practice for such investments, the return on equity can rise to 20%. This observation leads us to the conclusion that a feed-in tariff, such as is already available in the wealthier Member States of the European Union, is sufficient to attract investment for the building and operation stage of a geothermal electricity-generating plant, <u>if only the exploratory and drilling stages are completed</u>."* (Christian Boissavy, 2014).

It is therefore an important element of geothermal heating project that there are options and possibilities of support from public authorities towards the exploration and the drilling stage of such project. In the above mentioned paper it is recommended that the support should cover 75% - 80% of the exploration and drilling cost if the project fails. This is especially important due to the risk of test drilling. In Iceland for example, the test drilling for such projects can be refunded by the Energy Fund if the test drilling is not successful. On average the electricity generating geothermal plants are considerably larger and more expensive, than heat generating geothermal plants and the risks (investment & operation) for electricity generating geothermal plants over longer period of time is therefore larger. Regarding heat generating geothermal plants, the benefits are greater when high temperature resources is used to generate both heat and electricity than when it is used for heat alone.

The geothermal heat generation has several advantages, such as:

1. Economic opportunity and savings.
2. Improvement of energy security.
3. Reducing greenhouse gas emissions.
4. Harnessing natural resources.
5. Reducing dependency on fossil fuels for energy use.
6. Local payback in exchange for local support for deep drilling,
7. They complement existing district-heating networks offering an alternative to other fuels
8. They can be combined with smaller binary cycle (if economics allow) electricity-generating plants to bring up the utilisation of the reservoir to the maximum
9. Partial recovery of costs for failed drilling for a geothermal power project
10. May be a useful complement to regional and local economic development programmes with positive effect on employment and the viability of public infrastructure.
11. They raise public awareness for the geothermal energy to a broader section of the public
12. Improving quality of life.

It is difficult or impossible to present standard costs of geothermal district heating project as it varies between region and variable conditions. Nevertheless, the costs of such a project can be estimated, based on the most important parameters for the understanding of the individual projects, by;

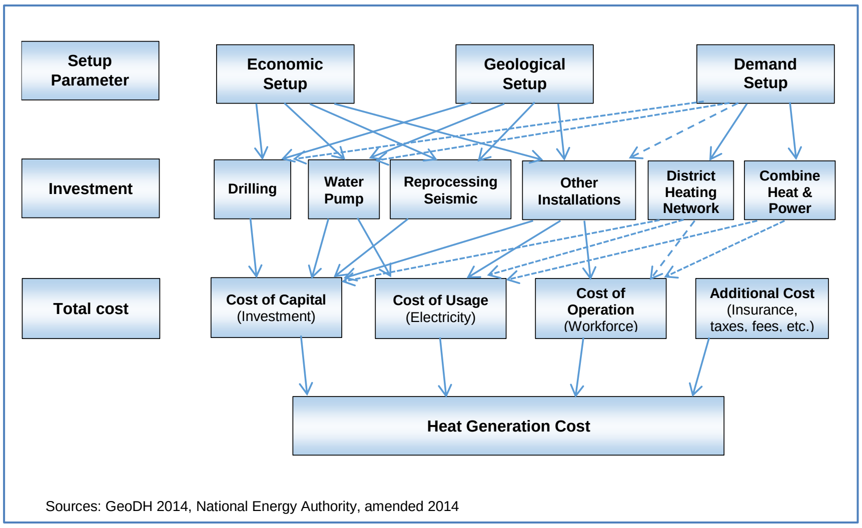
- firstly defining the basic conditions affecting the heat generation cost and
- secondly by developing theoretical projects in order to explore economic viability.

Key factors for geothermal district heating project are:

1. geological framework,
2. economic conditions, and
3. demand.

Although it is difficult to estimate the profitability of such project, the cost for each project can be based on the demand structure, the geological structure, the costs of capital and the existing geological data, as is shown on figure, 2.4.3.2.

Figure 2.4.3.2. **Cost Structure of Geothermal Heat Generation**

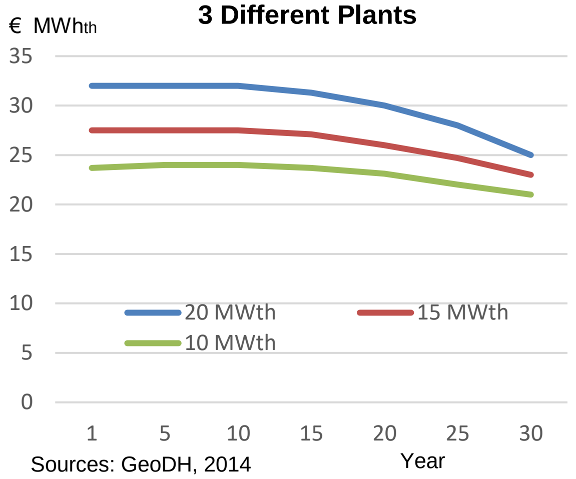


The demand side plays an important role in defining the project and the investments e.g. the drilling of boreholes, size of the water pump, buildings, a district heating network and a power plant's mechanisms. In addition the evaluation of heat generation costs depends on the geothermal energy resource. It should also be noted that, many of these cost elements are the same as for a standard heat generation installation. However, due to the fact that every location has different demand conditions, (pre-feasibility study), it is not possible to incorporate these factors in a general heat generation cost calculation. Moreover, many costs are equal to those of a conventional heat generation installation. A paper for GeoDH 2014 presented a calculation estimating the cost of a geothermal heat generation project. The calculation was based on following costs elements.

- Costs of capital (investments for drilling, water pump, substation, depreciation),
- Operational cost (electricity for pumping & equipment, maintenance).

However, in addition to these costs, geothermal heat generation plants have to be connected to broader heat or electricity of other energy networks like a gas-fired or coal-fired power plant to be able to cope with peak loads. That kind of cost is not included in the project example that will be described, in the example, figure 2.4.3.3. [4]

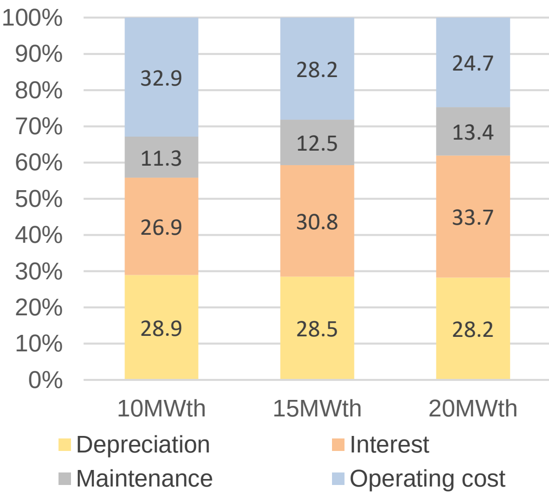
Figure 2.4.3.3. **Heat Generation Cost of 3 Different Plants**



Sources: GeoDH, 2014

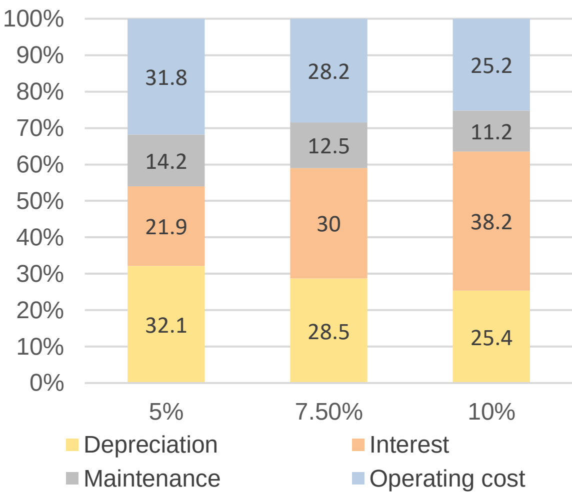
Calculations on geothermal heat generation cost carried out for GeoDH 2014, involved three projects 10, 15 and 20 MW_{th} as shown in figure 2.4.3.3. It is interesting that the figure illustrates that the generation cost is stable for the period of 30 years, (due to lower costs of capital over time), which is opposite to the trend for forecasted prices for fossil fuels. Higher cost for 15 and 20 MWth projects than 10 MWth, is due to higher capital cost in form of interests coming from more expensive drilling.

Fgure 2.4.3.4. **Cost Structure of Generation Project Depending on Size**



Sources: GeoDH, 2014

Figure 2.4.3.5. **Cost Sture of Generation Project and Sensitivity Analysis of Interest**

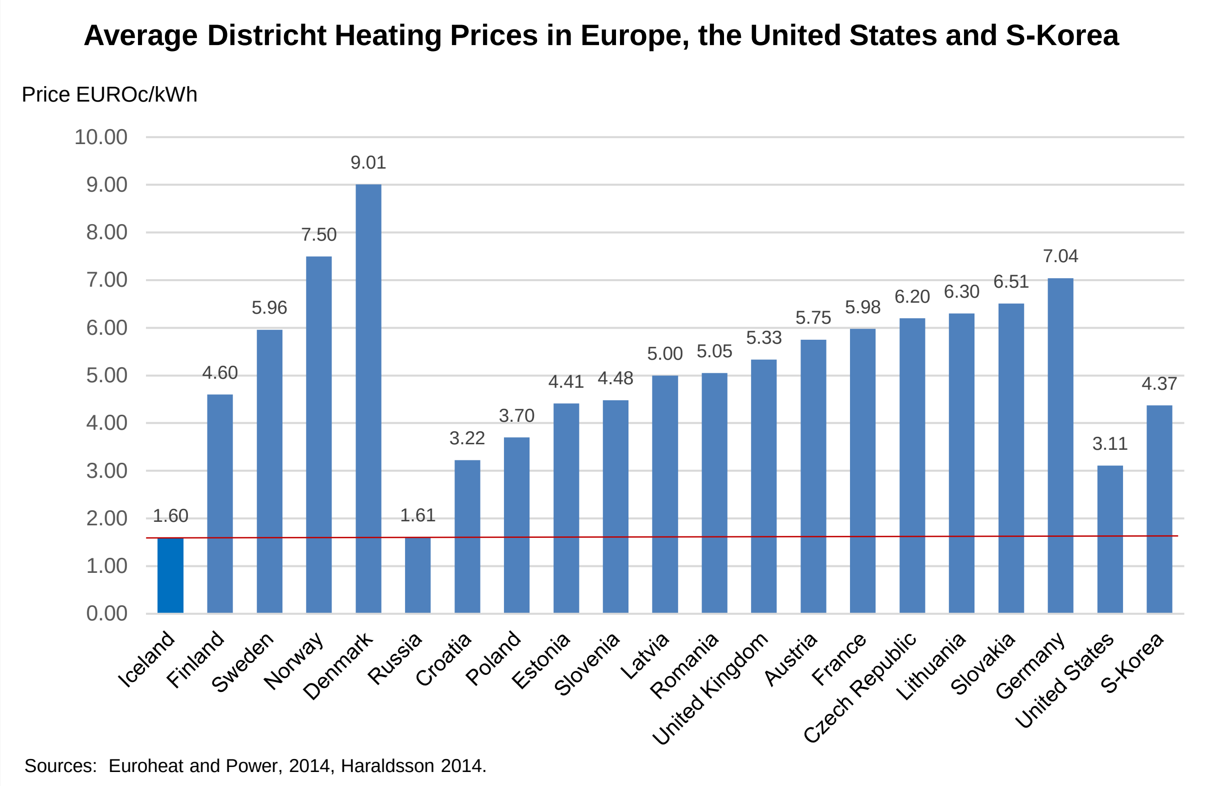


Sources: GeoDH, 2014

As can be seen from figure 2.4.3.4, the cost structure is different depending on size of project, but for all projects the capital cost (depreciation and interests) is the far biggest part of the overall cost, as this is capital intensive sector. For the 10 MW_{th} case, the biggest single cost factor is operation coming from electricity cost to run the water pump. For the biggest project the largest cost factor is interests. As these projects are capital intensive, interests play a major role regarding profitability, as can be seen for the sensitivity analysis in figure 2.4.3.5, (15MWth) where the 5% interests cost go from 21,9% up to 38,2% if the interests are 10%. Rates of Interests are therefore one of the biggest risk factors.

[4] The geothermal generation heat project provides the base load energy for district heating, which will be delivered to the district heating network, total hours of the plant will be 8.000 hours/year. The focus will be on generation cost so no revenues will be calculated. Life time of the project is estimated 30 years of operation; repayment of loans is 30 years, depreciation off the drilling is 50 years, depreciation of the substation is 30 years, depreciation of the pump is 3 years and interest rate will be 7.5%. The costs for a district heating network and special installations, as well as taxes and fees, are not included.

2.4.4 Global Price Comparison of Geothermal District Heating



Due to its diffusive nature, there are economic limits to the geographic transport of heat. As a result, the utilization of geothermal resources for direct applications is quite localized, as demonstrated by the fact that the longest geothermal transmission pipeline in the world, found in Iceland, is 64 km in total (Georgsson et al., 2010). In contrast, electricity can be transmitted thousands of kilometres and oil can be shipped around the globe. In Europe, gas is a common source of heat that can be transported in pipelines over thousands of kilometres. Nevertheless, local resources are commonly used where possible, which results in substantial differences in the energy mix between countries. Figure 2.4.4.1 shows this variation for heating in the Nordic countries. It is evident that district heating systems are quite widespread in the region with the exception of Norway, where electricity covers 70-80% of heating demand, with the remainder primarily met by bioenergy (7%), oil (7%) and district heating (4%) (NVE, 2013).

Out of all countries surveyed by Euroheat & Power, Iceland has the lowest district heating price of 0,93 €¢/kWh compared with an arithmetic mean value of 4,04 €¢/kWh, a standard deviation of 2.00 €¢/kWh, and a maximum value of 9,01 €¢/kWh. The great variation in prices within the Nordic countries, which all have cold climates and therefore a considerable need for heating, is of particular interest. Out of the 20 surveyed countries, the highest price is encountered in Denmark and the second highest in Norway, whereas Sweden has the 8th highest price and Finland lies slightly below average. It is probable that the reasons are not only economic, but also political. In general, taxes tend to be high in the Nordic countries and countries with limited domestic energy options, such as Denmark, may want to keep energy prices high in order to promote efficiency and limit consumption. Furthermore, environmental considerations may contribute to high prices. The fortune of Icelandic consumers is therefore the abundance of low-price, environmentally friendly geothermal heat that translates to the lowest average district heating price on record in Europe and possibly the wider world.

In the United Kingdom, one of Iceland's neighbouring countries, the main source of energy for heating is gas (Association for the Conservation of Energy, 2013). In 2009, the average gas price in the UK was 11,84 EUR/GJ, including all taxes and levies (Eurostat, 2014). Assuming 80% efficiency (Association for the Conservation of Energy, 2013), brings the price up to 14.80 EUR per GJ of usable heat. This translates to 5,33 EUR¢/kWh, or 7,12 USD¢/kWh, which is slightly above the average price for district heating in Europe, and substantially higher than the price in Iceland. From these comparisons, it is evident that Icelandic geothermal district heating prices are very competitive. However, it is important to be aware of differences in climatic conditions between countries that lead to differences in the length of the heating season. Shorter heating seasons may lead to higher unit prices, as district heating companies must cover incurred costs based on sales over a limited time period each year. Other factors that influence heat demand, and thus consumers' wallets, include:

- ***Ambient temperature:*** The heat flow through a building wall is directly related to the temperature difference over the wall, indicating that year-to-year fluctuations in ambient temperature affect heat demand as was clearly observed in Norway in 2010 (NVE, 2013).
- ***Indoor temperature*****,** which is influenced by personal comfort choices, habits, prices and other factors, and can therefore vary over the population of a country. It is possible that averages are slightly different between countries.
- ***Insulation and airtightness of buildings*****,** which may vary between countries.
- ***Ventilation,* preferences** of home owners.

CONCLUSION

Despite hypothetical arguments, imprecision in data, and a rough methodology, the comparisons presented show that the utilization of geothermal resources for space heating in Iceland is of substantial economic benefit to Icelandic consumers. (Haraldsson, Economic Benefits of Geothermal Space Heating from the Perspective of Icelandic Consumers, 2014).

2.4.5 The Geothermal Global Market Structure

<table>
<tr><td colspan="7">Geothermal Project at Stage of Development
(Examples of companies)</td></tr>
<tr><th>Preliminary Survey</th><th>Exploration</th><th>Test Drilling</th><th>Field Development</th><th>Engineering</th><th>Construction</th><th>O&M</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">ISOR (Iceland)

West –JEC (Japan),
GEO-t (Germany),
SKM (New Zealand),
GeothermEX (USA),</td><td colspan="2">Icelandic Drilling (Iceland)

Thermasource (USA),
Baker Huges Drilling (US),</td><td>Mannvit, Verkís, Efla, Reykjavik Geothermal (Iceland),

Power Engineering (US),</td><td>Mitsubishi, Fuji, Toshiba (Japan),
UTC Power (US, Italy),
Alstom (France)</td><td>CFE, EDC</td></tr>
<tr><td></td><td colspan="6">Landsvirkjun, Reykjavík Energy, HS Energy (Icelandic Geothermal Companies)

PT Pertamina (Indonesia), Ormat (Israel, USA)</td></tr>
<tr><td colspan="4">CFE (Mexico), EDC (Philippines)</td><td></td><td></td><td></td></tr>
<tr><td colspan="7">Worldwide only a few companies cover all phases of geothermal development
Sources: ESMAP, 2012, US Department of Energy 2014, National Energy Authority Iceland, 2014.</td></tr>
</table>

The global geothermal sector includes about 20 large firms providing a wide range of services, expertise with specific set of services for a project developer. A geothermal development process normally lasts 5 - 7 years – and about half the cost of a geothermal project is incurred prior to the drilling of production wells, front-loading both the costs and risk profiles of a geothermal project compared with alternative technologies. Few vertically integrated firms are active at all stages of a project's development, but the majority of geothermal firms specialize in a specific niche or set of niches, including Icelandic companies. One such firm from Iceland (ISOR) is a world leader in the exploration and confirmation of geothermal resources, through the use of geophysical, geological, and geochemical analyses.

2.4.6 Demo - Business Model - for Geothermal District Heating and Gas

This demo case is based on comparison between a DH network using natural gas and a geothermal DH, in the Paris area, described in DeoDH paper 2014. The project (geothermal doublet) has been running for 31 years. However, the geothermal water flow rate is decreasing. (GeoDH, 2014).

Table 2.4.6.1. **Comparison of DH powered 100% with gas, and geothermal + gas.**

Annual expenses (K Euros no VAT)	Gas	Geothermal
(k = 1000)		solution
Gas to be purchased on the market	3.830	
Gas to be purchased on the market		1.099
Electricity consumption for gas plant	22	22
Electricity for geothermal pumping		240
Ordinary geothermal maintenance		550
Ordinary gas station maintenance	423	
Ordinary gas station maintenance		200
Ordinary network maintenance	326	326
Geothermal installation replacement		246
Total annual expenses	**4.601**	**2.683**

Table 2.4.6.2 **Operating and maintenance cost**

	Operating costs and maintenance	k Euros
	Geothermal loop	
P1	Electricity	240
	Corrosion inhibitors	70
	Water	5
P2	Regular maintenance	30
	Electrical Logging	20
P3	Heavy maintenance	88
	Equipment replacement	40
	Work force and 24/24h follow up	15
	Stock ,for repairs	15
P´3	Work over in the wells	55
	Insurance	45
	District heating network surface installations	
P1	Electricity	20
	Natural gas	1.100
P2	Work force and 24/24h follow up	420
P3	Equipment replacement	320
P´3	Stocks for repair	50
	Insurance	150
	Total	**2.683**

It has been decided to re-drill a new doublet in order to continue to exploit the heat underneath the city. The two deviated wells are expected to be drilled in 2015 and the new doublet will be put in production in the winter 2016. The new doublet is designed in big diameter in order to allow the production of 350 m3/h, which represents a heat power of 12,2 MW assuming a production temperature at 70°C and a reinjection at 40°C.

These new doublets can be re-cased after 35 years of exploitation and restart an exploitation period of 35 years even at reduced production flow rate. Consequently, the new doublet will be exploited for a minimum time period of 70 years from 2016 to 2086.

Technical aspects of the project were as follows:

1) Heating needs of the existing network: 67 480 MWh/year.
2) Total needs including the losses: 81.980 MWh/year.
3) Geothermal station power 15 MW.
4) Geothermal annual production: 5 300 MWh.
5) Pumping system power for production: 400 kW and 1.650 MWh/year.
6) Pumping system power for injection: at 600 kW and 1.900 MWh/year.
7) Back up and complementary energy used is natural gas.
8) Back-up power installed at 41MW with boiler efficiency at 90%.
9) Annual gas consumption: 20.347 KWh.

Operational benefits of geothermal

If we look at the operating and maintenance costs it is expressed into four sections for both systems: geothermal loop including the well, the main heat exchanger, and surface and network installation downstream from the heat exchange with hot geothermal water (Table 2.4.6.2.) Table 2.4.6.1, shows that the annual benefits to exploit the DH network using the geothermal doublet are of 1918 K€ (difference between 4.601 with gas and 2.683 with geothermal + gas).

Investment cost of a new geothermal doublet

The total investment cost for the new geothermal doublet is 11.930 k€ + 2.370 k€ (see table 2.4.6.3 and 2.4.6.4) or total 14,300 k€. (This includes doublet of drilling in 9''5/8 casing at the top of the reservoir with a maximum deviation of 50° - and all the equipment in the well and at the surface to exploit the geothermal water).

Investment cost – Payback time of the geothermal CAPEX

If we look at the CAPEX[5] model, for geothermal the value is 14.300 K€ and the annual benefit of expenses using geothermal - amounts to1.918 K€. The conclusion is payback period of 7, 45 years of the investment, if we exclude the financial approach and the fact that the community has to borrow the main part of the investment.

The main financial factors

The main financial factors of the project were as follows. Project life is 20 years, discount rate at 6%, interest rate at 3,2 inflation rate at 2%, annual escalation electricity price at 2%, annual gas escalation price at 5%, annual heat escalation price at 3%, and electricity purchase at 70€/MWh. The investment is 14.300 K€ and the equity at 400 K€.

Table 2.4.6.3**. Investment cost, geothermal loop at the surface.**

Geothermal loop at the surface	K Euros
EurosProduction pump (300 m3/h)	215
Pumping tubing (DN 175 coated)	140
Transformer	100
Piezometric tubing	10
Inhibitors line and accessories	180
Injection pump	60
Frequency variators	80
Regulation cos phi	20
Titanium plate heat exchangers	215
Handling of equipments	20
Geothermal water piping at the surface	210
Filters station	25
Monitoring of the loop including instruments	15
Water tank (4m3)	25
Digital systems	20
Architect, engineering and control	300
Heat station surface piping (DN 200 to 350)	450
Connection to the grid	90
Electric rack	95
Pumps for secondary loop	100
Total	**2.370**

Table 2.4.6.4**. Investment cost of drilling 2 deviated wells**.

Drilling of 2 deviated wells	K Euros
EurosGrant application ADEME	10
Insurance application SAF Environment	10
Geothermal lease and application for permits	95
Civil works (platform, fence, anti-noise , cellars)	700
Cranes works, transportation, storage	60
Drilling rig mob, demob and moving	650
Drilling (energy included)	2.200
Overreaming	250
Drilling mud	520
Drilling tools	170
Deviational including personnal	700
Electrical logging	520
Casings	920
Installation of casings (accesories , screwing)	310
Cementing	900
Stimulation and development	85
Acidizing jobs	130
Mud treatment and cuttings removal	960
Well heads and valves	130
Geological follow up	410
Supervision on site 24/24	400
Cleaning of the platform	500
Insurance SAF short and long term	630
Engineering	190
Provision for unexpected	480
Total	**11.930**

Key Findings – Cost Comparison – kWh Produced by Natural Gas and Geothermal

The key findings of this demonstrative example in France- is that the actual production cost of the heat generated using 100% gas is about 56 €/kWh for a final selling price to the consumer at 70 € including everything.

However, the same kWh produced with a mix of natural gas (24,82%) and geothermal (75,18%) is 32,7 €/kWh. The benefits and difference which is 23,3 €/kWh will allow to finance the construction of the doublet. The annual production of the project is 81.980 kWh/ year with a turnover of 5.739 k €. The annual profit using geothermal is 1.918 K €.

This profit will pay back the investment cost in 7,45 years – meaning that after 8 years the community will start to gain about 2 million euros per year. (GeoDH, 2014). This demo example, shows the opportunities and economic benefit that may be gained from geothermal resources in combination with other energy resources in district heating.

[5] CAPEX = Capital expenditure

Table. 2.4.6.5. **Business Model - for Geothermal District Heating and Gas**

Years	Base	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
BASIC DATA																					
Project life (years)	20																				
Investments K €	14.300	7.150	7.150																		
Debt k €	12.297																				
Debt k €																					
Debt K €																					
Equity k €	4.000																				
Discout rate %	6																				
Interst rate %	3,2																				
Inflation %	2																				
Annual OM cost k €		0	0	2.683	2.737	2.791	2.847	2.853	2.910	2.968	3.028	3.088	3.357	3.424	3.493	3.562	3.634	3.706	3.781	3.856	3.933
Geothermal production				78.161	78.161	78.161	78.161	77.223	77.223	77.223	77.223	77.223	80.662	80.662	80.662	80.662	80.662	80.662	80.662	80.662	80.662
Geothermal selling price €/MWhr	70	0,00	0,00	70,00	72,10	74,26	76,49	78,79	81,15	83,58	86,09	88,67	91,33	94,07	96,90	99,80	102,80	105,88	109,06	112,33	115,70
Equity depreciation (linear) k €	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Profit taxation rate %	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal revenues k €				5.471	5.635	5.804	5.979	6.084	6.267	6.454	6.648	6.847	7.367	7.588	7.816	8.050	8.292	8.540	8.797	9.061	9.333
ECONOMIC ANALYSIS																					
Years of loan repayment	20	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Years of loan repayment	14							0	1	2	3	4	5	6	7	8	9	10	11	12	13
Years of loan repayment	9												0	1	2	3	4	5	6	7	8
Dept 1 repayment annuity k €		1.008	989	969	949	930	910	890	871	851	831	812	792	772	753	733	713	694	674	654	635
Dept repayment annuity k €								0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dept repayment annuity k €													0	0	0	0	0	0	0	0	0
Dept repayment annuity k €		1.008	989	969	949	930	910	890	871	851	831	812	792	772	753	733	713	694	674	654	635
Interest on debt k €		394	374	354	334	315	295	275	256	236	216	197	177	157	138	118	98	79	59	39	20
Interest on debt k €																					
Annula interests on debt (depti)																					
Interest on debt k €		394	374	354	334	315	295	275	256	236	216	197	177	157	138	118	98	79	59	39	20
Net income k €		-8.358	-8.339	1.619	1.749	1.883	2.022	2.141	2.286	2.435	2.589	2.747	3.018	3.192	3.370	3.555	3.745	3.940	4.142	4.351	4.565
Cost effectiveness		0,00	0,00	0,30	0,31	0,32	0,34	0,35	0,36	0,38	0,39	0,40	0,41	0,42	0,43	0,44	0,45	0,46	0,47	0,48	0,49
FINANCIAL RATIOS																					
Net present value (NPV) k €	**12.727**																				
Internal rate of return (IRR) %	**12,7**																				
Profitability index (PI)	**1,99**																				

2.5 Scenarios for a 50 MW Geothermal Power Plant

2.5.1 The Financial Model

The risk involved in new geothermal projects is generally a major barrier for the development, as well making it difficult to persuade independent power producers (IPP) and investors to accept the risk and complete the total financing. Geothermal projects require considerable initial capital and investment long before the stream of income. The World Bank, development banks, and development agencies have examined how they can best assist new geothermal projects in developing countries.

To explain this complicated problem one must present clearly the basic assumptions and results of financial analyses. It must be clear what matters most and which assumptions are essential. Case histories from countries which have attained successful development may be of aid in that respect. The case of Iceland is a good example, since in many countries the conditions for development may be similar to those in Iceland some 40 years ago. For comparison it may also be worth to examine why countries that have most of the natural conditions required have not succeeded in their development.

To illustrate the importance of financing geothermal projects Table 3.1 presents an accurate financial model for a conventional 50 MW geothermal power plant utilizing two-phase flow of steam and water from a high temperature field. A size of 50 MW is chosen as a recommended first step in the development of a new field. The model is based on discounted cash flow analysis at fixed prices in the beginning of year 2014.

The model outlines capital cost, operating cost, drilling of make-up wells, alternatives in financing, and the tariff required to meet expected ROE requirements. Cash flow in the period of construction and the period of operation is calculated as net present value (NPV) using weighted average cost of capital (WACC) after taxes. The calculation shows internal rate of return for the project (Project IRR), the internal rate of return for equity (Equity IRR) considering the cash flow net of financing, and the payback time. It then calculates the levelized cost of energy and its division due to investment cost and operating cost. The levelized cost is convenient in comparing different energy resources.

The capital cost is estimated to be 4 MUS$/MW and the annual operating cost, including the cost of make-up wells to maintain the flow of steam, is estimated to be 2 cents/kWh or 3,9% of the capital cost. It is assumed that 12 full size production wells are required, yielding an average electric generation of 4,2 MW/well. In addition 6 reinjection wells are required. Annual production at full capacity is assumed to be 90%, income tax 20% and loans are paid back in 25 years.

The table presents five scenarios of financing a project in a country beginning the development, and for comparison two scenarios are given for a new plant in Iceland which has the advantage of advanced development. In scenario A the project receives no initial grant but is financed by a company aiming, because of high risk, at 25% ROE. In scenario B an initial grant of 30 MUS$ pays the cost of exploration and the drilling of four “full size” 2500 m deep directional appraisal wells. The project is then taken over by IPP companies and investors aiming at 25% ROE. In the third scenario C it is assumed that the initial grant and appraisal have reduced the risk to a level where the IPP companies and investors accept 20% ROE. Scenario D assumes the same grant but corporate finance instead of project finance. The acceptable ROE requirements are assumed to be lowered to 12,5%. Finally, scenario E assumes no grant, 12,5% ROE and corporate finance as in D.

The table offers comparison of the different scenarios. IPP companies and investors will be reluctant to enter scenario A because of high risk. The tariff is calculated to be 13.27 cent/kWh for electricity delivered at the power plant. Levelized cost (LCOE) is 5.15 cent/kWh whereof 3.95 cent/kWh are due to investment but 1.19 cent/kWh due to operation. In scenario B the 30 MUS$ grant reduces the risk and attracts IPP companies and investors. The tariff is reduced to 10,19 cents/kWh but the levelized cost is not changed as the operating cost and the weighted average capital cost (WACC) have not changed.

Table 2.5.1.1. **Finance scenarios for a 50 MW geothermal power plant in a country starting geothermal development and a new 50 MW plant in a country advanced in the development.**

High temperature 50 MW single flash geothermal project		A country beginning geothermal development.					Country: Advanced development.	
			Project finance		Corporate Finance		Project Fin.	Corpor. Fin.
1. Capital expenditures, wells and steps in financing (+/-)		A	B	C	D	E	F	G
Plant size	MW	50	50	50	50	50	50	50
Capital expenditures: Capex over six years	**MUS$**	**200**	**200**	**200**	**200**	**200**	**150**	**150**
Capital expenditures: Capex per MW	MUS$/MW	4,0	4,0	4,0	4,0	4,0	3,0	3,0
Exploration and production wells	Nr.	12	12	12	12	12	9	9
Average well productivities	MW	4,2	4,2	4,2	4,2	4,2	5,6	5,6
Re-injection wells	Nr.	6	6	6	6	6	6	6
Financing of first drilling & scientific work	MUS$	30	30	30			22	
Financial Close in Project finance reached at	MUS$	60	60	60			35	
Total scientific work, drilling and re-injection	MUS$	100	100	100	100	100	58	58
Power plant, turbines, steamfield, etc.		100	100	100	100	100	93	93
2. Capital structure, interest, return on equity and WACC (+/-)		A	B	C	D	E	F	G
Equity: 30%	MUS$	60	51	51	51	60	45	45
Debt: 70%	MUS$	140	119	119	119	140	105	105
Grant	MUS$	0	30	30	30	0	0	0
Grant	% of Capex	0%	15%	15%	15%	0%	0%	0%
Interest on debt: % in real terms	%	6%	6%	6%	6%	6%	4%	3%
Required rate of return on equity	%	25%	25%	20%	12,5%	12,5%	14,0%	11,0%
WACC: Before tax	%	11,7%	11,7%	10,2%	8,0%	8,0%	7,0%	5,4%
WACC: After tax	%	10,9%	10,9%	9,4%	7,1%	7,1%	6,4%	5,0%
3. Plant capacity factor and annual generation (+/-)		A	B	C	D	E	F	G
Plant capacity factor	%	90%	90%	90%	90%	90%	92,5%	92,5%
Maintenance and internal power consumption	%	10%	10%	10%	10%	10%	7,5%	7,5%
Generation (MW x capacity x 365 x 24)	GWh/Year	394,2	394,2	394,2	394,2	394,2	405,2	405,2
Annual revenues	MUS$	52,3	40,2	34,6	26,5	30,6	21,6	17,0
4. Operation and Maintenance costs including make-up (+/-)		A	B	C	D	E	F	G
O&M incl. Make-up. Annual prod. decline 2-3%.	cent/kWh	2,0	2,0	2,0	2,0	2,0	0,85	0,85
O&M incl. Make-up. Annual prod. decline 2-3%.	% of CapEx	3,9%	3,9%	3,9%	3,9%	3,9%	2,3%	2,3%
O&M incl. Make-up. Annual prod. decline 2-3%.	MUS$/Year	7,9	7,9	7,9	7,9	7,9	3,4	3,4
5. Tax, depreciation and years in calculation		A	B	C	D	E	F	G
Income tax	%	20%	20%	20%	20%	20%	20%	20%
Depreciation, straight line	Years	25	25	25	25	25	25	25
Loan maturity period	Years	25	25	25	25	25	25	25
Operating life time	Years	25	25	25	25	25	25	25
6. Financial calculations: Tariff, IRR, Payback and LCOE		A	B	C	D	E	F	G
Tariff	cent/kWh	13,27	10,19	8,78	6,72	7,76	5,33	4,21
Project IRR (from free cash flow to firm: FCFF)	%	15,3%	11,3%	9,3%	5,9%	7,7%	8,3%	5,7%
Project NPV	MUS$	53,9	5,1	-1,3	-18,3	8,4	23,3	9,7
Equity IRR (from free cash flow to equity: FCFE)	%	25,0%	25,0%	20,0%	12,5%	12,5%	14,0%	11,0%
Equity NPV	MUS$	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Pay-Back	Years	6,0	7,7	9,1	12,4	10,3	10,3	13,1
Discounted Pay-Back (disc. at WACC)	Years	11,0	22,2			22,0	17,5	22,1
Levelized Cost of Energy	cent/kWh	5,15	5,15	5,00	4,76	4,76	2,97	2,82
a) LCOE Capital	cent/kWh	3,95	3,95	3,72	3,34	3,34	2,35	2,16
b) LCOE O&M	cent/kWh	1,19	1,19	1,28	1,42	1,42	0,62	0,67
7. Other assumptions:		No resource tax (royalties), tax holidays or carbon credit revenues.						

In scenario C the expected ROE is reduced from 25% to 20%. The tariff is reduced to 8.78 cents/kWh and the levelized cost to 5,00 cents/kWh as the reduced ROE lowers WACC.

This scenario would be of interest in a country beginning to develop geothermal resources. The difference in tariff from scenario A to C is 4,49 cents/kWh which corresponds to nearly 18 MUS$ saving per year for the consumers. In 25 years of operation the difference adds up to 442 MUS$ at a fixed price index. Scenario D assumes a grant, corporate finance instead of project finance and lower ROE. The tariff is reduced to 6,72 cents/kWh. In scenario E there is no grant and the tariff is raised to 7,76 cents/kWh.

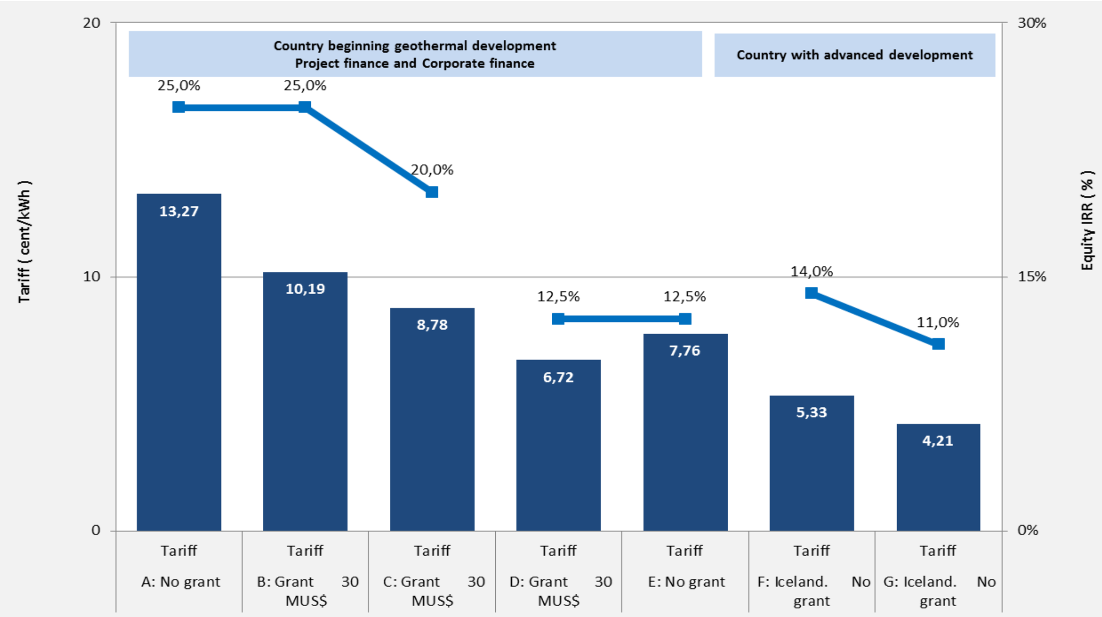
Table 2.5.1.2. **Tariff, return on equity (ROE), internal rate of return (IRR), and discounted payback years for a 50 MW plant in a country starting geothermal development and a 50 MW plant in a country advanced in the development.**

High emperature single flash 50 MW plant	Scenario	CapEx MUS$	Grant MUS$	Return on Equity	Financing	Tariff cent/kWh	ROE %	IRR %	Discounted Pay-back years	Project NPV MUS$	Tariff A=100%
Country: Beginning geothermal development.	A	200		25,0%	PF	13,27	25,0%	15,31%	11,0	53,9	100%
	B	200	30	25,0%	PF	10,19	25,0%	11,31%	22,2	5,1	77%
	C	200	30	20,0%	PF	8,78	20,0%	9,26%	0,0	-1,3	66%
	D	200	30	12,5%	CF	6,72	12,5%	5,87%	0,0	-18,3	51%
	E	200		12,5%	CF	7,76	12,5%	7,66%	22,0	8,4	58%
Country: Advanced development.	F	150		14,0%	PF	5,33	14,0%	8,28%	17,5	23,3	40%
	G	150		11,0%	CF	4,21	11,0%	5,67%	22,1	9,7	32%
PF Project finance. CF Corporate finance.											

It is of interest to compare the scenarios A to E for a 50 MW plant presented in Table 3.1, with scenarios for a new 50 MW plant projected in countries which have attained successful development, such as Iceland. They are shown in columns F and G of the table. Conditions in Iceland are in many respects more favourable than in countries starting geothermal development. The geothermal fields are often located near inhabitable areas with existing electrical network and power companies have knowledge and experience in erecting geothermal power plants. Scenario F assumes capital cost near 3 MUS$/MW and a total cost of 150 MUS$ for a 50 MW plant.

The difference in capital cost of 1 MUS$/MW results from cheaper drilling in Iceland and the expected average yield of 5,6 MW/well. The plant in Iceland would require 9 production wells and 6 reinjection wells. The annual operating cost is expected to be 0,85 cents/kWh or about 2,3% of the capital cost. This is considerably lower than in a country starting geothermal development. The scenario assumes project finance with 14% ROE and 4% real interests on loans. The result is a tariff of 5,33 cents/kWh and a LCOE of 2,97 cents/kWh. The LCOE can be divided to 2,35 cents/kWh for capital and 0,62% cents/kWh for operation and maintenance (O&M). Scenario G assumes corporate finance for the Icelandic project. The ROE is lowered to 11%, 3% interest on loans and the tariff to 4,21cents/kWh. The results for the different scenarios for a 50 MW plant and the example of a new 50 MW plant in Iceland are summarized in Table 2.5.1.1 and Figure 2.5.1.1

Fig. 2.5.1.1. **Tariff for a 50 MW plant in a country starting geothermal development (Scenarios A to E) and a new 50 MW plant in a country advanced in the development (Scenarios F and G).**



The availability of an initial grant may have a decisive impact on whether a geothermal project is realized or not in a country that is starting geothermal development. The difference between scenarios A and D shows that a grant and the resulting lower ROE requirements lead to a considerably lower tariff. As to the importance of grants one may mention that under the supervision of the World Bank (Global Geothermal Development Plan) certain donors have decided to support a 50 MW geothermal power plant in Djibouti with a 31,2 MUS$ grant. That grant shall be used to drill four full size exploration wells and provide sufficient data to decide whether to continue the project or not. Djibouti has devoted considerable effort and funds to explore geothermal fields. The country has no hydropower and neither coal nor oil. Domestic electricity production comes from diesel engines and the electricity price is among the highest in Africa. With the aid of a development bank, Djibouti has established electric connection to Ethiopia and a power purchase agreement between the countries has been signed. The agreement is however with limitations as power plants in Ethiopia are subject to unstable river flow. The project of Djibouti will be monitored by many countries interested in developing their geothermal resources and may be considered a critical test for initial geothermal development.

It is important to clarify the investment capital that is required in geothermal projects. Firstly, a thorough geological, geochemical and geophysical exploration identifies a promising field. The resource must then be verified by exploratory and appraisal drilling. If four full size wells of 2.500 m depth are drilled, the total investment of these investigations will amount to 30 MUS$. If the results are promising and justify continuation, further drilling must confirm 50-80% of the steam required for the projected plant to satisfy the criteria of loans from investors and development banks. This phase will cost another 30 MUS$. Having confirmed the steam, the project reaches Financial Close. Thirdly, additional wells must be drilled to provide steam for the projected plant and reinjection wells for the effluent water. These are assumed to cost 40 MUS$, bringing the total cost of scientific work and drilling up to 100 MUS$.

This large initial investment in geothermal projects has been the main barrier in the development and is difficult to overcome. The problem has been not been dealt with much, but full understanding is essential when seeking alternatives.

Figure. 2.5.1.2. **Breakdown of cost for a 50 MW project in a country beginning geothermal development. Source: ESMAP Geothermal Handbook 2012.**

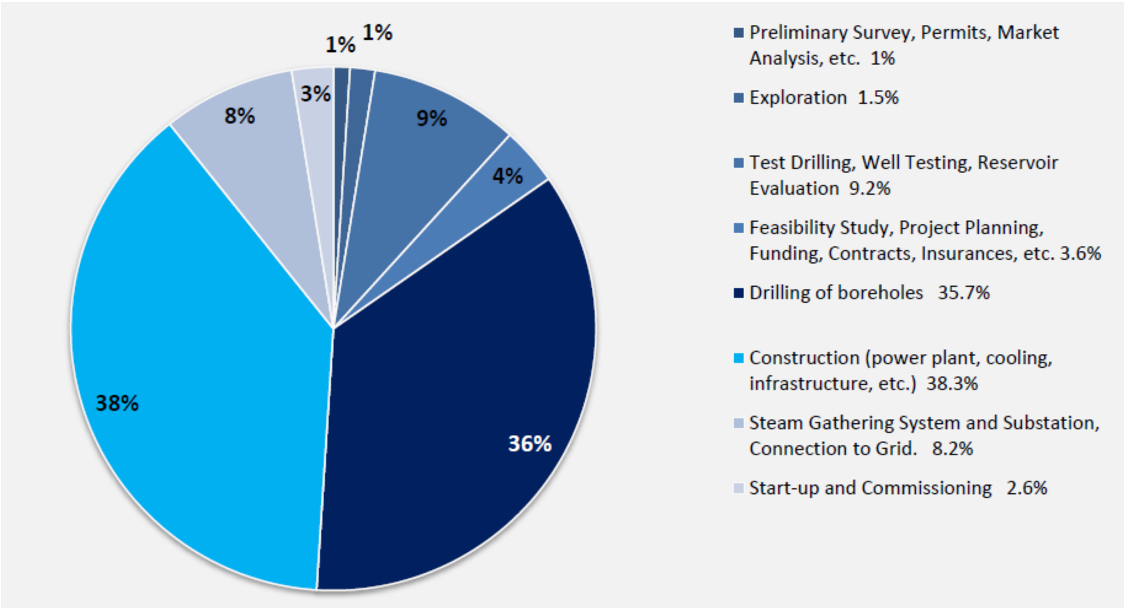


Fig. 2.5.1.2 shows a breakdown of cost for a 50 MW project in a country beginning geothermal development. Estimates of capital expenditure from various organisations range from 2 to 5 MUS$/MW, the difference being mainly due to cost of drilling and steam production. *ESMAP (2012)* has estimated the medium case to be 3,92 MUS$/ MW or 196 MUS$ for a 50 MW plant. Engineers involved in the design and operation of geothermal power plants believe that, in many cases, 2–3% of the upfront costs of a 50 MW geothermal power plants should be estimated to go into annual operating expenses. The analysis in scenarios A to E assumes annual operating expenses of 2 cent/kWh, or 3,9% of the upfront costs. This includes maintenance of steam production.

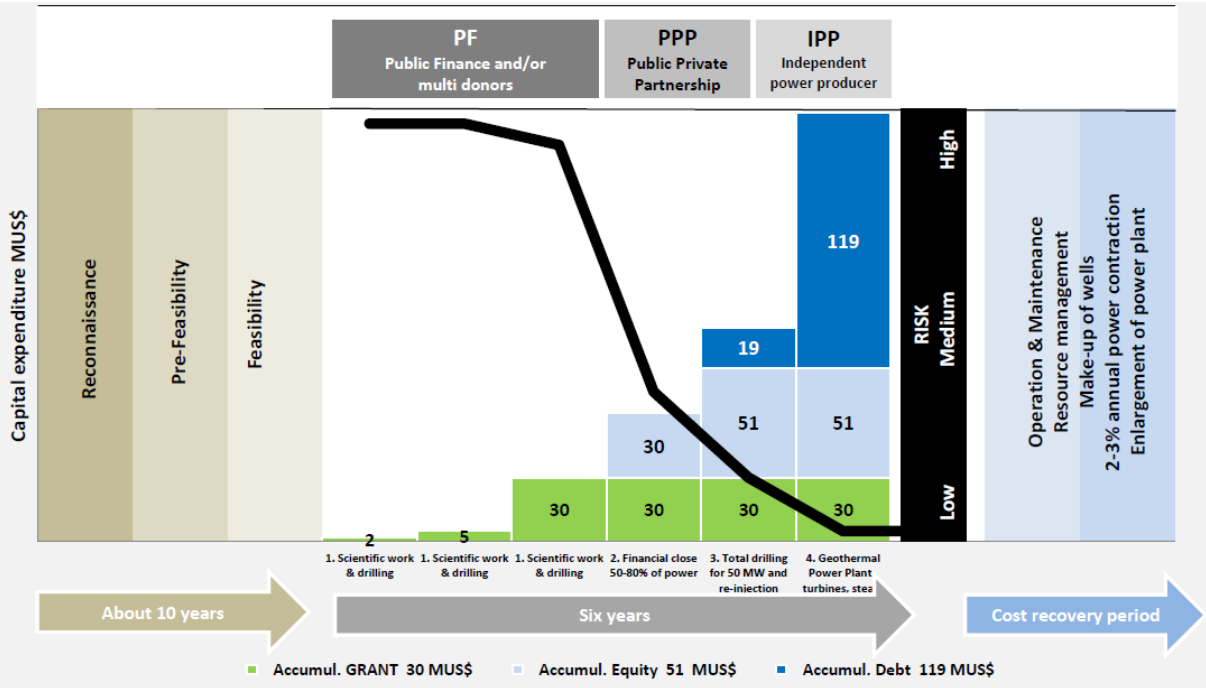
Sensitivity analysis

Sensitivity analysis has been carried out for the scenarios A to G, examining in detail the effect of variations in assumptions on the tariff and the rate of return. For these scenarios the most important items are the mode of investment, capital cost (WACC), grant and return on equity and timing. For example in scenario B an increase in capital cost by 25% would lower the return on equity from 25% to 17,1% and the internal rate of return from 11,31% to 8,92%. If the interest rate increases by 25% the return on equity is reduced to 23.7%. If the operating cost (O&M) rises by 25% the return on equity is lowered to 23,2%. The scenarios are calculated over 25 years but the results are not much affected by extending that time to 30 or 40 years as the last years count little in present value calculations. It is important to examine these items closely, especially the cost and timing of drilling.

2.5.2 The Implementation and Financing

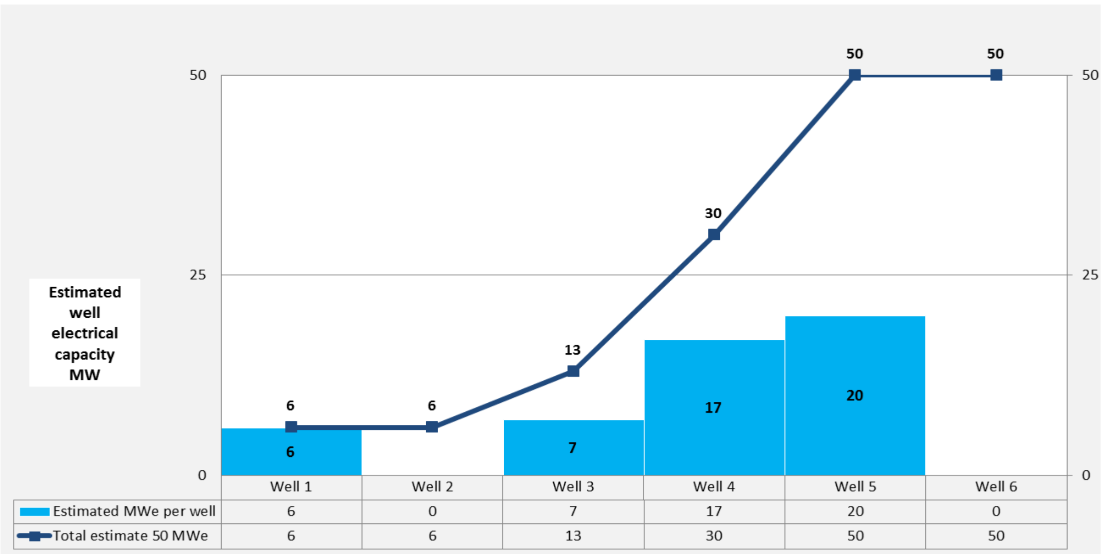
The development of a geothermal project from first reconnaissance to start-up of generation is a process that takes more than 10 years. Fig. 2.5.2.1 illustrates the progress and the major steps in financing a 50 MW power plant.

Figure 2.5.2.1. **Progress and financing of a 50 MW geothermal power project**



The first issue is to prepare reconnaissance for promising fields and define the role that geothermal energy might play in the future electrical system. If geothermal exploitation is considered feasible the next step is to build up knowledge and conduct research preparing the ground for this development. Basic information about the most promising areas for development must be collected. Public authorities must be involved and provide support. It is also necessary to search for investors or companies that might have interest in geothermal projects and electricity generation. There, one must face the financial barriers involved.

Figure 2.5.2.2. **Example of initial drilling in an Icelandic field**



For a 50 MW geothermal power plant exploration, drilling and reservoir evaluation demand an initial investment of 30 MUS$ and another 30 MUS$ are required to prove the field capacity and reach Financial Close. The total capital cost of the plant is estimated 200 MUS$ and the time from first exploration drilling to first generation is about 6 years.

The black line in Fig. 2.5.2.1 indicates how the risk declines as the drilling progresses and in the final stage of construction the risk is no greater than in other energy projects. After start of generation operation takes over. The scheduled cost recovery period is usually 25 years but the lifetime of a geothermal plant can be much longer. It is generally recommended that geothermal plants are built up in several steps. Enlargements are thus natural for geothermal projects if the reservoir has reserves in capacity.

Fig. 2.5.2.2 presents an example from a field in Iceland. Six wells have been drilled and the output is considered sufficient for 50 MW of electric generation. It is still uncertain how many additional wells are required to supply a 90 MW plant. One may figure the different situation of the project if well no. 6 had been drilled as one of the first four in the sequence. Then the proven steam after 4 wells would only have been sufficient for a production of 13 MW. In the scenarios A to E for a 50 MW plant the average yield per well was assumed 4,2 MW per well. The first 4 wells would thus have yielded 3,8 MW less than the 16,8 MW assumed in the scenarios. Which effect would that have had on the decision whether to continue or not? What changes the situation for better in the example are wells 4 and 5 which are very good producers of 17 and 20 MW. With these the total production of 6 wells becomes 50 MW or 8,3 MW per well.

The scenarios A to E assume that 12 wells are needed for a 50 MW plant. If only 6 wells are required the drilling cost is considerably lowered and the tariff reduced. For scenario B e.g. the tariff would be lowered from 10.19 cents/kWh to 8 cents/kWh. In other cases more than 12 wells might be required and that would raise the tariff correspondingly. Many ideas have been put forward regarding mitigation funds that could insure projects against large deviations in drilling cost. Insurance companies on the common market have worked on such proposals. The insurance fees are though likely to be high and to reflect the risk involved in drilling in new fields.

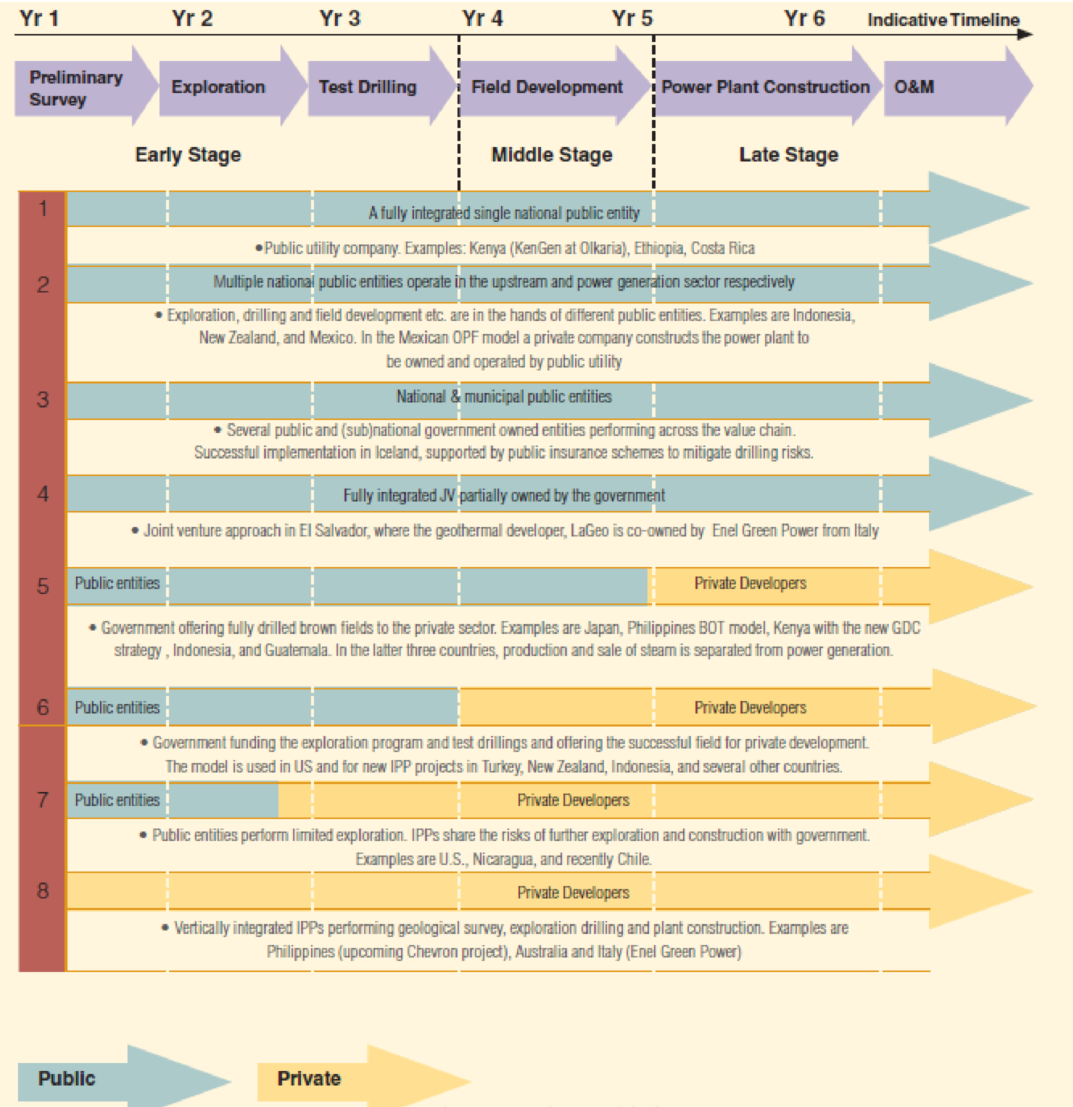
3 International Development and Financing of Geothermal Projects

3.1 International Development Models of Geothermal Projects

When looking at international experience regarding development of geothermal models one finds that there are different models all over the world, as can be seen in enclosed figure with eight different models that have been utilized in the international practice of geothermal power development. As the figure shows, the early stage of geothermal project development depends heavily on public sector investments, but the private sector has a tendency to enter the project at later stages.

The financing arrangements and the risk can vary widely. In Mode 1 the project is financed either by the national government and state-owned utility, or by government in conjunction with grants from donor nations and loans from international lenders. In this model, risk is borne almost exclusively by the national government and will only be reduced by revenues from the sale of electricity and by grants from donor nations, if available. In the enclosed figure it can be seen that most private investors stay away from taking the full resource risks in geothermal projects. Model 7 is a more typical case for a privately led development. In this model, government companies perform limited exploration, the data being in the public domain and accessible by developers. (ESMAP, 2012)

Figure 3.1.1. **Different models of private and public geothermal projects**



Sources: ESMAP, 2012

3.2 International – Financing Models of Geothermal Projects

3.2.1 Financial Options for Different Project Phases

As the previous discussion indicates, mobilizing capital for geothermal development projects from commercial sources is more complicated than for conventional power projects, and for most other renewable energy technologies. This is especially true for early stages of project development—particularly the test- and initial production drilling, when the risk is still high and the costs involved can be millions of dollars. However, the conditions for financing are rather different at various phases of the project, each phase calling for a different menu of financing options. Table 3.1 summarizes these options, breaking the geothermal development process into three distinct stages:

- early stage (high risk);
- middle stage (medium risk); and
- late stage (low risk).

Figure 3.1.2. **Financing Options for Different Stages of a Geothermal Development Project**

Project Development Stage	**Early Stage** Surface, Exploration, Test Drilling Initial Production Drilling	**Middle Stage** Resource, Confirmation, Field Development, Complete Production Drilling	**Late Stage** Power Plant, Engineering, Construction and Commissioning
Risk of Project Failure	**High**	**Medium**	**Low**
Typical Financing Sources	• Balance sheet financing by large developer • Private equity (project finance) possible but with high risk premium • Government incentives (capital cost sharing, soft loan or guarantee) • Concessions funds from international donors.	• Balance sheet financing, corporate debt or bonds issued by a large developer • Public equity issuance • Construction (short-term) debt • Loan guarantee by government • Long-term debt or guarantees from IFIs • Export credit agency financing	• Construction debt • Long-term debt from commercial sources • Long-term debt from IFIs • Partial risk guarantee or partial credit guarantee instruments to attract or improve tenor and terms of commercial debt • Export credit agency financing

Sources: ESMAP, 2012

It is hardly a possible option to depend on commercial capital for geothermal development even in developed countries. As it is difficult to get access to support capital in those markets, incentives like loan guarantees and investment tax credits are often granted by government to geothermal developers. As the challenges to attract private capital to geothermal projects are often greater in developing countries, the burden of the public sector (governments, international donors, and financial institutions) to contribute financial support is likely to be an essential element of success in mobilizing capital to such projects. It has been estimated by ESMAP that since the financial crisis in 2008, development banks have provided 53% of total geothermal project financing, and the financing provided by those banks was a major factor in bringing geothermal project financing to a record-high level of US$ 1,9 billion invested in 2010 (BNEF 2011). (ESMAP I. W., 2012).

3.2.2 Geothermal Development Assistance – Global Lessons Learned

When looking for guidelines for successful Geothermal Development Assistance at Global level, is it valuable to look for key lessons learned from International Financial Institutions. The Energy Sector Management Assistance Program (ESMAP) is a global, multi-donor technical assistance trust fund administered by the World Bank and cosponsored by 13 official bilateral donors, established 1983.

Based on their long and professional experience - their recommendation regarding geothermal Development Assistance is as follows: "*Official Development Assistance (ODA) available from multilateral and bilateral development banks, as well as from climate finance facilities, has a key role to play in supporting geothermal energy development. The concessional nature of capital supplied by climate finance vehicles, such as the Clean Technology Fund (CTF) and the Scaling-up Renewable Energy Program (SREP), coupled with the involvement of major international development organizations, such as multilateral development banks (MDBs), creates unique opportunities for leveraging capital from various other sources to support low carbon investments.*

Considerable efforts and resources in recent years have been devoted to attempts to set up funds that use concessional financing to mitigate geothermal resource risk. Two significant programs, the Europe and Central Asia (ECA) GeoFund and ArGeo, supporting the development of such funds have been initiated under the auspices of the World Bank. In both cases, the Global Environment Facility (GEF) has been the main source of concessional capital. The design and operation of these programs has helped the international community learn valuable lessons and develop a better understanding of the available options for the future.

Key principles underlying the design of a successful global or regional MDB-supported facility to promote geothermal development have emerged from this experience that can be summarized as follows:

1. *The facility needs to be well staffed and professionally managed.*
2. *It needs to have a critical mass of concessional capital sufficient to leverage co-financing from the market at large—including private sector debt and equity.*
3. *The greatest impact from concessional financing on the bankability of a typical mid-size geothermal power project can be expected when such financing is for the test drilling phase of project development.*
4. *Success during the test drilling phase is key to bridging the crucial gap between the early start-up phases that are unlikely to attract debt financing and the more mature phases of the project when financiers begin to see the project as increasingly bankable.*
5. *The geographic scope of the project portfolio should cover areas containing well established and highly promising geothermal reservoirs, principally those suitable for electricity generation. The areas should also be sufficiently wide to allow for a diverse portfolio of geothermal project locations to reduce the concentration of resource risk.*
6. *The operational procedures of the facility should include incentives for the management to apply prudent investment risk management principles and techniques.*

Possible designs for a donor-supported geothermal development facility include: a direct capital subsidy or grant facility; a loan (on-lending) facility; and a risk guarantee or insurance facility. The choice of the design depends on the particular circumstances of the country or region and of the donor agencies involved. In principle, any of these designs can reduce the private investors' risk and thus reduce the risk premium for the return on equity and the overall cost of capital, opening up new opportunities for attracting investments to scale up geothermal power." (ESMAP I. W., 2012)

II GEOTHERMAL RESOURCES IN THE ANDEAN REGION

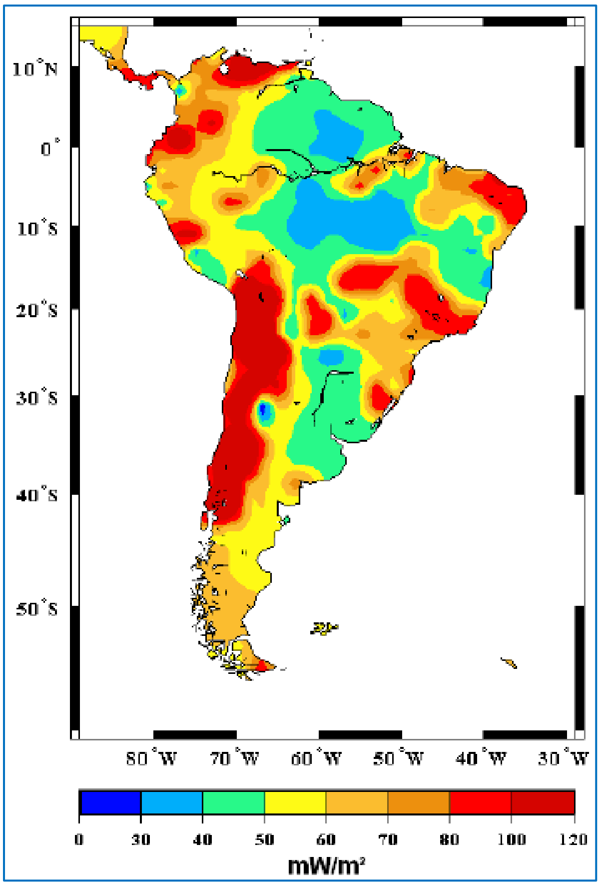
4 The Andean Region, geothermal challenges and opportunities

4.1 Geothermal Resources in S-America

In a recent study by Ingimar G. Haraldsson, Deputy Director of The United Nations University Geothermal Program in Iceland (UNU-GTP), it is stated that “South America holds vast stores of geothermal energy that are largely unexploited. These resources are the product of the convergence of the South American tectonic plate and the Nazca plate that has given rise to the Andean mountain chain. High temperature geothermal resources in Bolivia, Chile, Colombia, Ecuador and Peru are mainly associated with volcanically active regions, although low temperature resources are also found outside them. All of these countries have a history of geothermal exploration, which has been reinvigorated with recent world-wide attention to the utilization of environmentally benign and renewable resources. The paper provides an overview of their main regions of geothermal activity and recent developments in the geothermal sector are reviewed.

South America has abundant geothermal energy resources. In 1999, the Geothermal Energy Association estimated the continent’s potential for electricity generation from geothermal resources to be in the range of 3.970-8.610 MW, based on available information and assuming the use of technology available at the time (Gawell et al., 1999). Subsequent studies have put the potential much higher, as a preliminary analysis of Chile alone assumes a generation potential of 16,000 MW for at least 50 years from geothermal fluids with temperatures exceeding 150°C, extracted from within a depth of 3.000 m (Lahsen et al., 2010). In spite of this enormous potential, the only geothermal power plant which has been operated on the continent is the 670 kW binary demonstration unit in the Copahue field in Argentina, which was decommissioned in 1996 (Bertani, 2010).”

Figure 4.1.1. **Heat Flow Map of South America**



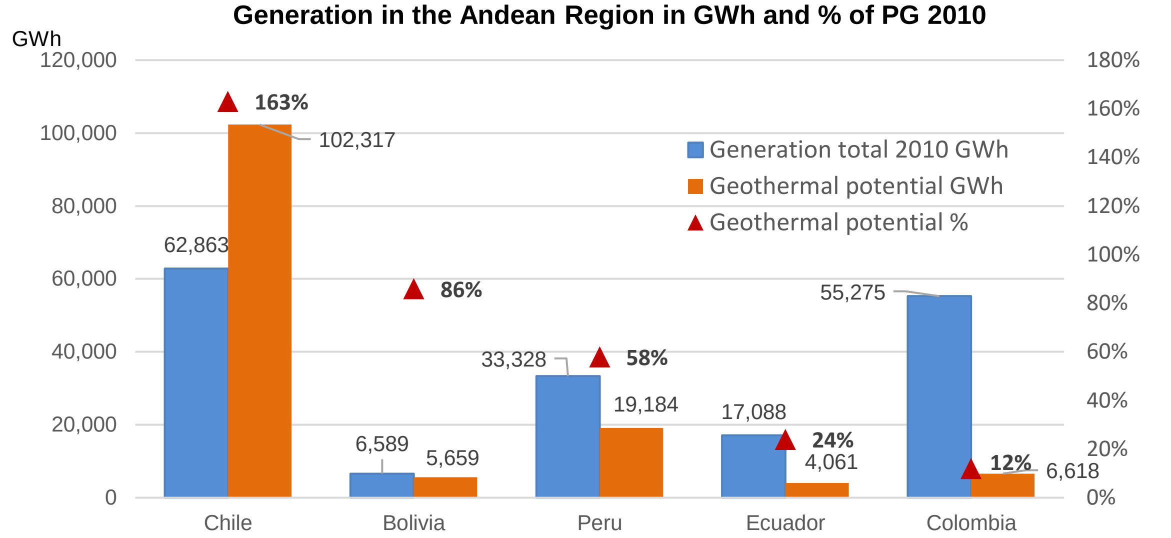
In a recent study, Cardoso et al. (2010) employed updated data sets on crustal seismic velocities, gravity anomalies, radiogenic heat production, terrestrial heat flow and thermal springs to produce a heat flow map of South America Figure 4.1.1. Their results indicate that most of the continent’s high temperature resources occur within:

- Well known sectors of magmatic activity in Chile;
- The Altiplano region of Bolivia;
- Isolated pockets along the western Andean belt in Peru; and
- Several localities along the magmatic arc covering western Ecuador, central volcanic belt of Colombia and southern Venezuela.

While many of these regions have long been known for volcanic and geothermal activity, the heat flow map is helpful for visualization on a continental scale.” (Haraldsson, Geothermal Activity in South America, 2013).

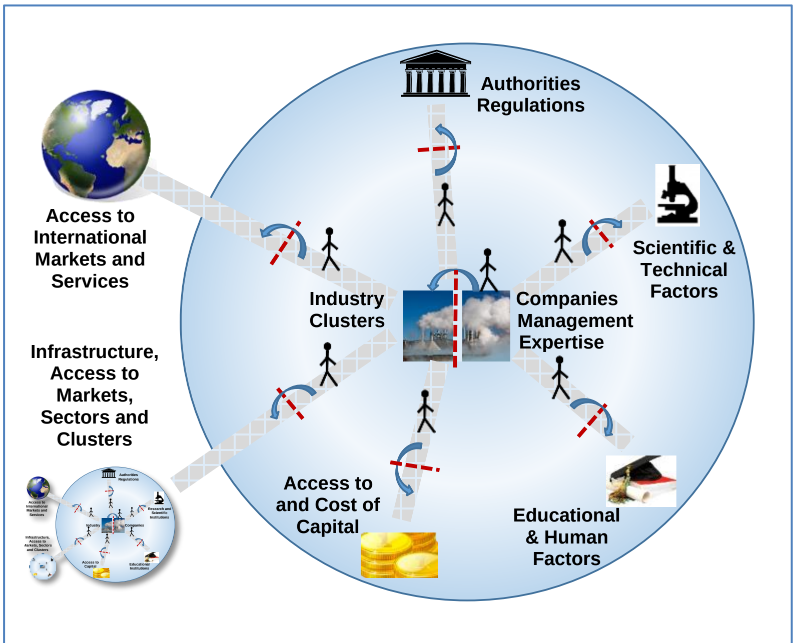
Based on World Energy Council 2007 Survey of Energy Resources, the US EIA and Haraldsson 2013, it has been estimated that in the Andean countries there is abundant geothermal generation potential. In comparison to total generation the geothermal potential generation in these countries are: in Bolivia 86% of 6.589 GWh, Chile 163% of 62.863 GWh, Colombia 12% of 55.275 GWh, Ecuador 24% 17.088GWh and Peru 58% of 33.328 GWh. (Haraldsson, Geothermal Activity in South America, 2013).

Figure 4.1.2. **Comparison of Power Generation (PG) 2010 and Potential Geothermal Generation in the Andean Region in GWh and % of PG 2010**



Sources: US EIA 2010. Haraldsson 2013

Figure 4.1.3. **Competitiveness of the Geothermal Sector**



Source: Sölvell & Lindquist 2012, Amended, B. Petursson, National Energy Authority, 2014

Regardless of this enormous geothermal potential possibility in the ANDEAN countries, there is still no geothermal generation power plant in operation. Geothermal energy has been an under-developed energy source in South America, but it has the potential of providing reliable base load electricity, reducing greenhouse gas emissions, lessening reliance on imported energy, bringing electricity to the rural poor and possibly lowering electricity prices. The exploitation of geothermal resources can thus help raise the standard of living in the countries along the Andean mountain range, while also contributing to the UN Millennium Development Goals and a better worldwide environment. (Haraldsson, Geothermal Activity in South America, 2013).

Evaluation of the Geothermal Sector – Opportunities and Policy Options

When formulating policy recommendations for the geothermal sector in the ANDEAN Region, the enclosed model of seven factors of geothermal competitiveness, challenges and opportunities, was used to highlight the key elements for policy recommendations and options in the concerning countries. (Petursson, 2014, 2012)

Success for the geothermal sector in the concerning countries is not only based on engineering planning in concerning projects, but also on several other policy factors, including these seven factors for competitiveness, in addition to international and Icelandic geothermal lessons learned.

4.2 Peru

4.2.1 Background information

Geographic Location

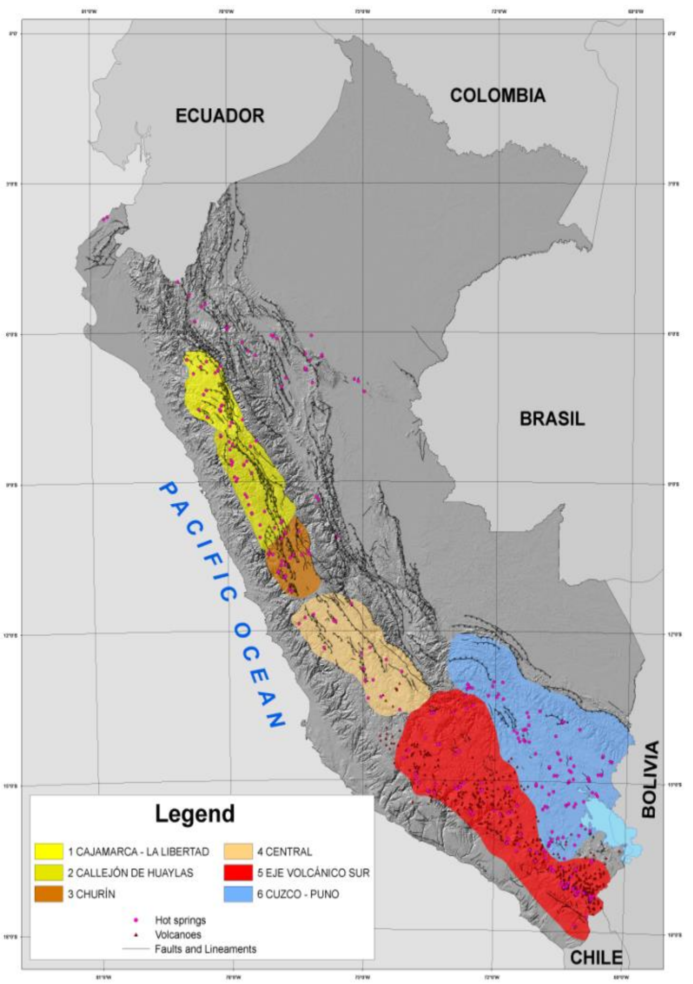
The Republic of Peru is located in the western and inter-tropical part of South America. It borders Ecuador and Colombia to the north, Brazil to the east, Bolivia to the southeast, Chile to the south and the Pacific Ocean to the west. Peru is the third largest country in South America with a large diversity of ecosystems and natural mining and energy resources.

Population and Economy

The population of Peru is 31 million inhabitants, GDP 206 billion US$, GDP per capita is 6.700 US$ and annual increase of inflation was 2,8% in 2013, general government debt as % of GDP was 19,6% and government credit rating 64,9 (of 1-100). The most problematic factors for doing business in Peru are: Inefficient government bureaucracy 22%, corruption 15%, restrictive labour regulation 12%, inadequate supply of information 10% and inadequate educated workforce 8%. (Forum, 2014).

Geothermal Potential

The largest part of the geothermal resources identified in Peru are located along the Andean mountain range associated to quaternary volcanism. The International Geothermal Association (IGA) reported on their web page that Peru would have a potential capacity of 2,4 MW_t (thermal MW) by 2010, but there are no further details about the applied methodology or any source of this number.



Additionally, on December 2009, the Japan International Cooperation Agency (JICA), INGEMMET, and Peru's Ministry of Energy and Mines (MEM) started the elaboration of the Master Plan for Development of Geothermal Energy in Peru, reporting 61 areas with geothermal energy potential, from which 13 were selected as the ones with the highest potential.

Unfortunately, the official results have not yet been published for this research. Nonetheless, it is estimated that Peru has a potential capacity of 3.000 MW. Besides, there are studies of 2 projects with a minimum of 200 MW total, they are both located in region W of the Southern Volcanic Belt in Tacna, in the geothermal fields of Borateras (50 MW) and Calientes (150 MW). Despite favourable conditions, the drilling of the first well has not begun yet, and the construction of the first station is unclear as well.

The installed generating capacity in Peru is composed of 45 power plants with a rating of over 18 MW which have a total capacity of 6.963 MW. This group is formed by 23 hydroelectric plants adding up to 3.152 MW and 28 thermal power stations with a combined capacity of 3.811 MW. Nine of these thermal facilities are operating with natural gas and have a total capacity of 2.658 MW.

The following diagram appears in the IRENA Report showing the development phases on a typical geothermal power generation project and some of the barriers that IRENA have been identified in Peru to the deployment of this renewable energy, which will be discussed. (IRENA, Initiative for the Development of the Geothermal Energy in the Andean Region, Peru, 2013)

Years		1	2	3	4	5	6	7	8	
Exploration	Preliminary Survey									It is required to have an environmental study and there are no standardized criteria or specific guidelines for geothermal projects. There are no specialized human resources in geothermal energy within the Ministries and regulating organizations. The validity period for Phase 2 of exploration is too short to develop all the required research. There is not enough information within society and local communities on the benefits of geothermal energy and there is opposition to it in some regions.
	Preliminary exploration studies									
	Administrative procedure to obtain the authorization for exploration									
	Exploration Phase 1.									
	Geological, geophysical and geochemical studies									
	Exploration Phase 2.									
	Exploratory wells drilling (at least 3 wells of no less than 1,000 meters.									
	Well and reservoir testing									
Research, Engineering and Management	Basic engineering									There are several regions with geothermal potential that have been defined as ecological reserves and the authorities have not defined the treatment that will be given to these areas regarding geothermal exploitation. The lack of human resources specialized in geothermal energy can slow down all stages and increase the cost.
	Environmental studies									
	Engineering studies									
	Administrative procedure to obtain the concession for exploration									
Construction	Roads and Access									Currently there are no projects in this stage. However an issue that must be solved is the acceptance of geothermal projects within communities.
	Local permits									
	Production well drilling									
	Re-injection well drilling									
	Power plant construction (EPC)									
	Transmission lines									
	Commissioning									

This diagram gives a good summary over main challenges regarding general power plant generation project process in Peru. As can been seen from this diagram, the main challenges in Peru are the lack of human resources specialized in geothermal energy, that can slow down all stages and increase the cost.

This kind of mapping of challenges and opportunities within the typical geothermal projects process is a valuable assessment and tool, towards constructive policy proposals in the sector.

4.2.2 Main Challenges

Authorities and Regulatory Factors
The Ministry of Energy and Mines, the Administrator Organization for the Investment in Energy and Mines (OSINERGMIN), the Committee for the Economic Operation of the System (COES) and the National Institute for Mining and Metallurgy (INGEMMET).

- Lack of policy to promote investments for geothermal energy.
- Lack of human resources in administration with expertise on geothermal energy.
- Regional differences in land ownership regulation.
- Lack of flexibility in the environmental permits granted.
- The requests for environmental assessments are not standardized, but should be.

Industry, Companies, Projects
In the Republic of Peru, the initiatives in geothermal development were driven by the INGEMMET. Although there is a lot of interest from the private sector in the development of geothermal exploitation for the generation of electricity, there are no operating geothermal projects within the region.

- There are no well drillings despite approval to private parties.
- Up until April 2012, there have been 21 authorizations issued by DGE.

Scientific and Technical Factors
At the INGEMMET, there are technicians with geothermal knowledge, but they are not participating directly in the tasks of geothermal promotion, authorization and regulation.

- Imported technical teams are present for almost every geothermal activity.
- Most of the technical degrees and specializations are oriented towards the mining sector.

Educational and Human Factors

- Lack of specialists in geothermal topics at the scientific, engineering and technical levels.
- Lack of specialists in environmental assessments for geothermal projects.
- Lack of specialized services companies.
- Some donors have offered geothermal training courses.

Access to, and cost of Capital
The lack of sources of financing for geothermal development happens all along the Andean region, because the governments of the countries now avoid being guarantors of the loans that are offered to the developers. This is probably one of the main reasons why not a single kW of electricity is generated with geothermal energy in the region.

- It has been impossible to finance geothermal projects, despite geothermal resources.
- No financial institution is offering financing for the development of geothermal projects.
- Authorities are more supportive of the development of hydroelectric stations than geothermal.

Infrastructure, Access to Markets, Sectors and Clusters

- Difficult access to transmission lines in areas with geothermal potential.
- Standards for geothermal projects are not in place.

Access to International Markets and Services
The value and importance of international cooperation is of critical importance in a complex development industry and projects like geothermal. It is beneficial to get quick access to knowledge, education, techniques, finance etc. to speed up the process based on good practice learned.

- Lack of international cooperation in various fields of geothermal expertise and finance.

4.2.3 Opportunities and Policy Options

There are several options regarding geothermal possibilities and policy formulation, based on opportunities and by steps towards overcoming barriers and challenges already identified. The opportunities and policy options are for example:

Authorities and Regulatory Factors

- Publicise the characteristics and benefits of geothermal energy for regional development
- Design regulation specific to the promotion of direct uses of geothermal energy
- Promote cooperation with international organisations.

Industry, Companies, Projects

- Promote alliances with research centres and educational institutions for the formation of specialised human resources.
- Promote cooperation with IFI for financing, donor support and consulting.
- Organize fora, workshops and conferences to improve knowledge on geothermal energy.
- Identify geothermal energy-related productive chains.

Scientific and Technical Factors

- Promote relationships with industry.
- Promote alliances with research centres and educational institutions for the formation of specialised human resources.

Educational and Human Factors

The Centre of Renewable Energies from the National Engineering University, in Lima, offers some geothermal-related subjects, but there is no further support for the generation of the technicians needed for the geothermal industry**.**

- Creating seminars and specialized courses on the different stages of a geothermal project and adding them to the existing engineering degrees.
- Give the personnel technical training to participate in the different stages of a project.
- Implement programs for scientific development
- Implement programs for technical development.

Access to, and cost of Capital

- Promote additional access to financing geothermal projects – domestic and international.
- Increase access to capital by providing capital to exploration and test drilling e.g. soft loans or donor grants. The financial structures must include the risks at the beginning of projects.
- Operating costs of geothermal power plants are low and are not affected by fossil fuel prices.

Infrastructure, Access to Markets, Sectors and Clusters

- Develop options to connect transmission lines to areas with geothermal potential.
- Promote alliances with research centres and educational institutions for the formation of specialised human resources.
- Promote training in the banking system for the development of financial mechanisms specific to geothermal energy.
- Awareness; organize workshops & conferences to improve knowledge of geothermal energy.
- Increase the available knowledge about opportunities and benefits of geothermal resources.

Access to International Markets and Services

- Support international cooperation in area of geothermal knowledge, training and service.
- Promote international cooperation with IFI and donors on finance, grants and funding.
- Support international consulting cooperation on various fields of geothermal expertise.
- See addition elements regarding Capacity building chapter 9.
- See additional items, in Conclusion chapter 10.
- See additional items in chapter 4.3. Iceland Partner in a Large 500 million US$ - WB Geothermal Project in Africa

4.3 Chile

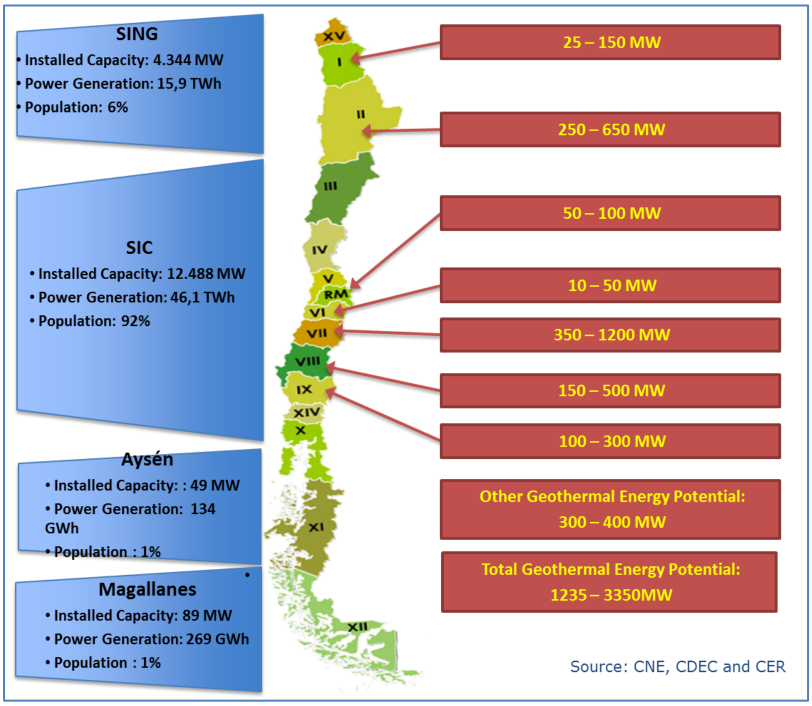
4.3.1 Background information

Geographic Location
Chile is located on the south-western end of the American Continent, between the Andean mountain range and the Pacific Ocean. It is a territorial area of 4.200 kilometres long by 180 km wide that comprises a great variety of climates: from arid deserts in the north of the country to the cold glaciers of Patagonia in the south, including forests, jungle, lakes, volcanoes and mountainous ranges.

Population and Economy 2014
With 17,8 million inhabitants, it is one of the fastest growing economies of Latin America, GDP 277 billion US$, GDP per capita is 15.800 US$, an annual increase of inflation of 1,8% in 2013, general government debt 12% of GDP and government credit rating 81 (of 1-100). The most problematic factors for doing business in Chile are: Restrict labour regulation 18%, inadequate education of workforce 16%, and inefficient government bureaucracy 12%. (Forum, 2014).

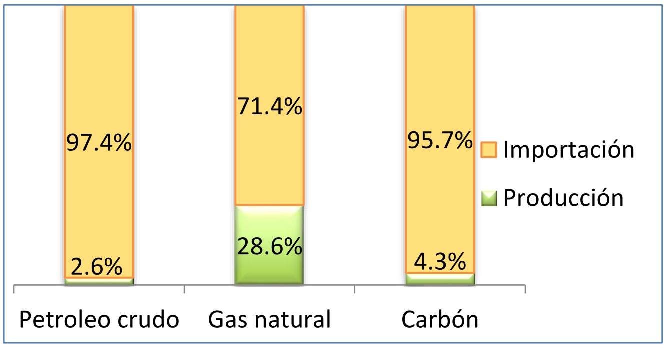
Geothermal Potential
Chile is one of the countries with great volcanic activity, with almost 3.000 volcanoes, of which 80 have frequent eruptions. Hot springs of water have been detected in around 270 volcanic sites, which is favourable evidence for further geothermal exploration activities.

University of Chile has estimated a potential of around 16.000 MW, but on the other hand, the National Petroleum Company (ENAP), is less optimistic and estimates geothermal potential at about 3.350 MW.



During the 80s, power generation was accomplished with 72% of hydroelectric power plants and 27% of conventional thermal power stations. The potential geothermal of Chile is among the highest in the world but it is difficult to accurately quantify the potential of geothermal energy. Although Chile has a large geothermal potential to generate electricity, and despite all the concessions that have been granted no geothermal power plant is yet under construction.

Fossil energy sources are very limited in Chilean territory. In 2011 the domestic production of crude oil covered only 2,6% of the demand and, as can be seen from the following graph, only 4,3% of the demand for coal is produced indigenously while for natural gas that number is 28,6%.



The following diagram appears in the IRENA Report showing the development phases on a typical geothermal power generation project and some of the barriers that IRENA have been identified in Chile to the deployment of this renewable energy, which will be discussed in the following chapters.

Years		1	2	3	4	5	6	7	8	
Exploration	Preliminary exploration studies									There is no sufficient and adequate information on the potential of geothermal resources in Chilean territory to promote investments.
	Administrative procedure to obtain the Concession for exploration									The response time of the Ministry of Energy is variable due to lack of personnel and formal procedures for evaluation.
	Surface exploration									The exploration phase in geothermal projects is capital intensive; guaranteeing access to venture capitals is an important issue. The design of financial mechanisms to share or minimize the risk will be a key element to geothermal energy deployment. The validity period for exploration concessions is too short for the type of studies that must be developed (two years with the possibility of a one-time only extension of two more years if there is a progress of 25% of the investments). The limited availability of specialized machinery and equipment in the country, and the import restrictions can increase the project costs and extend the exploration stage.
	Geological, geophysical and geochemical studies									
	Deep exploration									
	Exploratory well drilling									
	Well and reservoir testing									
Research, Engineering and Management	Basic engineering									Lack of specialised human resources is a challenge in Chile. It is necessary to design training programmes and strengthen the formation of human resources in specific topics of geothermal energy.
	Environmental studies									
	Engineering studies									
	Administrative procedure to obtain the Concession for exploitation									Under current legislation it is required to demonstrate the existence of geothermal resources to apply for a production concession, which requires having very detailed information and can be discouraging to possible investors.
Construction	Roads and Access									Many sites with geothermal potential are found in remote regions. The large investment in transmission lines that has to be included in the investment plans usually detracts from the economic feasibility of the project or can even make the project unviable.
	Local permits									
	Geothermal production well drilling									
	Re-injection well drilling									
	Power plant construction									
	Transmission lines									
	Commissioning									

This diagram gives a good summary over main challenges regarding general power plant generation project in Chile. A can been seen from this diagram, the main challenges in Chile are regarding administration. This kind of mapping of challenges and opportunities within the typical geothermal projects process, is a valuable assessment and tool, towards constructive policy proposals in the sector. The main challenges highlighted for Chile in the Irena Report are described as,, "From the analysis of the barriers for geothermal energy in Chile 5 sets can be defined grouping such obstacles by their nature and by the impact they would have on restricting or simulating the start-up of new geothermal projects. This grouping is also helpful in the proposal of solution alternatives. (IRENA, Initiative for the Development of the Geothermal Energy in the Andean Region, Chile, 2013)

4.3.2 Main Challenges

Authorities and Regulatory Factors
The response times from government agencies are very long. Environmental evaluation of relevant projects takes up to two years, geothermal concessions take up to 400 days, and longer if there is complaint process, and land registration, purchase or lease, can take up to 700 days.

- Lack of mechanisms to promote investments specifically for geothermal energy.
- Regional differences in land ownership regulation.
- Lack of flexibility in the environmental permits granted.
- Approval of laws is a very long process.
- Response periods for administrative processes from agencies are excessively long.
- Lack of specialists in environmental assessment of geothermal projects.

Industry, Companies, Projects
The development of geothermal energy in Chile is mainly dependent on the interaction and collaborative work among different sectors such as government, private enterprise and academia. There are around twenty geothermal energy companies, however it is important to note that such companies are project developers, not providers of related services.

- There are developers with little experience in the electricity market.
- Lack of specialized service companies.
- Lack of sufficient and adequate information on the potential of geothermal resources.
- Territorial conflicts with native communities.
- Negative perception about the environmental impact of geothermal energy.

Scientific and Technical Factors
The area of technical training is of great importance since it implies the development of skills non-existent currently in Chile.

- Lack of sufficient information on the potential of geothermal resources in Chilean territory.
- Lack of human resources.

Educational and Human Factors
Only one educational institution is specialising in geothermal energy, the Centre of Excellence in Geothermal Energy of the Andean (CEGA). Its objective is to improve and increase knowledge on geothermal energy both in Chile and in the rest of the Andean countries.

- Lack of specialists in geothermal topics at the scientific, engineering and technical levels.
- Lack of specialists in environmental assessments for geothermal projects.
- Lack of specialised services companies.

Access to, and cost of Capital
There is a lack of knowledge regarding geothermal energy and the perception of risk in geothermal projects in financial institutions. Two types of risks are facing projects; exploration risk and volatility of prices in a marginal costs market.

- Limited access to financing.
- Difficulty in negotiating long-term contracts.

Infrastructure, Access to Markets, Sectors and Clusters
In the last decade, the electricity market in Chile has confronted multiple challenges such as dry seasons caused by climatic and hydrological events, cuts in the supply of natural gas, increase in atmospheric pollution, emissions from fuels such as diesel and coal, and continuous increase in energy demand at the same time.

- Difficult access to transmission lines in areas with geothermal potential.
- Extreme weather conditions.
- Long distance to market.

Access to International Markets and Services
The value and importance of international cooperation on subjects and levels are of critical importance in a complex development industry and projects like geothermal, it is beneficial to get quick access to knowledge, education, techniques, finance etc. to speed up the process based on good practice learned.

- Lack of international cooperation in various fields of geothermal expertise and finance.

4.3.3 Opportunities and Policy Options

There are several options regarding geothermal possibilities and policy formulation, based on opportunities and by steps towards overcoming barriers and challenges already identified. The opportunities and policy options are for example:

Authorities and Regulatory Factors

- Publicise the characteristics and benefits of geothermal energy for regional development
- Design regulation specific to the promotion of direct uses of geothermal energy
- Promote cooperation with international organisations

Industry, Companies – Projects

Government and development enterprises should work together to identify common points of interest and generate programs for scientific and applied research as well as for the financing of education via scholarships and student loans.

- Organize fora, workshops and conferences to improve knowledge on geothermal energy.
- Identify geothermal energy-related productive chains.
- Promote the creation of specialised services companies.
- Promotion policy for geothermal energy is vital to increase awareness of its benefits.

Scientific and Technical Factors

Research centres and academic institutions should act as promoters of technical knowledge and formation of human resources for the future of geothermal energy should increase collaboration.

- Promote alliances with research centres and educational institutions for the formation of specialised human resources.

Educational and Human Factors

It is necessary to strengthen the formation of human resources in geothermal energy.

- It is necessary to promote training and educational programs at the regional level.
- Promote relationships with industry. Implement programs for scientific development.
- Implement programs for technical development.

Access to, and cost of Capital

It is necessary to have a promotion policy for geothermal energy, showing its many benefits including economics benefits.

- Creation of risk-capital funds. Promote training in the banking system for the development of financial mechanisms specific to geothermal energy.
- The financial structures must include the risks there are at the beginning of projects.
- Operating costs of geothermal power plants are low and are not affected by fossil fuel prices.

Infrastructure, Access to Markets, Sectors and Clusters

- It is important to recognise that this energy source represents a real alternative to provide energy security, trade competitiveness and economic stability to the country.

Access to International Markets and Services

- International cooperation in area of geoscientific research, development, and service.
- International cooperation on education and training.
- International cooperation with IFI and donors on finance, grants and funding.
- International consulting cooperation in various fields of geothermal expertise.
- Awareness building regarding several valuable elements of geothermal resources, economic, energy security, mitigation of climate change, etc. with several stakeholders authorities, industry, municipalities and public, in various forms, seminars, meetings and information.
- Support and strengthening Geothermal Clusters and cooperation.
- See additional elements regarding Capacity building chapter 9.
- See additional items, in Conclusion chapter 10.

4.4 Bolivia

4.4.1 Background information

Geographic Location
Bolivia is located in the central region of South America. Bolivia borders with Brazil to the north and east, with Argentina to the south, with Peru to the west, with Paraguay to the southeast and with Chile to the Southwest. It is one of the two land locked countries of South America (the other one is Paraguay).

Population and Economy 2014
Population is 11 million, GDP 29,8 billion US$, GDP per capita is 2.700 US$, and an annual increase of inflation 5,7% in 2013. The most problematic factors for doing business in Bolivia are: Access to financing 20%, restrictive labour regulations 18,5%, foreign currency regulations 13%, inefficient government bureaucracy 10,7%, and inadequate supply of infrastructure 10,3%. (Forum, 2014).

Geothermal Potential
The geothermal studies in Bolivia continued to be performed only in the area of Laguna Colorada. The only available information regarding the rest of the areas of geothermal interest is their location, as shown in the enclosed figure as relevant studies are lost. The geothermal resources of Bolivia have always been considered as a potential source of electric power generation. The Laguna Colorada field has been explored up to the feasibility phase, and this field holds a power of 280-370 MW_e and a certified power of 120 MW_e for 25 years (CFE, 1997). (IRENA, Evaluation Study of the Current Conditions and Development Potential of Geothermal Energy in the ANDEAN Countries: Bolivia, 2103)

4.4.2 Main Challenges

Authorities and Regulatory Factors
The Vice Ministry of Electricity and Alternative Energies is the authority that governs geothermal energy in Bolivia. The National Company of Electricity (ENDE) is responsible for the execution of geothermal projects and it covers both production and distribution of electricity and has major importance. Nevertheless, the company has a weakness due to lack of experienced professionals in geothermal energy. The Vice Ministry of Electricity and Renewable Energy is arranging a cooperation with the Government of Japan (JICA) to update the National Inventory of Geothermal Resources. The summary of main challenges in this category are for example:

- Necessity of advising in the regulatory aspects.
- Lack of mechanisms to promote investments specifically for geothermal energy.
- Lack of specialized and/or experienced professionals in area of geothermal energy.
- Lack of regulatory framework.
- No applicable regulations regarding the granting of geothermal power permits.
- The lack of a regulatory framework, indispensable to attract private investments that demand clarity and stability in the “rules of the game”.
- There are no regulations to support the FIT or RPS type operations, neither to promote the participation of the private sector, such as the BOT type.

Industry, Companies, Projects

The State, has granted a 40 year concession in 1991 to the company ENDE, which plans the development and exploitation of the Laguna geothermal field and the main objective is to incorporate 100 MW of power to the National Interconnected System (SIN) through the installation of 4 generation groups of 25 MW each. The development of the project has been divided into two stages: first, exploration and test drilling and secondly production drilling and construction. ENDE will perform an open international bidding process for the development of stage I of the project. A referential budget has not been determined yet, nor the potential sources of financing for the second stage of the project. The summary of main challenges in this category are for example:

- Unclear sources of project funding and timetable.
- Private sector is not participating in geothermal projects, as the generation costs are higher than the natural gas alternatives.

Scientific and Technical Factors

Vice Ministry of Electricity and Alternative Energies of the MHE has started a technical cooperation with JICA, of the Government of Japan, to update the National Geothermal Inventory with a referential budget of USD 2.5 million, with an undetermined term and start date.

- Lack of technologic assistance and availability of local experts.
- There is a need for stronger technical institutions and capabilities in the area of geothermal.

Educational and Human Factors

There is lack of specialized and/or experienced national staff in geothermal energy projects, which constitutes a significant institutional weakness and therefore there is urgent need for training and education in geothermal resources. The main challenges in this category are for example:

- Lack of specialized and/or experienced professionals in geothermal energy projects.
- Need to implement training program in various geothermal technical fields.

Access to, and cost of Capital

Only the Central Bank, a public entity, has participated in credit operations to finance geothermal projects. There are no records of the participation, or interest to participate, by the private banking sector.

The main challenges in this category are for example:

- Limited access to financing.
- High capital cost of geothermal projects, e.g. to expensive exploration and test drilling.
- Geothermal projects are financially nonviable due to their high generation costs, which surpass the natural gas alternatives in Bolivia.
- The necessity to cover high capital costs.

Infrastructure, Access to Markets, Sectors and Clusters

The fees in the electric sector are calculated based on the subsidized price of natural gas of 1.3 USD/MPC, while the cost of opportunity varies between 6 and 7 USD/MPC. The same complication also affects hydroelectric projects.

The main challenges in this category are for example:

- Difficult access to transmission lines in areas with geothermal potential.
- Market distortions by subsidy to natural gas electricity generation.
- Little expertise and services regarding geothermal factors.

Access to International Markets and Services

There seems to be limited international cooperation in the area of a geothermal sector, except in a few specific projects. The main challenges in this category are for example:

- Limited international cooperation in the area of geothermal energy.
- There is a need for broad international cooperation in various fields e.g. regarding access to capital and donor funding and geothermal education and training.
- Need for international cooperation to formulate options for geothermal policy and roadmaps based on international lessons learned for similar cases.

4.4.3 Opportunities and Policy Options

There are several options regarding geothermal possibilities and policy formulation, based on opportunities and by steps towards overcoming barriers and challenges already identified. The opportunities and policy options are for example:

Authorities and Regulatory Factors

- Prepare Policy Roadmap which identifies the corresponding strategy actions.
- Publicise the characteristics and benefits of geothermal energy for regional development.
- Design regulation specific to the promotion of direct uses of geothermal energy.
- Strengthening institutional and professional capacity regulating administration.
- Promote cooperation with international organisations on Geothermal Policy.

Industry, Companies - Projects

- Improve framework conditions to encourage participation of the private sector in geothermal projects.
- Increase the geothermal technological and educational knowledge of the sector.
- Increase international cooperation of the geothermal private sector.

Scientific and Technical Factors

- Increase technologic assistance and availability of local experts.
- There is a need for stronger technical institutions and capabilities in the area of geothermal energy/research.

Educational and Human Factors

- Increase training programs in various geothermal technical fields.
- Promote relationships with international training bodies.
- Need to implement training programs in various geothermal technical fields.

Access to, and cost of Capital

- Promote additional access to financing geothermal projects – domestic and international.
- Lower barriers for high capital cost by providing exploration and test drilling e.g. soft loans or donor grants.
- The financial structures must include the risks there are at the beginning of projects.
- Operating costs of geothermal power plants are low and are not affected by fossil fuel prices.

Infrastructure, Access to Markets, Sectors and Clusters

- Develop options to connect transmission lines to areas with geothermal potential.
- Abolish distortions by subsidy to natural gas electricity generation.
- Upgrade expertise regarding geothermal factors.
- Promote alliances with research centres and educational institutions for the formation of specialised human resources.
- Promote training for bankers, regarding financing of risky geothermal projects.
- Awareness building - organize fora, workshops and conferences to improve knowledge on geothermal energy.
- Identify geothermal energy-related productive chains.
- It is important to increase the available knowledge about opportunities and benefits of the utilization of geothermal resources.

Access to International Markets and Services

- Support international cooperation in area of geothermal knowledge, training and service.
- Promote international cooperation with IFI and donors on finance, grants and funding.
- Support international consulting cooperation on various fields of geothermal expertise.
- See additional elements regarding Capacity building chapter 9.
- See additional items, in Conclusion chapter 10.
- See additional items in chapter 4.3. Iceland Partner in a Large 500 million US$ - WB Geothermal Project in Africa.

4.5 Ecuador

4.5.1 Background information

Geographic Location

The Republic of Ecuador is located in the north-western area of South America. It is crossed by the equatorial line, so its territory is located in both hemispheres. It comprises two separate areas: the continental territory, which includes some islands adjacent to its coast, and the archipelago of Galapagos, which is located at a distance of almost 1,000 km from the Ecuadorian coast. It borders to the north with Colombia, to the south and east with Peru, and with the Pacific Ocean to the west.

Population and Economy 2014

Population is 14.6 million, GDP (US$ billions) 67, GDP per capita is (US$) 7.700 and annual increase of inflation was 4.4% in 2013. The most problematic factors for doing business in Ecuador are: Political instability, access to financing and practice of the informal sector. (WB, 2012)

Geothermal Potential

In 1979, the former Ecuadorian Institute of Electricity, INECEL, and the Latin American Organization of Energy, OLADE, with the advice of the companies AQUATER of Italy, BRGM of France and the Institute of Electrical Research of Mexico, IIE, developed the "National Geothermal Reconnaissance of Ecuador", which produced information about the most interesting prospective areas for the existence of financially viable geothermal systems, ordered by their priority for the continuation of studies: GROUP A: Tufiño, Imbabura-Cayambe and Chalupas. GROUP B: Ilalo, Chimborazo and Cuenca. The area of Cuenca is considered a priority.

The Master Plan of Electrification 2012 – 2021, PME, has foreseen that geothermal studies must have the following sequence of culmination:

- Pre-feasibility of the Chachimbiro geothermal project: February 2012.
- Pre-feasibility of the Chacana geothermal project: May 2012.
- Pre-feasibility of the binational Tufiño – Chiles – Cerro Negro: December 2013.
- Chalpatan geothermal project: December 2012.

The same PME recommends that the studies of the main geothermal locations should be continued with the aim of incorporating a geothermal plant of 30 MW_e at the beginning of 2019. The binational project Tufiño-Chiles (50 MW) has July 2017 as its predicted date of entry to the system. None of the geothermal studies being developed in Ecuador have obtained international cooperation resources. These projects are exclusively developed through consultanship contracts that are convoked, assigned and supervised by CELEC EP, with the exception of the Tufiño-Chiles project, which is under the responsibility of the company ISAGEN from Colombia. (IRENA, Evaluation Study of the Current Conditions and Development Potential of Geothermal Energy in the ANDEAN Countries: Ecuador, 2013)

4.5.2 Main Challenges

Authorities and Regulatory Factors

The National Geological Mining and Metallurgic Institute (INIGEMM), does not fulfil any specific function as to exploration and development of geothermal resources, except for the drafting of the national geological map and performing the scientific and technological research in the fields of geology and hydrogeology, which may be considered limitations related to geothermics.

- Lack of a regulatory framework (UNEC).[6]
- Continuous changes in policy for the sector at the executive level (UNEC).
- Incomplete vision about the possibilities for exploiting the resource (UNEC).
- Lack of mechanisms to promote investments specifically for geothermal energy.
- Regional differences in land ownership regulation.
- Lack of flexibility in the environmental permits granted.

Industry, Companies, Projects

The geothermal activities that are currently developed in Ecuador exclusively concern pre-feasibility studies in three areas of interest, hired by CELEC EP with a local and a Spanish consultancy companies, and in the area of Tufiño-Chiles, through an agreement with ISAGEN from Colombia. The funding comes from an Inter-American Development Bank, IDB.

- In Ecuador there is no possibility of obtaining a concession for the development and exploitation of geothermal resources.
- Lack of any successful exploration experiences for this resource (UNEC).
- Lack of specialised services companies.
- No deep geothermal wells have been drilled in Ecuador with the purpose of discovering a resource.

Scientific and Technical Factors

There is a need for more specialized professionals and/or with experience in geothermal energy projects in the nation.

- Lack of up-to-date technical information (UNEC).
- Lack of specialists in geothermal topics at the scientific, engineering and technical levels.
- Lack of specialists in environmental assessments for geothermal projects.

Educational and Human Factors

It would be necessary to extend training to environmental, legal and financial issues involved in the development of geothermal resources.

- Scarcity of specialized human resources (UNEC).

Access to, and cost of Capital

At present time there is no background of any participation or manifestation of interest, by the private banking sector in financing geothermal exploration or development activities.

- Lack of financing sources for risky investments (UNEC).
- Limited access to financing.
- Difficulty in negotiating long-term contracts.

Infrastructure, Access to Markets, Sectors and Clusters

- Difficult access to transmission lines in areas with geothermal potential.
- Extreme weather conditions.

Access to International Markets and Services

The current lack of international cooperation initiatives in Ecuador constitutes a weakness, which accentuates the lack of specialized human resources to cover the planning, supervision, inspection and control activities of the geothermal projects.

- Lack of international cooperation in geothermal fields.

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[6] (UNEC) = United Nations Economic Commission for Latin America and the Caribbean.

4.5.3 Opportunities and Policy Options

There are several options regarding geothermal possibilities and policy formulation, based on opportunities and by steps towards overcoming barriers and challenges already identified. The opportunities and policy options are for example:

Authorities and Regulatory Factors

- Publicise the characteristics and benefits of geothermal energy for regional development
- Design regulation specific to the promotion of direct uses of geothermal energy
- Promote cooperation with international organisations

Industry, Companies - Projects

- Promote alliances with research centres and educational institutions for the formation of specialised human resources
- Promote training in the banking system for the development of financial mechanisms specific to geothermal energy
- Creation of risk-capital funds
- Organize fora, workshops and conferences to improve knowledge on geothermal energy
- Identify geothermal energy-related productive chains
- Promote the creation of specialised services companies

Scientific and Technical Factors

- Promote relationships with industry
- Implement programs for scientific development
- Implement programs for technical development.

Educational and Human Factors

The need to undertake, as soon as possible, a training program on human resources in fundamental technical disciplines is becoming evident: geothermic, earth sciences, geophysics, geochemistry, isotopic geochemistry, chemical analyses of waters and gases, strategic planning, regulatory aspects, etc.

Access to, and cost of Capital

- Promote additional access to financing geothermal projects – domestic and international.
- Lower capital cost by providing soft loans / grant for test drilling.
- The financial structures must include the risks there are at the beginning of projects.
- Operating costs of geothermal power plants are low and are not affected by fossil fuel prices.

Infrastructure, Access to Markets, Sectors and Clusters

- Develop options to connect transmission lines to areas with geothermal potential.
- Promote training in the banking system for the development of financial mechanisms specific to geothermal energy.
- Awareness building - organize fora, workshops and conferences to improve knowledge on geothermal energy.
- It is important to increase the available knowledge about opportunities and benefits of the utilization of geothermal resources.

Access to International Markets and Services

In developing countries, the projects oriented to covering the initial phases of geothermal exploration, including a human resources training component, are usually assumed by international cooperation.

- Support international cooperation in the area of geothermal knowledge, training and service.
- Promote international cooperation with IFI and donors on finance, grants and funding.
- Support international consulting cooperation on various fields of geothermal expertise.
- See additional elements regarding Capacity building chapter 9.
- See additional items, in Conclusion chapter 10.
- See additional items in chapter 5.1. Iceland Partner in a Large 500 million US$ - WB Geothermal Project in Africa.

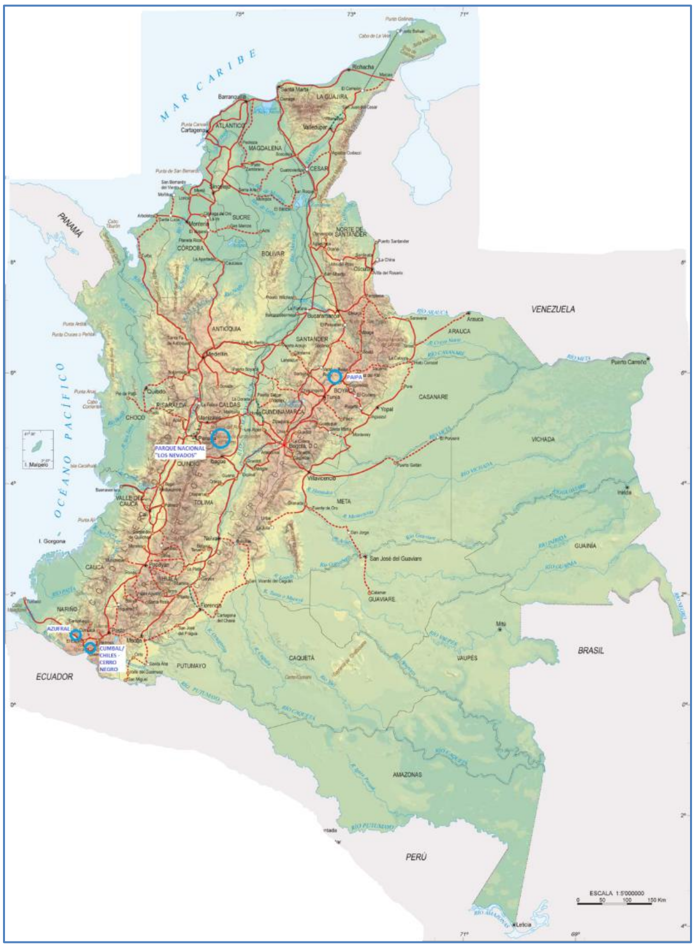
4.6 Colombia

4.6.1 Background information

Geographic Location
The Republic of Colombia is located at the northeast of South America. It borders the Republic of Panama and the Caribbean Sea to the north, with the Republics of Venezuela and Brazil to the east, with the Republics of Peru and Ecuador to the south and with the Pacific Ocean to the West. Its geographical location is strategic because it is a connection point between the countries of the northern and southern hemispheres, and it also has extensive coasts in the Pacific and Atlantic oceans. The Andean mountain range crosses Colombia longitudinally from north to south.

Population and Economy
Population is 47,2 million, GDP (US$ billions) 382 GDP per capita is (US$) 8.100 and annual increase of inflation was 2% 2013. The most problematic factors for doing business in Bolivia are: Corruption 19%, inadequate supply of infrastructure 14%, inefficient government bureaucracy 12%, tax regulations 9%, crime and theft 8%. (Forum, 2014).

Geothermal Potential
Colombia has particular geological conditions originated from its location in the north-western extreme of South America, in an area in which interactions between the South American, Nazca and Caribbean plates generate a very complex tectonic environment. In 1982 the Latin American Energy Organization, OLADE, with the advice of the company Geotermica Italiana/INTECOL, and the former Colombian Institute of Electricity, ICE, performed a National Geothermal Reconnaissance Study that identified the following areas of priority interest: 1) Natural Park "Los Nevados" Volcanic Complex., 2) Chiles-Cerro Negro, 3) Cumbal, 4) Azufral de Tuquerres, 5) Paipa-Iza,



Some regional complementary studies were performed:

- United States Trade and Development Agency, USTDA-Boston Pacific Company, BPC, ISAGEN, INGEOMINAS (2009): Basic Feasibility for the Potential Geothermal Utilization in Colombia.
- Colombian Geological Service (2008): Map of geothermal gradients.
- Colombian Geological Service (2009): Map of heat flow in the Llanos Orientales basin.
- Colombian Geological Service (2012): National Inventory of Thermal Springs of Colombia.

Some studies have been performed in Colombia in the last few years. One of the most recent studies was the "Basic Feasibility Study for the Potential Geothermal Utilization in Colombia", which was financed by the USTDA and carried out, in 2009, by the Boston Pacific Company, with the participation of ISAGEN and INGEOMINAS. (IRENA, Evaluation Study of the Current Conditions and Development Potential of Geothermal Energy in the ANDEAN Countries: Colombia, 2013).

4.6.2 Main Challenges

Authorities and Regulatory Factors
The Ministry of Environment and Sustainable Development is the ruling entity for the management of the environment and renewable natural resources.

- Lack of mechanisms to promote investments specifically for geothermal energy.
- Externalities of conventional technologies not being taken into account.
- Regional differences in land ownership regulation.
- Lack of flexibility in the environmental permits granted.
- Insufficient information on the usable power potential.

Industry, Companies, Projects

- Lack of interest of the private sector.
- Incipient state of exploration activities that, after several years, have not presented results regarding the resource.
- Some cases of overlapping areas of nature conservation and indigenous reserves with geothermal potential areas.

Scientific and Technical Factors

- Lack of specialists in geothermal topics at the scientific, engineering and technical levels.
- Lack of specialists in environmental assessments for geothermal projects.
- Lack of specialised services companies.

Educational and Human Factors

- Need to link university research policies with the needs of resource development.
- Need to strengthen human talent to support the exploration, development and exploitation of the resource.

Access to, and cost of Capital
The financing of the geothermal exploration studies currently underway has originated from bilateral cooperation non-reimbursable funds (USTDA) and multilateral organizations (BID-FNAM), complemented with local contributions from the involved public companies.

- No contributions have originated from the national public or private banking sectors or from private investors. The state budget cannot provide capital contributions for the exploration or development of natural resources.
- Difficulties to get access to international credits, due to lack of sovereign guarantee covered by the state, which is impeded by the regulations established by the model in force.
- Limited access to financing.
- Difficulty in negotiating long-term contracts.

Infrastructure, Access to Markets, Sectors and Clusters

- Difficult access to transmission lines in areas with geothermal potential.
- Extreme weather conditions.

Access to International Markets and Services
The current lack of international cooperation initiatives establishes a weakness, which highlights the lack of specialized human resources to cover the planning, supervision, inspection and control activities of the geothermal projects.

- Lack of international cooperation in geothermal fields.

4.6.3 Opportunities and Policy Options

There are several options regarding geothermal possibilities and policy formulation, based on opportunities and steps towards overcoming barriers and challenges already identified. The opportunities and policy options are for example:

Authorities and Regulatory Factors

A complete regulatory framework is needed, to harmonize the characteristics of the current model with incentive policies for the development of geothermal energy.

- Design regulation specific to the promotion of direct uses of geothermal energy.
- Promote cooperation with international organisations.
- The establishment of a domestic body that will exclusively focus geothermal power is needed and greater inter-institutional coordination.
- Specific regulatory framework for the granting of licenses or permits to explore and develop geothermal power.

Industry, Companies - Projects

Currently, there are two generation companies that are developing projects of exploration of geothermal resources; the Public Companies of the City of Medellin E.P.M. and ISAGEN S.A. E.S.P.

- Promote alliances with research centres and educational institutions for the formation of specialised human resources.
- Promote training in the banking system for the development of financial mechanisms specific to geothermal energy.
- Organize fora, workshops and conferences to improve knowledge on geothermal energy
- Promote the creation of specialised services companies.

Scientific and Technical Factors

- Promote relationships with industry.
- Implement programs for scientific development.
- Implement programs for technical development.

Educational and Human Factors

Universities can play an important role as permanent support infrastructures for research and development projects related to geothermal energy.

- Need to strengthen human talent to support the exploration, development and exploitation.
- Need to link university research policies with the needs of resource development.

Access to, and cost of Capital

It is essential to design financial instruments that will promote options of geothermal power, both the initial risk and benefits to the decrease of emissions and the replacement of fossil fuels.

- The financial structures must include the risks there are at the beginning of projects.
- Operating costs of geothermal power plants are low and are not affected by fossil fuel prices.

Infrastructure, Access to Markets, Sectors and Clusters

- Establish and consolidate the existence of a domestic geothermal power authority.
- Promotion is needed for international agencies to include geothermal power options in their agendas, to make viable actions to promote the benefits of the geothermal power use.

Access to International Markets and Services

The international cooperation initiatives that have materialized in recent years are also interesting, because they contribute to the strengthening and diffusion of actions oriented to the exploration and development of geothermal resources.

- International agencies have to include geothermal power options in their agendas, to make viable actions to promote the benefits of the geothermal power use.
- International cooperation might play an important role in the planning and development of training and educational programs for human resources as well as developing the sector.

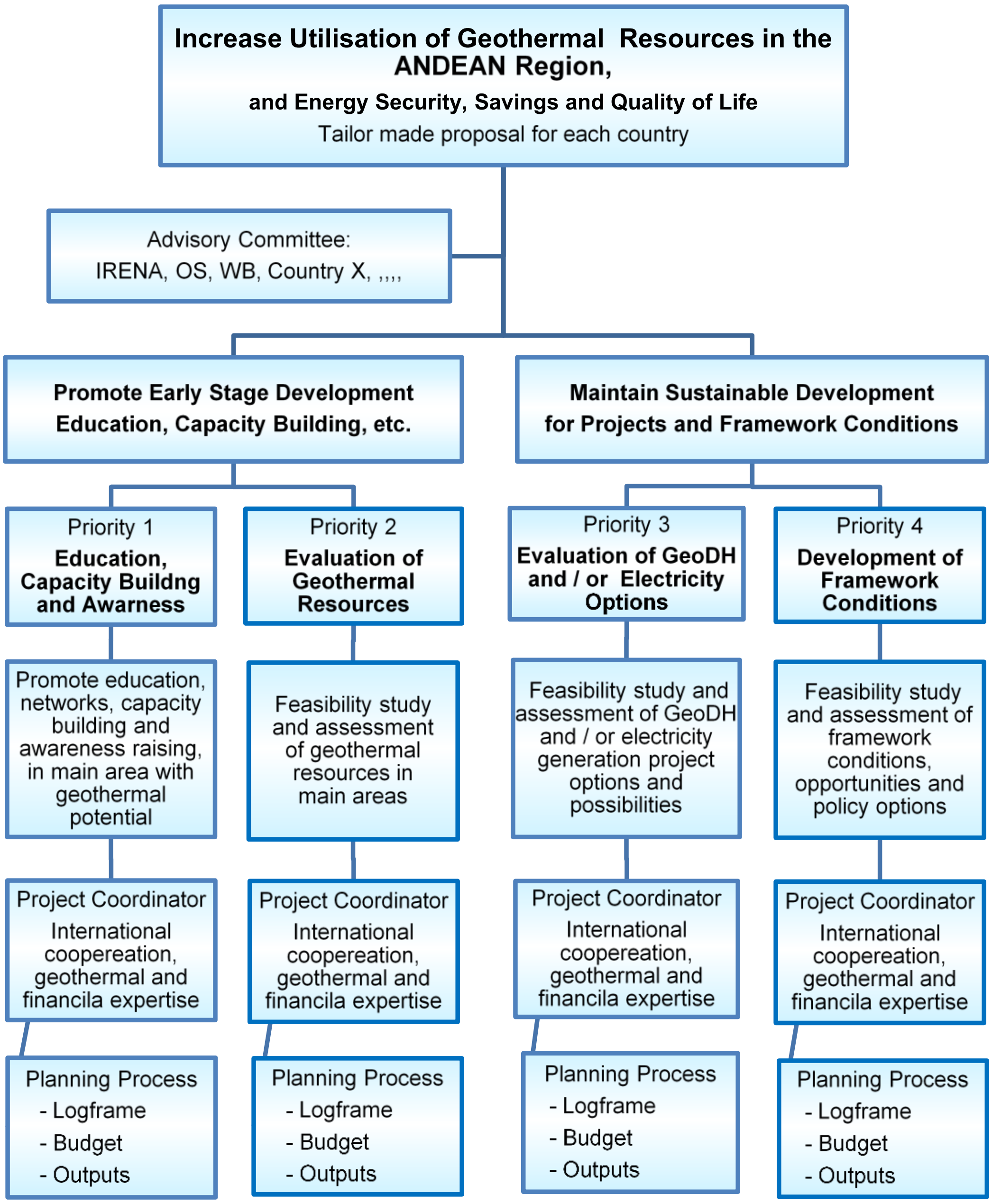
4.7 Opportunities and Policy Options for the Andean Region

Key elements in the development of geothermal energy and financing of renewable energy projects throughout the Andean Regions, depend on international cooperation of these countries with the most experienced geothermal countries, stakeholders, internationals financial institutions and donors. Successful energy / geothermal projects depends also in general on following items.

- **Education capacity building, networking and awareness.**
- **Evaluation of geothermal resources.**
- **Promotion of geothermal power generation and district heating.**
- **Development of framework conditions and possibilities.**
- **International cooperation, geothermal and financial expertise**.

These main options are shown in enclosed figure 3.7.1, which need additional work and planning in cooperation with relevant stakeholders and countries.

Figure 4.7.1. **Opportunities and Policy Option for the ANDEAN Countries**



Sources: Orkustofnun, OS, (National Energy Authority) Iceland, 2014

III GEOTHERMAL DEVELOPMENT AND EXPERIENCE IN ICELAND

5 Geothermal Resources in Iceland

5.1 The Nature of Geothermal Resources

Geological background
Iceland is a young country geologically. It lies astride one of the Earth's major fault lines, the Mid- Atlantic ridge. This is the boundary between the North American and Eurasian tectonic plates. The two plates are moving apart at a rate of about 2 cm per year. Iceland is an anomalous part of the ridge where deep mantle material wells up and creates a hot spot of unusually great volcanic productivity.

This makes Iceland one of the few places on Earth where one can see an active spreading ridge above sea level. As a result of its location, Iceland is one of the most tectonically active places on Earth, resulting in a large number of volcanoes and hot springs. Earthquakes are frequent, but rarely cause serious damage.

More than 200 volcanoes are located within the active volcanic zone stretching through the country from the southwest to the northeast, and at least 30 of them have erupted since the country was settled. In this volcanic zone there are at least 20 high-temperature areas containing steam fields with underground temperatures reaching 200°C within 1,000 m depth. These areas are directly linked to the active volcanic systems. About 250 separate low-temperature areas with temperatures not exceeding 150°C in the uppermost 1,000 m are found mostly in the areas flanking the active zone. To date, over 600 hot springs (temperature over 20°C) have been located (Fig. 5.1.1).

Fig. 5.1.1. **Volcanic zones and geothermal areas in Iceland.**

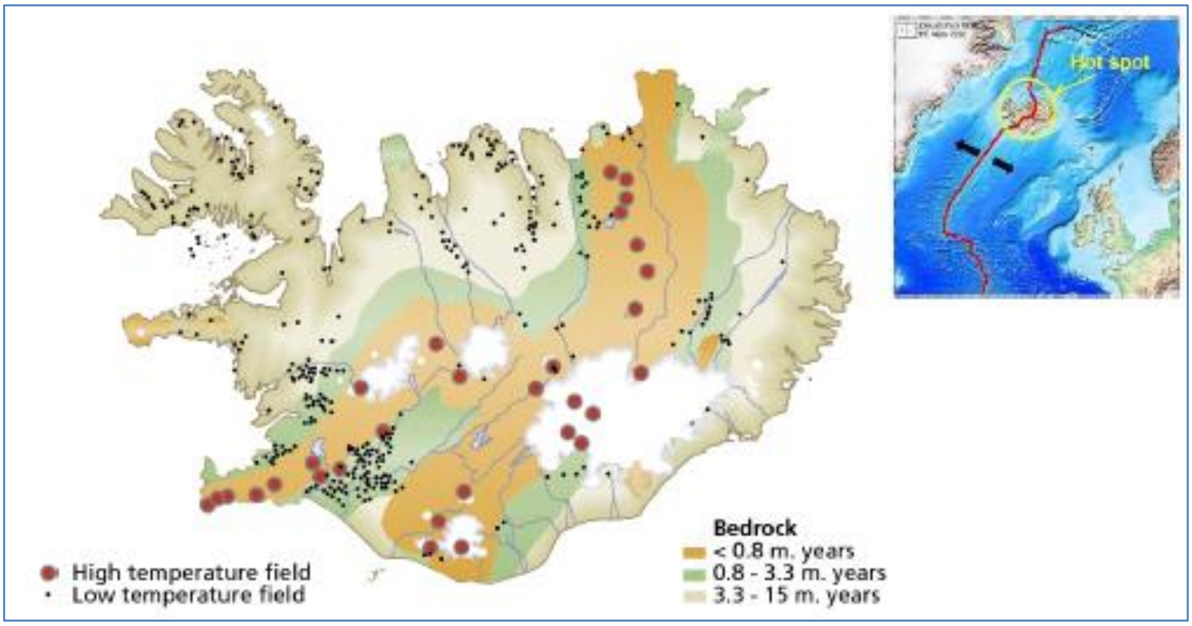


Fig. 5.1.2. At top heat flow map of Iceland and below estimated temperature distribution at 1 km and 2 km depths.

Energy current and stored heat

The energy current from below Iceland has been estimated to be about 30 GW (1 GW = 10^9 W). About 24 GW are carried by flowing magma and 6 GW by heat conduction. This only considers land above sea-level, while considerable additional energy also flows up through the ocean floor around the island.

Energy flows through the crust, which also stores great amounts of energy. Near the surface the energy current splits between; 7 GW by volcanic activity, 8 GW by water- and steam-flow in geothermal areas and 15 GW by heat conduction. (Atlas for Geothermal Resorces in Europe, 2002)

The total energy stored in the crust of Iceland, from surface down to 10 km depth, amounts to about $12 \cdot 10^{14}$ GJ. Above 3 km depth the energy stored is only about $1 \cdot 10^{14}$ GJ. Again, these results only apply to the crust directly below the section of the country above sea-level.

The concentration of energy is greatest within the volcanic zone, in particular in the high-temperature systems. The thermal energy stored in five of the largest high-temperature systems is estimated to account for 70% of the total energy stored in all high-temperature systems in Iceland.

Fig. 5.1.2 presents a simple sketch of the energy current and stored heat, i.e. the components of the geothermal potential of Iceland.

Fig. 5.1.2. **At top heat flow map of Iceland and below estimated temperature distribution at 1 km and 2 km depths**

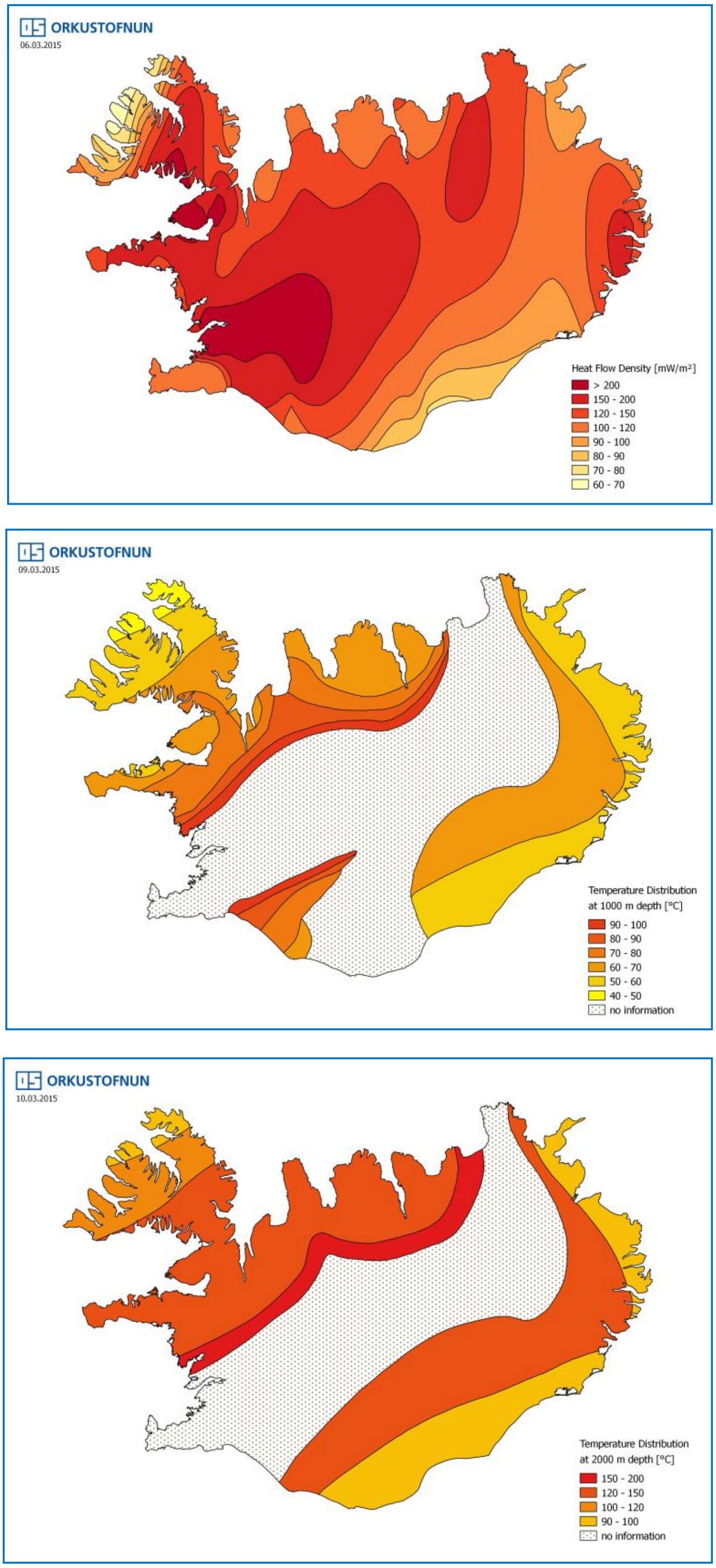
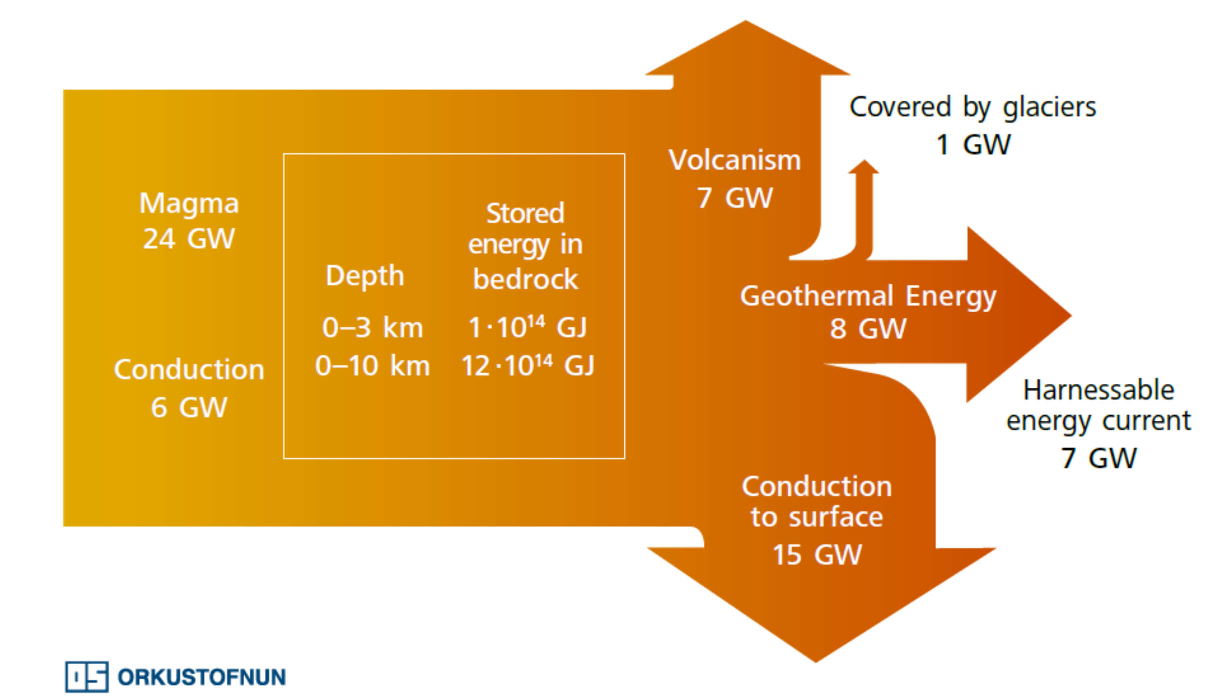


Fig. 5.1.3. **Terrestrial energy current through the crust of Iceland and stored heat.**



5.2 The nature of low-temperature systems

The low-temperature systems are all located outside the volcanic zone passing through Iceland (see Fig. X). The largest of these systems are located in southwest Iceland on the flanks of the western volcanic zone, but smaller systems can be found throughout the country. On the surface, low-temperature activity is manifested in hot or boiling springs, while no surface manifestations are observed on top of some such systems. Flow rates range from almost zero to a maximum of 180 liters per second from a single spring. The heat-source for low-temperature activity is believed to be Iceland's abnormally hot crust, but faults and fractures, which are kept open by continuously ongoing tectonic activity, also play an essential role by providing channels for the water that circulates through the systems, and mines the heat. The temperature of rocks in Iceland generally increases with depth. Outside the volcanic zones the temperature gradient varies from about 150°C/km near the margin to about 50°C/km farther away.

The nature of low-temperature activity may be described as follows: Precipitation, mostly falling in the highlands, percolates down into the bedrock to a depth of 1 - 3 km, where the water is heated by the hot rock, and subsequently ascends towards the surface because of reduced density. Systems of this nature are often of great horizontal extent and constitute practically steady state phenomena.

The most powerful systems are believed to be localised convection systems where the water circulates vertically in fractures of several kilometers of depth. The water then takes up the heat from the deep rocks at a much faster rate than it is renewed by conduction from the surroundings. These fields are therefore believed to be of transient nature, lasting some thousands of years.

5.3 The nature of high-temperature systems

High-temperature areas are located within the active volcanic zones or marginal to them. They are mostly on high ground. The rocks are geologically very young and permeable. As a result of the topography and high bedrock permeability, the groundwater table in the high-temperature areas is generally deep, and surface manifestations are largely steam vents. Hydrogen sulphide present in the steam tends to be oxidised at the surface by atmospheric oxygen, either into elemental sulphur, which is deposited around the vents, or into sulphuric acid, which leads to acid waters altering the soil and bedrock.

The internal structure of fossil high-temperature systems can be seen in Tertiary and Quaternary formations, where erosion has exposed rocks that were formerly at a depth of 1–3 kilometers. The system's heat source is generally shallow magma intrusions. In the case of high-temperature systems associated with central volcanic complexes the intrusions often create shallow magma chambers, but where no central volcanoes have developed only dyke swarms are found. Intrusive rocks appear to be most abundant in reservoirs associated with central complexes that have developed a caldera. The boiling point of water depends on the hydrostatic pressure. As the pressure increases with depth the temperature needed for the water to boil rises along a curve that is called the boiling point curve.

Temperatures in active, high-temperature systems generally follow the boiling point curve. The highest recorded downhole temperature is 450°C. Hydrological considerations and permeability data imply that the groundwater in the reservoir is undergoing a density driven vertical circulation. This groundwater is in most cases of meteoric origin. However, in three areas on the Reykjanes Peninsula it is partly or solely ocean water.

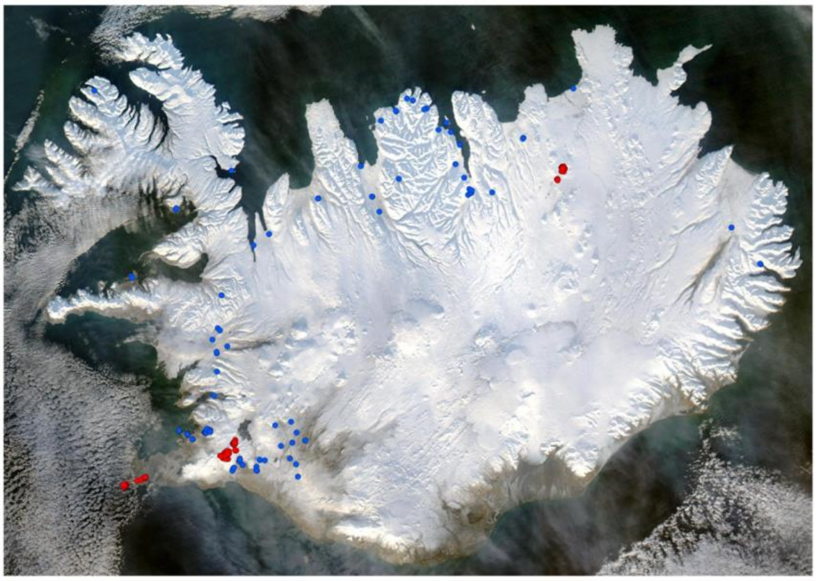
5.4 Wells in use in Iceland

Figure 5.4.1. **Satellite image of Iceland in winter time illustrating geothermal production wells in operation in year 2014 for geothermal power plants (red) and wells operated by heat utilities with a natural monopoly for distribution of heat. Over 100 production wells operated by small auto-producers are excluded.**

The average high temperature well is 1866 m deep, cased down to 1585 m.

For low temperature systems in total 173 wells are used and 9 hot springs with an average depth of 1055 m, cased down to 223 m (Oddsdóttir and Ketilsson, 2012).

See Figure 5.4.1 for wells to generate electricity (red) and only heat (blue) for district heating systems.

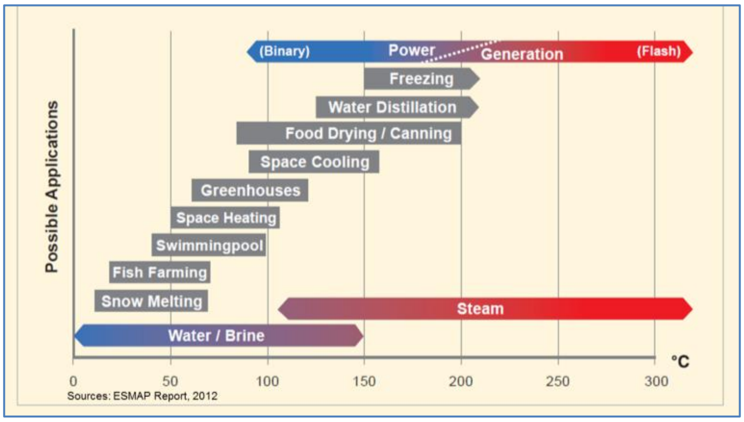


5.5 The History of Geothermal District Heating (GeoDH)

Fuel for heating houses

In a cold country like Iceland, space heating needs are greater than in most countries. In earlier centuries, peat was commonly used for heating houses, as well as seaweed. This continued even after the importation of coal for space heating was initiated, after 1870. In the rural regions, the burning of sheep-dung was common, as the distribution of coal or peat was difficult due to the lack of roads. The use of coal for heating increased in the beginning of the 20th century, and was the dominating heat source until the end of WWII. Oil for heating purposes first became significant after WWI, but by 1950 about 20% of families used oil for heating, while 40% used coal. At that time about 25% enjoyed geothermal heating services. Coal was practically eliminated from space heating in Iceland around 1960. Heating homes with electricity did not become common until larger electric power plants were erected in the 1930s and 1940s.

Figure 5.5.1. **Possible Utilisation of Geothermal Power**



Current Geothermal Heat Use

Geothermal utilization amounted to 28.1 PJ in 2014 as shown in Figure 5.1.2 using both IGA and IEA final use categories. Residential use amounted to 13.3 PJ, commercial services to 0.7 PJ, fisheries to 2.5 PJ, industry 0.9 PJ and services 10,7 PJ using IEA categories. Space heating amounted to 20.0 PJ, swimming and bathing 2.0 PJ, snow melting 2.0 PJ, fish farming 2.5 PJ, industrial use 0.9 PJ and greenhouses 0.7 PJ.

Figure 5.5.2**. Development in GDP, used electricity, geothermal heat, oil and coal per capita 1945 – 2010.**

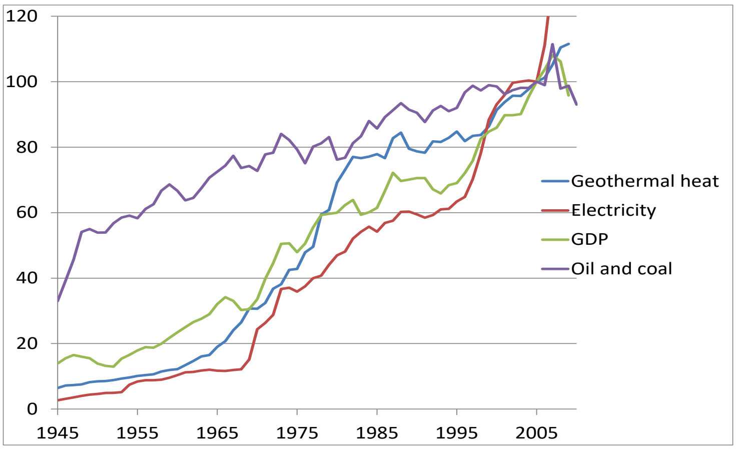
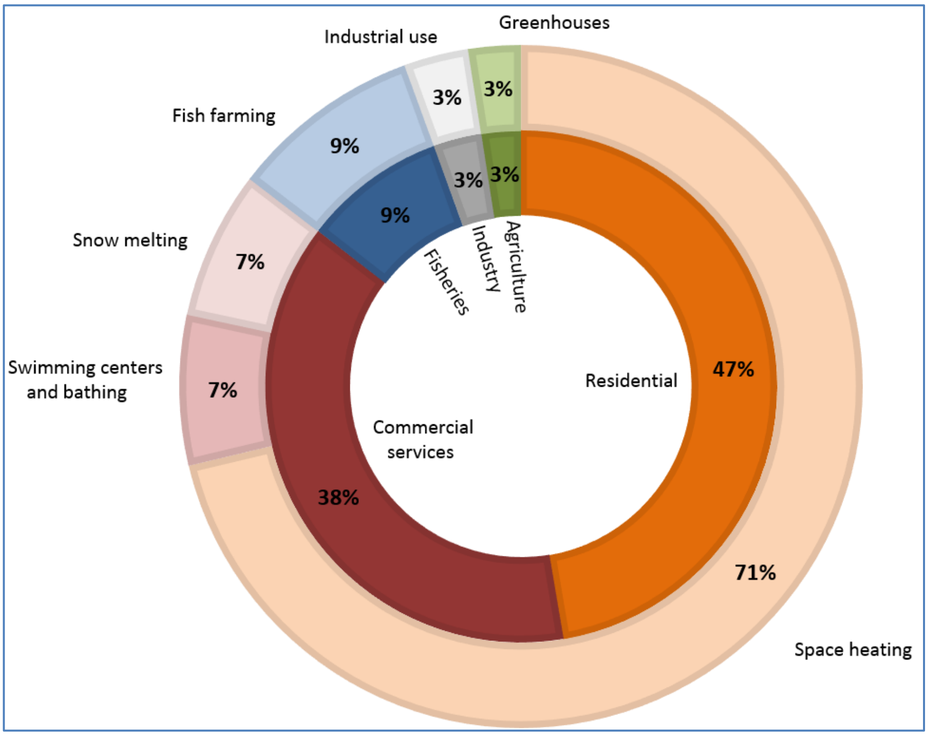


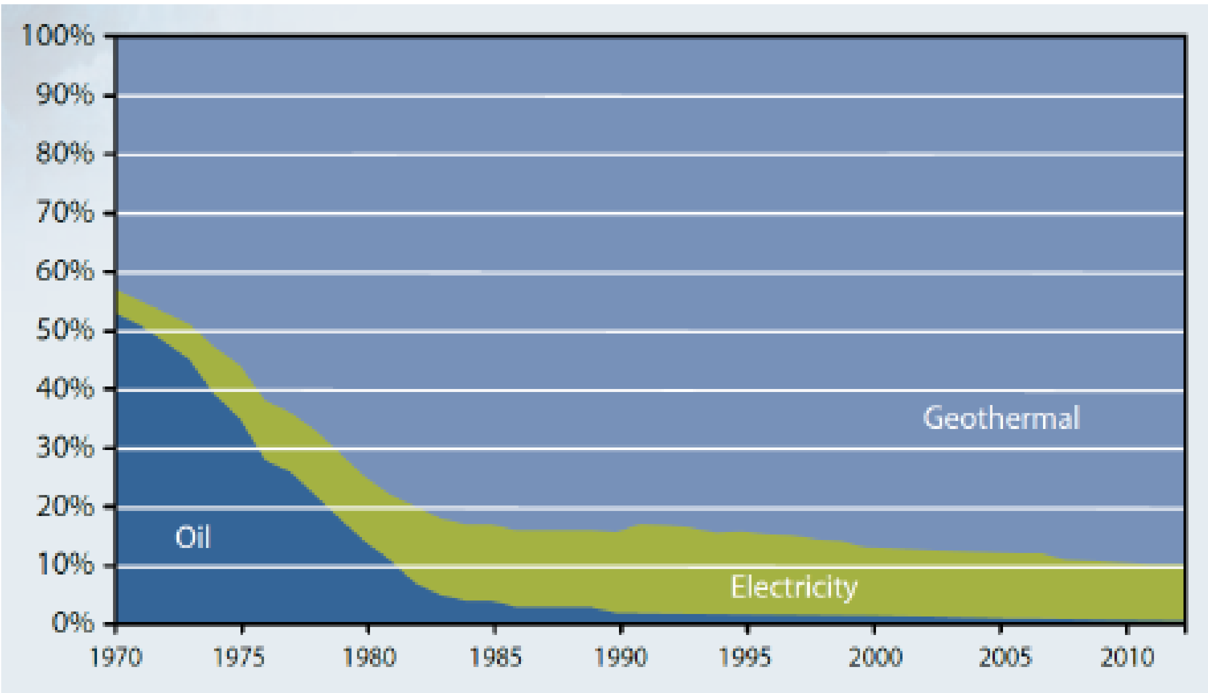
Figure 5.5.2. **Sectoral share of geothermal heat in Iceland in 2014. The outer ring uses categories of the International Geothermal Association (IGA) but the inner ring the categories of the International Energy Agency (IEA). In total 28, PJ.**



Space Heating

Over the last 70 years, there has been considerable development in the use of energy for space heating in Iceland. After WW2, The National Energy Authority (Orkustofnun) and Iceland Geosurvey (and their predecessors) have carried out research and development, which has led to the use of geothermal resources for heating in the households of 90% of the population. This achievement has enabled Iceland to import less fuel, and has resulted in lower heating prices.

Figure 5.5.3. **Relative share of energy resources in the heating of houses in Iceland 1970–2014.**



Industrial uses

• The diatomite plant at Lake Mývatn, near the Námafjall high temperature geothermal field, began operation in 1967, producing some 28,000 tonnes of diatomite filter annually for export. For environmental and marketing reasons, the plant was closed at the end of 2004. The plant employed about 50 people and was one of the world's largest industrial users of geothermal steam. The raw material was diatomaceous earth found on the bottom of Lake Mývatn. Each year the plant used some 230,000 tonnes of geothermal steam at 10-bar pressure (180°C), primarily for drying. This corresponds to an energy use of 444 TJ per year.

• The seaweed manufacturer Thorverk, located at Reykhólar in West Iceland, uses geothermal heat directly in its production. The company harvests seaweed found in the waters of Breidafjördur in northwest Iceland using specially designed harvester crafts. Once landed, the seaweed is chopped and dried on a band dryer that uses large quantities of clean, dry air heated to 85°C by geothermal water in heat exchangers. The plant has been in operation since 1975, and produces about 4,000 tonnes of rockweed and kelp meal annually using 36 l/sec of 112°C water for drying. The product has been certified as organic. The plant's annual use of geothermal energy is about 250 TJ.

• A salt production plant was operated on the Reykjanes peninsula for a number of years. The plant produced salt from geothermal brine and seawater for the domestic fishing industry as well as low-sodium health salt for export. During the plant's final years of operation, production was intermittent.

• Since 1986, a facility at Hædarendi in Grimsnes, South Iceland, has commercially produced liquid carbon dioxide (CO_2) from geothermal fluid. The Hædarendi geothermal field temperature is intermediate (160°C) and the gas content of the fluid is very high (1.4% by weight). The gas discharged by the wells is nearly pure carbon dioxide with a hydrogen sulfide concentration of only about 300 ppm. Upon flashing, the fluid from the Hædarendi wells produces large amounts of calcium carbonate scaling. In one well scaling is avoided by a 250 m long downhole heat exchanger made of two coaxial steel pipes. Cold water is pumped through the inner pipe and back up on the outside. Through this process, the geothermal fluid is cooled and the solubility of calcium carbonate increased sufficiently to prevent scaling. The plant uses approximately 6 l/s of fluid and produces some 3,000 tonnes CO_2 annually. The product is used in greenhouses, for manufacturing carbonated beverages, and in other food industries. The production is sufficient for the Icelandic market.

• Geothermal energy has been used in Iceland for drying fish for about 25 years. The main application has been the indoor drying of salted fish, cod heads, small fish, stockfish and other products. Until recently, cod heads were traditionally dried by hanging them on outdoor stock racks. Because of Iceland's variable weather conditions, indoor drying is preferred. The process is as follows: hot air is blown on the fish, and the moisture from the raw material removed. About 10 small companies' dry cod heads indoors. All of them use geothermal hot water. The annual export of dried cod heads is about 15,000 tonnes. The product is mainly shipped to Nigeria where it is used for human consumption.

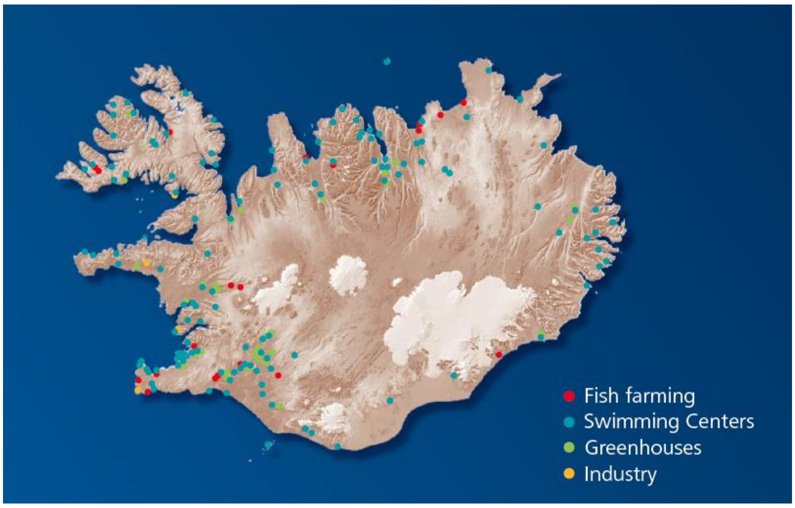
• drying pet food is a new and growing industry in Iceland with an annual production of about 500 tonnes.

Examples of additional industrial uses of geothermal energy that have been tried on a smaller scale are: retreading car tires, wool washing, curing cement blocks, drying of imported hardwood, and baking bread with steam.

Greenhouses

Apart from space heating, one of Iceland's oldest and most important usages of geothermal energy is for heating greenhouses. For years, naturally warm soil has been used for growing potatoes and other vegetables. Heating greenhouses using geothermal energy began in Iceland in 1924. The majority of Iceland's greenhouses are located in the south, and most are enclosed in glass. It is common to use inert growing media (volcanic scoria, rhyolite) on concrete floors with individual plant watering. Geothermal steam is commonly used to boil and disinfect the soil. The increasing use of electric lighting in recent years has extended the growing season and improved greenhouse utilisation.

Figure 5.5.3. **Satellite image of Iceland in summer time showing where geothermal is used for various uses like swimming, fish farming, industrial processes and heating greenhouses in year 2014.**



This development has been encouraged through governmental subsidies spent on electricity for lighting. CO_2 enrichment in greenhouses is also common, primarily through CO_2 produced in the geothermal plant at Hædarendi. Greenhouse production is divided between different types of vegetables (tomatoes, cucumbers, peppers, etc.) and flowers for the domestic market (roses, potted plants, etc.). The total area under glass increased by 1.9% per year between 1990 and 2000. It was about 194,000 m^2 in 2012 with plastic tunnels for bedding and forest plants included. Of this area, 50% is used for growing vegetables and strawberries, 26% for cutflowers and potplants and 24% are nurseries for bedding and forest plants.

The total production of vegetables in 2011 was about 18,000 tonnes. The share of domestic production in the total consumption of tomatoes is about 75% and for cucumbers about 90%. Over the last few years, there has been an increase in total production, even though the total surface area of greenhouses has decreased. This is due to increased use of artificial lighting and CO_2 in the greenhouse sector. Outdoor growing at several locations is enhanced by soil heating though geothermal water, especially during early spring. Soil heating enables growers to thaw the soil so vegetables can be brought to market sooner. It is estimated that about 120,000 m^2 of fields are heated this way. Soil heating is not a growing application, partly because similar results are commonly obtained at a lower cost by covering the plants with plastic sheets. Because of the increased use of artificial light it has decreased in recent years as the lights also give heat. The average energy consumption in greenhouses with artificial lightning amounts to 3.67 GJ/m^2, compared to 5.76 GJ/m^2 in greenhouses without artificial lightning.

Fish farming

Initially, Iceland's fish farming was mainly practised in shore-based plants. Geothermal water, commonly at 20-50°C, was used to heat fresh water in heat exchangers, typically from 5°C to 12°C. In the middle of the 1980s, there was a marked increase in the number of fish farms in Iceland and for a while there were more than 100 farms in operation, many of them quite small. The 1990's were marked by stagnation and for most years the total production remained between 3,000 and 4,000 tonnes. During this time, however, the production of arctic char increased steadily from 70 tonnes in 1990 to around 900 tonnes in 1999 at the expense of salmon production. In 2003, the total production increased significantly and reached a maximum of around 10,000 tonnes in 2006, mostly on the account of expanded salmon ocean ranching. As this farming method did not prove profitable, the total production declined by around 50% the following year and amounted to approximately 5,000 tonnes in 2007 and

2008. Arctic char accounted for 60% of the production, while cod and salmon accounted for 30% and 6% respectively.

Although heat exchangers are still used in some plants, direct mixing has become more common as the geothermal water has in most cases been shown to have no adverse effects on the fish. In some plants, however, the dissolved oxygen content has been increased by aeration or direct injection. As this farming process requires large amounts of water, some farmers have cut back on consumption and costs by recycling water through appropriate filters and adding oxygen. Geothermal water is commonly used to elevate temperatures in the hatching and early development stages of all farmed species, but cod and salmon are moved to salty or brackish cold water when a certain size is reached. Arctic char, however, is commonly raised at elevated temperatures in land based plants until harvesting. A faster growth rate is achieved by the warmer temperatures, thereby shortening production time. The temperature varies between species and development stages and commonly gets colder as the fish grow older and larger, mostly due to increased risk of parasites in warmer water with a high density of fish.

There are about 70 fish farms in Iceland at present with a total production of about 7,000 tonnes. Between 15 and 20 of them utilize geothermal water, mainly for production of juveniles of char and salmon. In landbased char production geothermal energy is also used for post-smolt rearing.

As production is expected to increase in the future, the utilisation of geothermal water in the sector is also expected to increase, especially in the smolt production (trout and salmon).

Bathing and recreation

Until early last century, Iceland's geothermal energy was limited to bathing, laundry and cooking. These uses are still significant. After space heating, and electricity generation, heating of swimming pools is one of the most important uses of geothermal energy. There are about 175 recreational swimming centres operating in Iceland, 150 of which use geothermal heat, not counting natural hot springs or the Blue Lagoon, the Myvatn Nature Baths and Nauthólsvík geothermally heated beach. Based on their surface area, 90% of the pools are heated by geothermal sources, 8% by electricity, and 2% by burning oil and waste. The combined surface area of all swimming centres in Iceland is about 37,550 m^2, not including the surface area of shallow relaxation pools. Most of the public pools are open-air pools used throughout the year.

The pools serve recreational purposes and are also used for swimming lessons, which are compulsory in schools. Swimming is very popular in Iceland and pool attendance has increased in recent years. In the greater Reykjavik area alone there are 17 public swimming centres. The largest of these is Laugardalslaug with a surface area of 2,750 m^2 plus five hot tubs in which the water temperature ranges from 35 to 42°C. Other health uses for geothermal energy are the Blue Lagoon at Svartsengi, the Fontana at Laugarvatn, the Bath Facility at Myvatn, and the Health Facility in Hveragerdi, comprising geothermal clay baths and water treatments. Typically, about 220 m^3 of water or 40 GJ of energy is needed annually for heating one m^2 pool surface area. This means that a new, medium-sized swimming pool uses as much hot water as is needed to heat 80–100 single-family dwellings.

Snow melting

Geothermal energy has been utilised to a limited extent to heat pavements and melt snow during the winter. The practice of snow melting has increased during the last two decades and now most new public car parking areas in regions enjoying geothermal district heating are provided with snow melting systems. Hot water from space heating returns at about 35°C, and is commonly used for de-icing sidewalks and parking spaces. Most systems have the possibility of mixing the return water with incoming hot water (80°C) when the load is high. In downtown Reykjavik, a snow-melting system has been installed under the sidewalks and streets over an area of 70,000 m^2. This system is designed for a heat output of 180 W per m^2 surface area. Iceland's total area of snow melting systems is about 1,200,000 m^2, of which about 725,000 m^2 are in Reykjavik. About half of the systems is in public areas, one fourth at commercial premises and one fourth by private homes. The annual energy consumption depends on the weather conditions, but the average is estimated to be 430 kWh/m^2 About two thirds of the energy is from return water from space heating systems.

Initial use of geothermal heat

In Reykjavik, extensive distribution of hot water for heating homes began in 1930 when a 3 km long pipeline was built to transport hot water from the Þvottalaugar (laundering springs) to two primary schools, a swimming hall, the main hospital and 60 family homes in the capital area. In 1943, a major step was reached when a new 18 km pipeline from Reykir, Mosfellssveit was put into use, and the Reykjavik District Heating Service began operating. By the end of 1945, 2.850 houses were connected. The population of Reykjavik at that time was just over 44.000. In addition to the development in the capital area, many communities around the country built their heating distribution systems in places where hot springs, or successful drilling yielded suitable geothermal water. Community schools in the countryside were also preferably located close to supplies of geothermal water, which was available for heating and swimming.

5.6 Public Support of Geothermal District Heating

Public support

Already by the 1940s, the State Electricity Authority promoted geothermal development and carried out a regional survey of geothermal areas suitable for space heating and explored promising fields with exploratory drilling. The capital Reykjavik obtained by law a monopoly on operating a geothermal heating service in the town and took initiative in production drilling and establishment of the first large geothermal district heating system. The State guaranteed loans for the construction of the system. In 1950 about 25% of families in the country enjoyed geothermal heating services, 40% used coal and 20% oil for heating. The cheap geothermal heating was attractive and intensified the flux of people from rural areas to the capital.

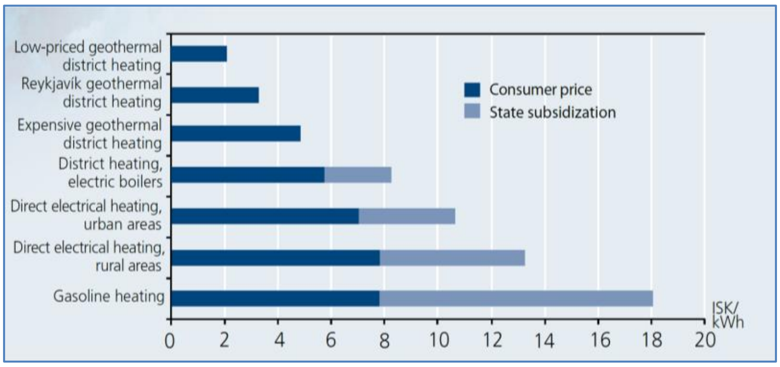
To balance that the national parliament approved an Act in year 1953 on geothermal heating services in communities outside Reykjavik which permitted the State to guarantee loans up to 80% of the total drilling and construction cost of heating services. Further, to encourage the development, the State raised a Geothermal Fund in 1961. The fund gave grants for reconnaissance and exploratory drilling carried out by the Geothermal Department of the State Electricity Authority and offered loans to communities and farmers for exploratory and appraisal drilling covering up to 60% of the drilling cost. If the drilling was successful the loans were to be paid back with highest allowed interests in 5 years after the heating service was up and running.

Lessons learned from Iceland

- Important to recognize the importance of GeoDH for
  - economy (savings),
  - energy security and
  - mitigate climate change
- Important to lower the risk of projects in the beginning e.g. by supporting exploration and test drilling
- Importance for Financial Institutions to recognise opportunities within GeoDH

If exploratory drilling failed to yield exploitable hot water, the loan was converted to a grant and not paid back. In this way the fund encouraged exploration and shared the risk. Within the next 10 years many villages used this support and succeeded in finding geothermal water. In 1967 the fund was merged with the Electricity Fund and named the Energy Fund. The Electricity Fund had since the 1940s supported electrification and transmission in rural areas.

Figure 5.6.1 **Comparison of Energy Prices for Residential Heating in Iceland in 2014**



By 1970 about 43% of the nation enjoyed geothermal heating, while oil was used by 53% of the population, and the remainder used electricity.

Space heating of residential buildings is subsidized by the state as shown on Figure 5.1.4. for those areas where geothermal based district heating systems are not reachable. The lump sum of this state subsidization for 8 years has been available to support home owners to transform to renewable heating (Act No. 78/2002). This has recently been increased by 50% to be equivalent of 12 years lump sum. In addition if the project receives other grants it will not effect in any way this lump sum payment. This has stimulated new geothermal based district heating systems to be installed like in the town of Skagastrond, operated by RARIK in year 2013.

The Government's role in developing geothermal energy

The government has encouraged the exploration for geothermal resources, as well as research into the various ways geothermal energy can be utilized. As stated earlier this work began in the 1940s at The

State Electricity Authority, and was later, for decades, in the hands of its successor, Orkustofnun (The National Energy Authority), established in 1967. The aim has been to acquire general knowledge about geothermal resources and make the utilization of this resource profitable for the national economy.

This work has led to great achievements, especially in finding alternative resources for heating homes. This progress has been possible thanks to the skilled scientists and researchers at Orkustofnun. After the electricity market was liberalized with adaption to EC Directive in year 2003 Orkustofnun only contracts research in the field of energy and a new state institute, Iceland GeoSurvey, was created which on a competitive basis takes part in projects mainly for the power companies and heat utilities but also for Orkustofnun. According to a new Energy Act in 2003, the Energy Fund is now under Orkustofnun.

Fig. 5.6.2. **Policy Priorities for Geothermal District Heating in Iceland**

Political, sectorial and public recognition / awareness for the importance for GeoDH Policy
- For **energy security, economic and environmental** reasons (oil crises / price), the GeoDH policy was recognized at national level and within main cities.

Grants to GeoDH for exploration and test drilling lowered risk for GeoDH - improved implementation
- The National Energy Fund (NEF) has financed several exploration and test drilling to assist the development even further. (Before 2010 - If the drilling is successful the – the grant is paid back.)

Grants to individuals (apartments) for transformation to GeoDH – improved implementation
- Grant for 8 years support transformation from electricity heating to GeoDH – by Heat Pump.

Grants to GeoDH companies (GeoDH Area) for transformation to GeoDH – improved implementation
- Grant for 12 years support transformation from electricity heating to GeoDH

Loans from NEF (risk related), for drilling geothermal district heating (GeoDH) – improved implementation
- Loans to GeoDH companies were valuable instruments.

Space heating support for homes which are out of geothermal areas
- Space heating of residential buildings is subsidized by the state for those areas where geothermal energy is not available.

Policy to replace electricity (high exergetic content) for space heating
- Aims at reducing electricity (high exergetic content) for space heating and replacing it with geothermal heating (low exergetic content) and contributing to improved energy quality management

New and effective exploration techniques have been developed to discover geothermal resources. This has led to the development of geothermal heating services in regions that were thought not to have suitable geothermal resources. Iceland's geothermal industry is now sufficiently developed for the government to play a smaller role than before. Successful power companies now take the lead in the exploration for geothermal resources, either geothermal fields that are already being utilized, or discovering new fields.

5.7 Economic impact

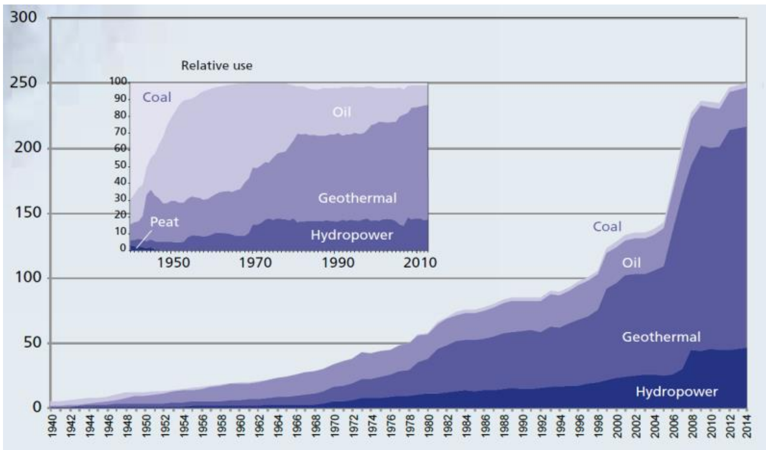
Influence of the oil crisis on energy prices

When the oil crisis struck in the early 1970s, fuelled by the Arab-Israeli War, the world market price for crude oil rose by 70%. At about the same time, close to 90,000 people enjoyed geothermal heating in Iceland, about 43% of the nation. Heat from oil served over 50% of the population, the remainder used electricity. In order to reduce the effect of rising oil prices, Iceland began subsidizing those who used oil for space heating. The oil crises in 1973 and 1979 (Iranian Revolution) caused Iceland to change its energy policy, reducing oil use and turning to domestic energy resources, hydropower and geothermal.

This policy meant exploring new geothermal resources, and building new heating utilities across the country. It also meant constructing transmission pipelines (commonly 10-20 km) from geothermal fields to towns, villages and individual farms. This involved converting household heating systems from electricity or oil to geothermal heat. But despite the reduction in the use of oil for space heating from 53% to 7% from 1970 to 1982, the share of oil still remained about 50% to 60% of the total heating cost due to rising oil prices.

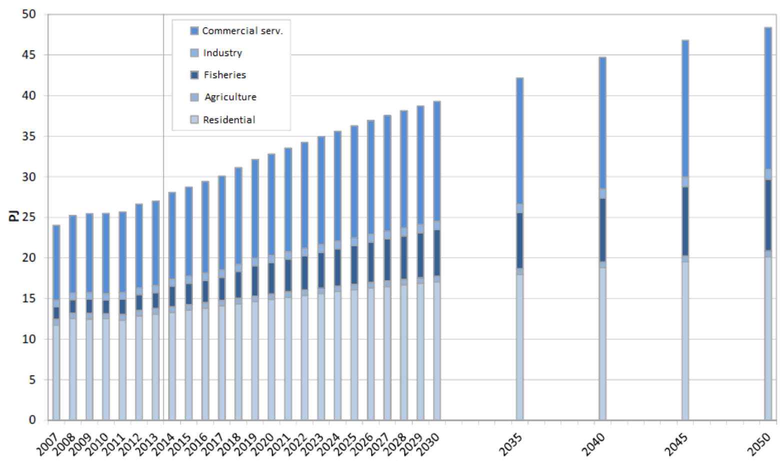
The relative share of energy resources used to heat households has changed since 1970 (Fig. 5.7.1). The increase in geothermal energy is clear, but after 1985 it has been steady for heat use. However according to Statistics Iceland a population growth of 36% is estimated to year 2050 and hence the total heat use is expected to increase by 70% until 2050 to almost 50 PJ. The proportion of the population using geothermal energy is also increasing, and could in the long run rise from its present ratio of 89% to 92% for residential heating. The share of oil for heating continues to decrease and is at present at about 1%. The share of electric heating is about 10% but one third of that comes from combined heat and power plants using geothermal where electricity is used to heat water for district-heating systems.

Figure 5.7.1. **Prime Energy use in Iceland 1940 – 2014**



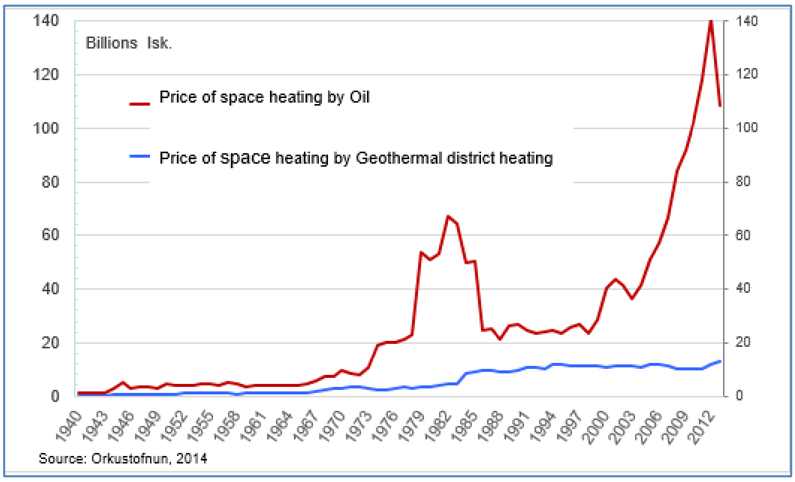
Primary energy use by Iceland has increased by large amounts in the last few decades. The primary energy use in 2010 was approximately 750 GJ per capita, which is among the highest in the world. Furthermore, when looking at the share of renewables in total primary energy use in the world, it can be seen that Iceland has the highest share, with 85%, and the average for Europe is 9%, USA 8%, Japan 3% and China 14% see. fig. 1.3.2.4, earlier in this report, chapter 1.

Fig.5.7.2. **Geothermal utilization in [PJ] plotted against time for the period 2007–2050 (Orkustofnun, 2015).**



The predominant reason for this is the large proportion of large industries in the consumption of electricity. Additional reasons are the relatively large proportion of electricity production from geothermal, heavy energy use by the fishing fleet and for transportation, and more need for energy for house-heating due to cold climatic conditions.

Fig.5.7.3 **Economic Benefits of Geothermal District Heating**
Price of a space heating by geothermal district heating and by oil 1914 – 2013.



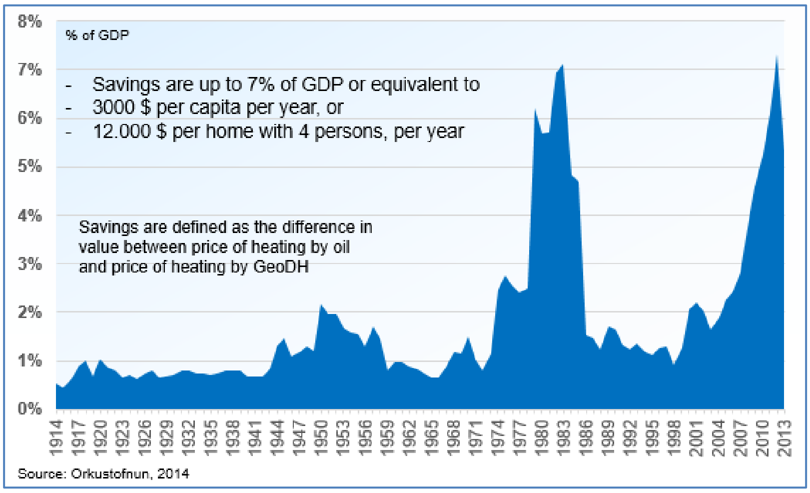
Benefits of using geothermal heat instead of oil

The economic benefits of the government’s policy to increase the utilisation of geothermal energy can be seen when the total cost of hot water used for space heating is compared to consumer cost if oil would be used, as shown in Fig. 5.3.2. The stability in the hot water cost during strong variations in oil cost is noteworthy.

In Fig 5.3.2 the blue line shows price for geothermal district heating – and the red line the calculated price for district heating by oil,(adjusted to the consumer price index 1 US$ = 120 ISK).

Oil heating is 2-6 times more expensive than geothermal heating throughout most of the period but peaks to 16 times more expensive in the period 1973 to 1985 and has risen again since 2007 to a present ratio of 10. In 2012 the difference in cost amounted to 80% of the state budget cost of health care in the same year.

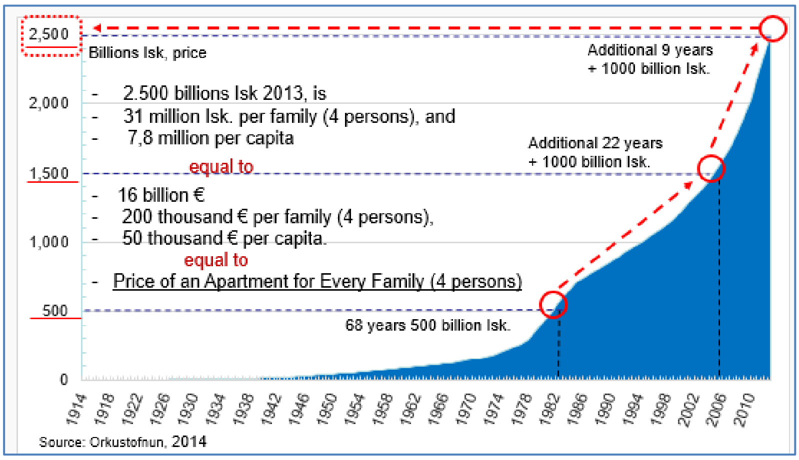
Figure 5.7. **Economic Benefits of Geothermal District Heating**
National Savings by Geothermal District Heating as % of GDP



Evaluations of the estimated savings might vary somewhat as some might claim that sources other than oil could be used for heating. Heating energy could have been obtained through an increased generation of electricity with hydropower, as is done in Norway.

Nevertheless, it is beyond dispute that the economic savings from using geothermal energy are substantial, had positive impact on the currency account and contributed significantly to Iceland's prosperity, especially in times of need. The annual savings have been in the range of 1-2% of the national product for most years but rise to 7% in the period 1973 to 1985 and are reaching that peak again in recent years. The 7% of the national product are equivalent to 3.000 US$ per capita.

Fig.5.3.4. **Cumulative Savings from Geothermal District Heating in Iceland 1914 – 2013**
2% interests, fixed price 2013



Besides the economic and environmental benefits, the development of geothermal resources has had a desirable impact on social life in Iceland. People prefer to live in areas where geothermal heat is available, in the capital area and in rural villages where thermal springs can be utilised for heating dwellings and greenhouses, schools, swimming centers and other sports facilities, tourism and smaller industry. Statistics show improved health of the inhabitants of these regions.

In recent years, the utilisation of geothermal energy for space heating has increased mainly as a result of the population increase in the capital area. People have been moving from rural areas to the capital area. As a result of changing settlement patterns, and the discovery of geothermal sources in the so-called "cold" areas of Iceland, the share of geothermal energy in space heating is still rising. It is also possible to evaluate cumulative savings of the Geothermal District Heating from 1914 – 2013, based on real price (fixed price 2013) and 2% annual interest rate.

Based on these calculations, the overall savings is equal to 31 million Isk per family (200 thousands €), which is equal to price of an apartment for every family (4 persons) in Iceland.

From 1982 – 2013 the majority of savings has happened after the GeoDH implementation and is about 2.000 billion Isk. This is equal to 64 billion Isk. (412.000.000 €) per year, or 800.000 Isk (5.160 €) per family, or about 70.000 Isk. (450 €) per month per family, after taxes.

According to information from Registers Iceland, 2.500 billion Isk, is equal to 80% of the total value of all residential houses and apartments in Iceland which was estimated around 3.200 billion Isk. 2013.

CO_2 Savings due to GeoDH

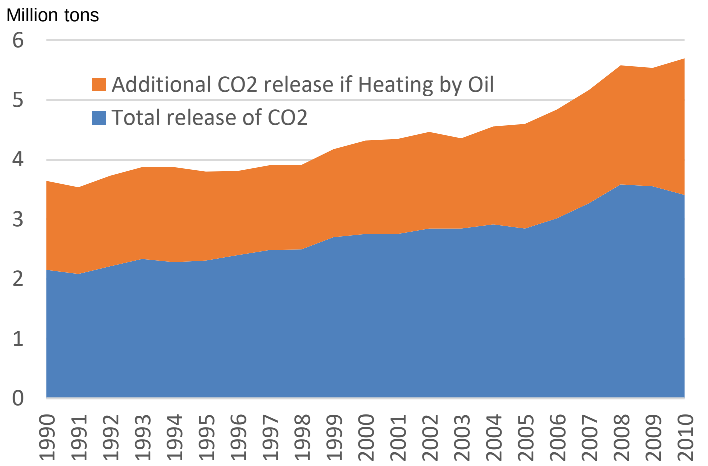
The use of geothermal energy for space heating and electricity generation has also benefited the environment, as both geothermal energy and hydropower have been classified as renewable energy resources, unlike carbon fuels such as coal, oil and gas. The benefit lies mainly in relatively low CO_2 emissions compared to the burning of fossil fuels.

On average, the CO_2 savings by using GeoDH have been around 1,5 million tons per year from 1990 – 2010 or 20 tons per family (4 persons). Cumulative savings during 1990 – 2010 are about 35 million tons, or 440 tons per every family.

These 440 saved tons of CO_2 have been important contribution for mitigation of climate change – not only in Iceland but on global level as well, as climate change has no border between countries or regions. Geothermal District Heating (GeoDH) in Iceland therefore contributes towards economic savings, energy security and reduction of greenhouse gas emissions.

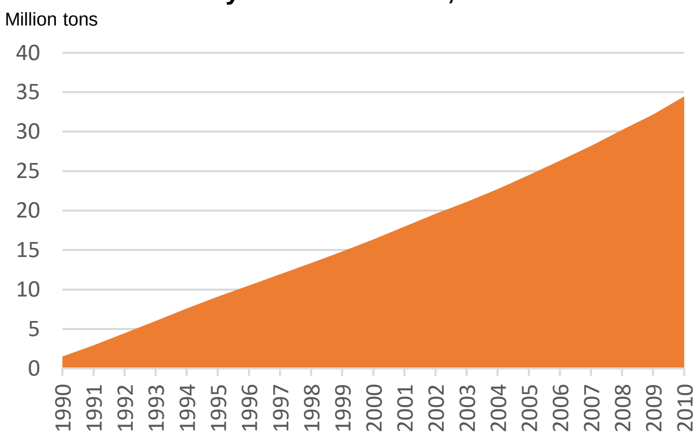
Figure 5.3.5. **Reykjavik**

Figure 5.3.6. **Reduction of CO_2 by using GeoDH instead of Oil 1990 - 2010**



Source: Orkustofnun, (National Energy Authorty) 2014

Figure 5.3.7. **Cumulative Savings of CO_2 due to GeoDH Systems in Iceland, 1990 – 2010**



Source: Orkustofnun, (National Energy Authorty), 2014

6 Geothermal Electricity Generation

6.1 Development in Iceland

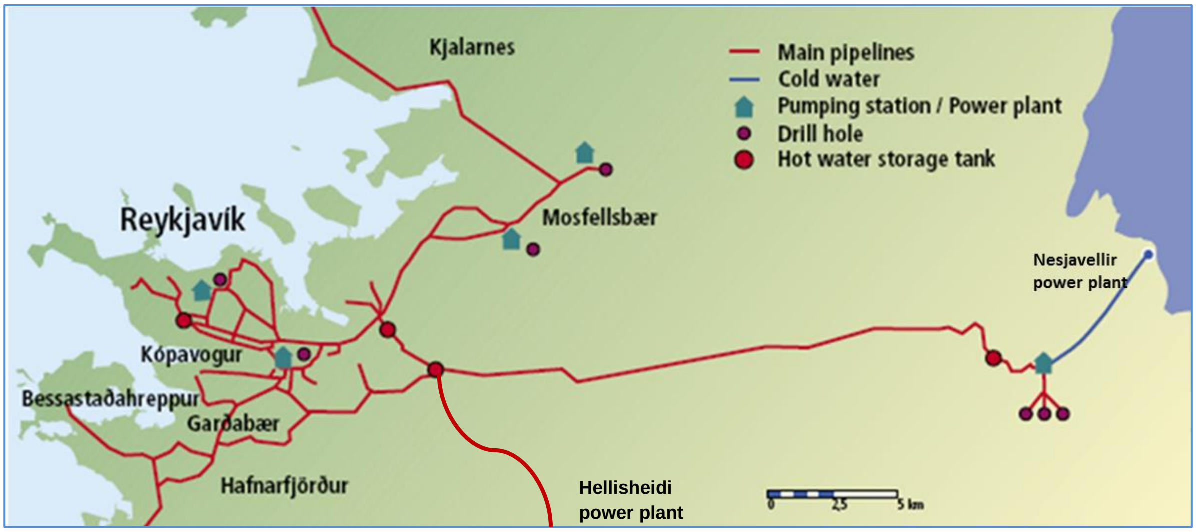
Geothermal resources have only a minor share in the worldwide generation of electricity but they have become of major importance in many volcanic regions which lack other resources for electricity generation. Leading countries in this development have been Italy, USA, New Zealand, Mexico, the Philippines, Indonesia, Iceland and Japan. In Africa, Kenya is the leading country but no development has occurred in S-America despite its large potential.

The initial build-up of capacity world-wide was slow but accelerated in the seventies due to rising prices of oil. In the last 25 years the capacity has increased on average by 250 MW per year. Compared to solar energy and wind power the development has been slow, despite considerable support from funds, public institutions and academic research. Science, technology and finance have not always succeeded in outlining to possible investors the barriers and risks involved, and how they can be mitigated.

The successful development of geothermal electricity generation in Iceland has raised interest. A country with 320 thousand inhabitants had in the year 2014 installed a capacity of 663 MW in geothermal power plants. This occurs in a country with a large potential in hydropower. Generally the risk in hydropower projects is considered less than in geothermal projects but the geothermal plants have the competitive advantage of serving the base load with full availability throughout the year. Power plants in Iceland have a total capacity of 2.637 MW generating in total 18,12 TWh in year 2014. The share of hydropower is 71% and that of geothermal 29% in electricity generation. Oil is only used for electricity generation in emergency cases.

Iceland has an area of 103.000 km^2. Two thirds of the population live in the capital area in the SW-part. Other inhabitants are settled in a number of villages, mostly around the coast, and in rural areas. Electrification has been developed over the last century. The country has many rivers draining water from the mountainous inland and glaciers. The electrification was initially in the hands of communities which erected small hydropower plants to serve their inhabitants but the networks were not interconnected.

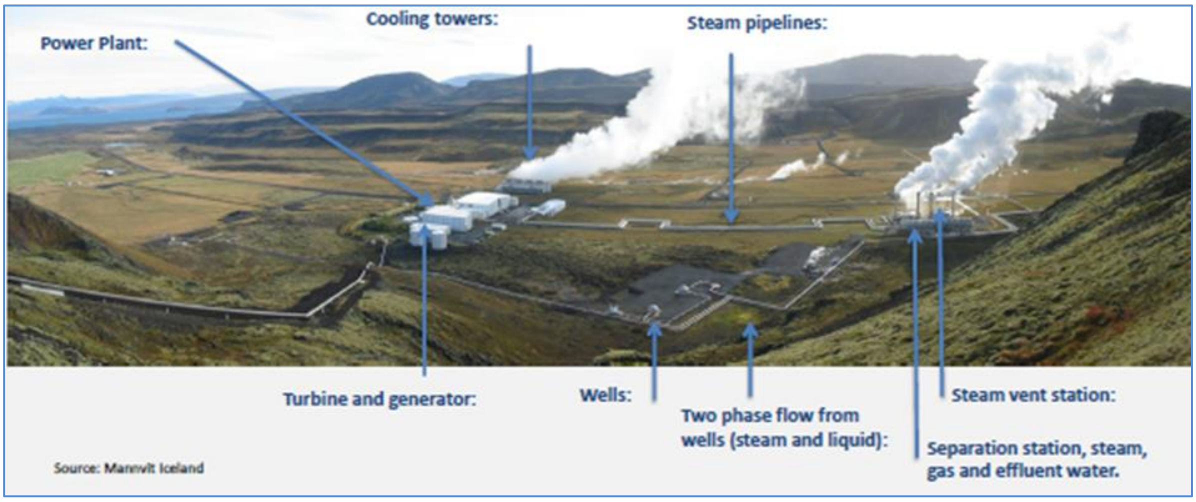
Figure. 6.1.1. **The Reykjavik District Heating System**



Geothermal district heating started on a small scale in Reykjavík in 1930 and today Orkuveita Reykjavíkur operates the largest municipal district heating. The system serves about 195.000 people in the capital area with hot water. From 1998 electricity has been co-generated from geothermal steam along with hot water for heating at Nesjavellir. About 70% of the energy used for district heating comes however directly from low temperature geothermal fields but about 30% from heating up cold water in combined heat and power plants using geothermal energy as the primary energy source.

A major change occurred in 1965 when the State and the capital Reykjavik established Landsvirkjun (the National Power Company) with the aim of building larger power plants and interconnecting the countrywide electrical networks. The company built a hydropower plant of 210 MW to provide electricity for an aluminium smelter in 1969, with financial support from the World Bank. Landsvirkjun has continued developing hydropower and geothermal power to serve energy intensive industries. The installed capacity in hydropower in Iceland is now 1.895 MW. The company does also operate one 60 MW geothermal power plant.

Figure 6.1.2. **The Nesjavellir Geothermal Power Plant in Iceland,**
120 MW Electric and 300 MW Thermal for Space Heating



Other major power companies are Reykjavik Energy with 423 MW installed in two geothermal power plants and HS Orka operating two geothermal power plants of 176 MW electric capacity. Three of the geothermal plants combine generation of electricity and production of hot water for space heating. Smaller companies operate hydropower plants with a total capacity of about 80 MW.

Figure 6.1.3. **The Hellisheiðarvirkjun Geothermal Power Plant**
303 MW Electric and 133 MW Thermal for Space Heating

The State and communities own 93% of the installed capacity but only 7% are in the hands of the private sector. The electricity market is dominated by few energy intensive industry companies which buy 77% of the production. The risk having few customers is balanced by power purchase agreements (PPA) which ensure steady use of energy and sales over tens of years. This leads to high utilisation factors in the power plants, about 75% in the hydro power and 90% in the geothermal plants. Long term contracts with trustworthy companies have also eased financing of the power projects.

Without the energy intensive industry the development would have been an order of magnitude less. A countrywide electrical network is served with major electricity transmission lines operated by Landsnet, a company in the ownership of the State. The emphasis has been on safe delivery rather than high return on equity (ROE). The owners of the energy companies have given their guarantee for favourable long term loans from development banks and commercial banks.

The share of own capital of the energy companies has been low and debts high and so the energy companies have had relatively low return on equity. The electricity price in Iceland is among the lowest in Europe. The price from Landsvirkjun to distribution companies 2012 was 3,12 cents/kWh and the average to the energy intensive industries 2,6 cents/kWh. The development of the energy sector has had beneficial influence on the labour market, built up know how, strengthened the pillars of national production, increased export and supported foreign exchange. (Landsvirkjun, 2012)

6.2 Drilling for geothermal water and steam

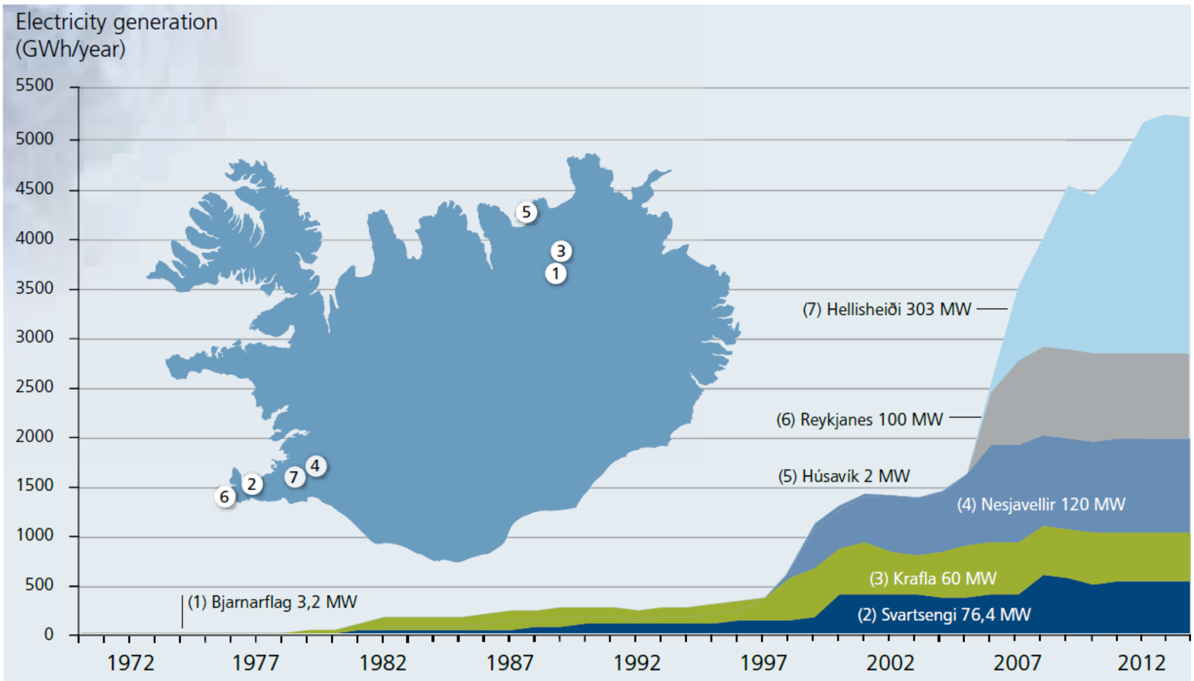
First attempts to drill wells in geothermal areas in Iceland began as early as in the year 1755 when exploration wells were drilled in search for sulphur near the Laugarnes hot springs in Reykjavík and in the high temperature field Krýsuvík on the Reykjanes Peninsula. In Krýsuvík the hole reached 10 m depth and erupted a mixture of steam and clay. Drilling with percussion rigs for potable water in Reykjavik shortly after 1900 was not successful but rumors that the boreholes had encountered traces of gold led to the purchase of a new percussion drilling rig which was nicknamed the “gold drilling rig”.

The Reykjavik Electricity Service became interested in drilling as they learned of successful drilling for steam in Lardarello in Italy to generate electricity. They bought the “gold drilling rig” and used it to drill 14 wells in the hot spring area of Laugarnes in Reykjavík 1928–30. The deepest well was 246 meters. No steam was found but the wells yielded significantly greater artesian flow of hot water than the hot springs prior to drilling. This success led to the first step in geothermal heating of houses in Reykjavik in 1930.

Until 1986 nearly all drill rigs were operated by the State Drilling Company. The emphasis was on discovering hot water for space heating all over the country. The wells were located near hot springs and also in regions where exploratory surveys and drilling indicated a high geothermal gradient. Some drilling also took place in the high temperature fields. Exploratory wells were drilled in Reykjanes to provide hot brine for a sea chemicals factory.

Drilling for cogeneration of hot water and electricity took place at Svartsengi and Nesjavellir and wells were drilled in Krafla to provide steam for the generation of electricity. There the drilling ran into difficulties because volcanic activity caused an influx of corrosive gases into the geothermal reservoir. The drilling company was privatized 1986 and now operates as Iceland Drilling Ltd but several other smaller drilling companies have also been established.

Figure 6.2.1. **Generation of Electricity using Geothermal Energy 1969–2014**



These smaller firms have overtaken most of the drilling in hot spring areas whereas Iceland Drilling Ltd has emphasized drilling boreholes in the high temperature fields. Among recent innovations in drilling technology are downhole hydraulic turbines that are driven by the circulation fluid and can rotate the drillbit much faster than the rotating string.

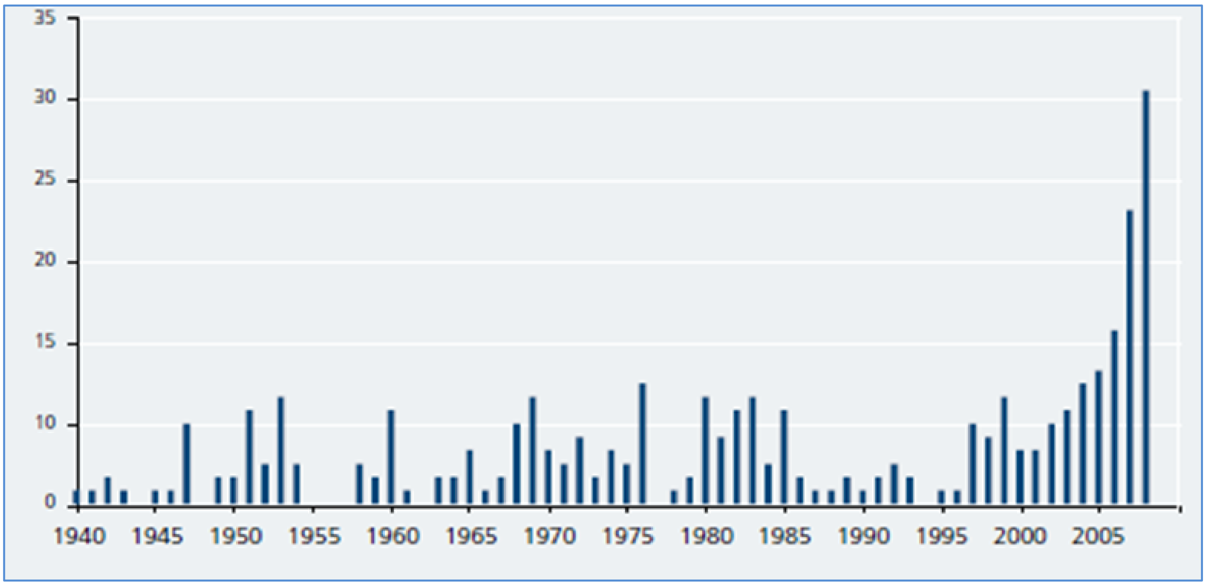
This technique yields a faster penetration rate and also allows for inclined directional drilling to intersect targets off the drilling platform. A cluster of wells can thus be drilled to different directions from the same drilling platform. Another novelty used in shallow holes is pneumatic hammers implanted with carbide balls that hammer the whole bottom several thousand times per minute and give a penetration rate of 10–30 m/hour.

The first geothermal unit was a 3 MW back pressure turbine installed in 1969. The Krafla plant (2x30 MW) was constructed in 1975-1977 but volcanic activity injected reactive gases into the reservoir and made the best part of it unexploitable for the next 15 years. The first unit began operating in 1977 but the second unit was not installed until 1997. The project was financed by the State with the purpose of providing electricity for Northern part of Iceland.

These difficulties were discouraging for further construction of geothermal power plants while there was more feasible potential available in hydro power. HS Orka installed several small units at Svartsengi as cogeneration with the production of hot water for space heating. This escalated with a 30 MW unit installed in 1999 and another in 2007, bringing the total capacity up to 76,4 MW. Reykjavik Energy began also cogeneration with hot water production at Nesjavellir with 2x30 MW units installed in 1998, and two more 30 MW units in 2001 and 2005.

Until 2003 only Landsvirkjun could sell electricity to the energy intensive industry but this changed with the new Electricity Act in 2003 which opened the door for competition between Icelandic energy companies serving that industry. Increased demand from the aluminum industry led HS Orka to build a 100 MW geothermal plant at Reykjanes in 2006 and Reykjavik Energy to build the Hellisheidi plant of 303 MW in the years 2006 to 2011. Without this increased demand from the aluminum industry the development of geothermal power plants in Iceland would have been much slower as the domestic market did not call for more than a minor increase in generation. Nowhere else do aluminum smelters rely as much on geothermal plants for electricity as in Iceland.

Figure 6.2.2**. Number of Wells Drilled in High Temperature Fields 1970–2008**



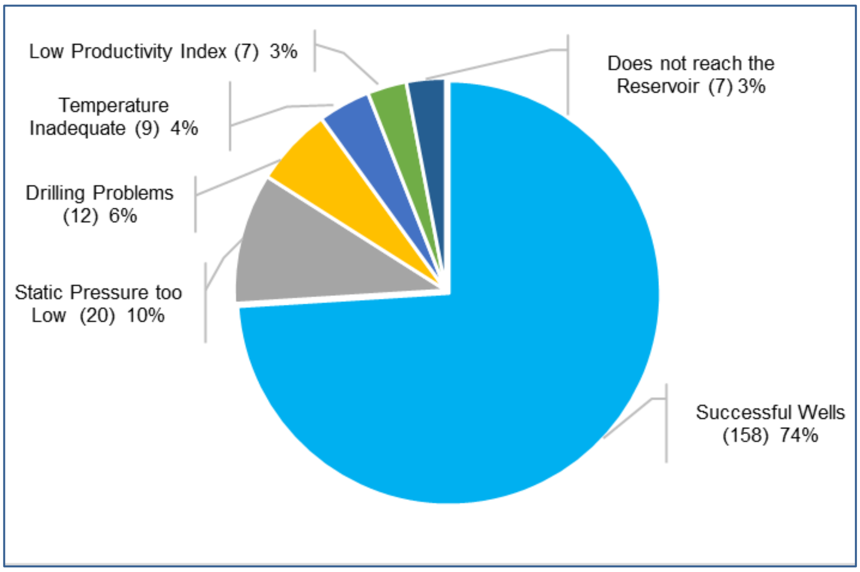
More than 300 wells have been drilled in steam fields for production. Of those 208 are deeper than 500 m, 36 reach more than 2000 m and six beyond 3000 m. In hot water fields about 860 production wells have been drilled. Thereof 291 are deeper than 500 m, 19 reach more than 2000 m and one beyond 3000 m. Wells drilled in search of high temperature gradients are more than 2600. Most of them are shallower than 100 m but some exceed 1000 m in depth. These wells are rarely intended for production. Steam field drilling for generation of electricity has dominated in the last decade as can be seen in Fig. 6.2.2. In 2008 31 wells were drilled in six steam fields with a combined depth of 67 km.

6.3 Success of High Temperature Geothermal Wells in Iceland

A recent report from ISOR (Sveinbjornsson, 2014), presents data on success rates in drilling 213 geothermal production wells and 21 injection wells drilled in seven high temperature fields in Iceland. The data was classified using the same criteria as in the International Finance Corporation (IFC) 2013 Report on the success of geothermal wells from 14 countries. A production well was deemed successful when it had sufficient capacity to be connected and utilized in the respective power plant. Injection wells that have shown a good injectivity or have been used for reinjection were deemed to be successful.

The main conclusions of the report were as follows: Of the 213 production wells analyzed, 158 or 74% were deemed to be successful. None of the fields has a success rate below 50%. About 6% of the total wells failed because of drilling problems, 4% found inadequate temperatures, 10% could not be operated at high enough static pressure, 3% had too low permeability and 3% were so shallow that they did not reach the reservoir.

Figure 6.3.1. **Success Rate and Problems of Production Wells in Iceland**



The average success rate improves from 43% for the first well to 60% for the first five wells and reaches a plateau of 74% after well number 15. The first 5 wells drilled in a field are classified as Exploration Phase, the next 25 as Development Phase and wells drilled thereafter as Operation Phase. The Exploration Phase has the most variable well success rates, which has though improved in recent decades. The probability of successful wells in the Development Phase is nearly 80%. It increases until the year 2000 but declines after that. The same trend is observed for wells drilled during the Operation Phase. The reduction in the success rate may reflect step-out wells or rapid development where adequate results did not arrive in time to impact the drilling plan.

The average capacity of all 213 drilled production wells is 4.9 MWe but 6,7 MWe for the 158 productive wells. The capacity has a lognormal distribution with a mean and most likely value of 4.8 MWe and a standard deviation of 2.3 MWe. The cumulative average capacity increases from 2.5 to 4.8 MWe during the Development Phase, and reaches 4.9 MWe during the Operation Phase.

The five main operating geothermal power plants in Iceland have a ratio of installed capacity divided by number of drilled production wells ranging from 1.3 to 5.3 MWe/well and a weighted average of 3.5 MWe/well. Wells of 2.000–2.500 m drilled depth have the highest average capacity of 5.8 MWe followed by wells of 1.500-2.000 m with an average capacity of 5.5 MWe. Wells with a regular production casing diameter of 200–250 mm have an average capacity of 5.5 MWe whereas wells with a large casing diameter of 300–350 mm have a capacity of 8.9 MWe.

The average capacity of directionally drilled wells is 6,.1 MWe compared to 4.0 MWe in vertical wells. There is a clear increase in capacity with increased enthalpy. Wells drilled into steam caps above two-phase reservoirs at 230–240°C have the highest capacity of 11.0 MWe and a 100% success rate. Wells in two phase reservoirs with T>300°C, are with an average of 6,2 MWe and 86% success rate.

7 Legal and institutional frameworks in Iceland

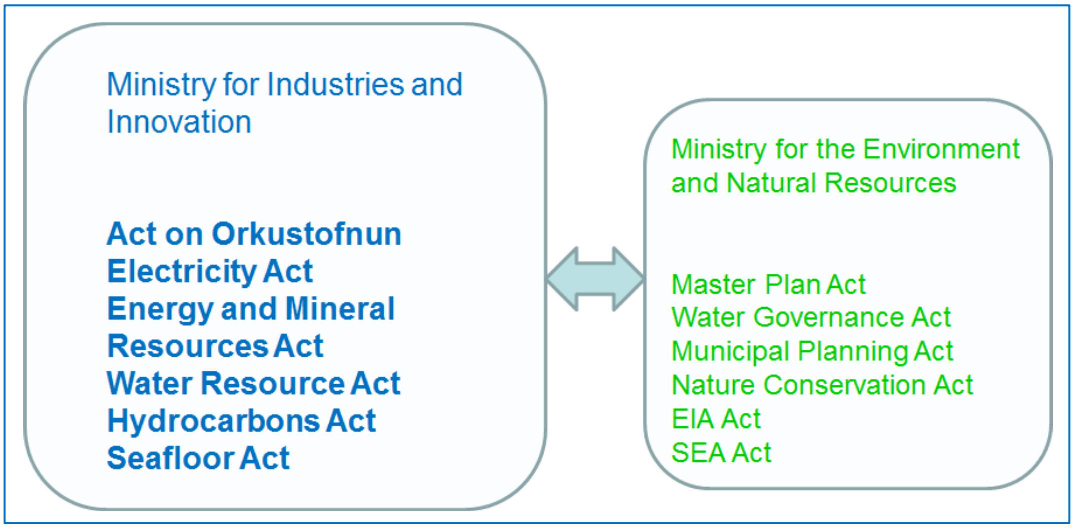
7.1. Introduction

A recent paper presents the current legal framework and national policy for geothermal development in Iceland (Ketilsson, 2015) where a broad overview is given.

The development of geothermal energy in Iceland has been on-going for many decades. Considerable experience and technical skills have been accumulated but the law is fairly recent. Despite the lack of appropriate laws, access to natural resources has led to an exceptionally high proportion of renewable energy in the country's total energy utilisation. Adaptation to the growing geothermal industry, as well as implementation of laws and regulations of EFTA and EEC have called upon new laws and reorganisation of authorities and institutes. As this history and the resulting legal and institutional framework can be a useful reference for other countries which are considering geothermal development a short description is presented here.

The *Act on Survey and Utilisation of Natural Resources* entered into force in 1998, replacing the *Act on Water Falls* from 1907. The main reason for the new act was to declare the ownership of the country´s natural resources after many years of debate in the Parliament on how the matter should be handled.

Figure 7.1.1 **Public Administration in Iceland, related to Geothermal Development**



The *Electricity Act* entered into force in 2003, thereby implementing European laws, according to the agreement Iceland has made as part of the European Economic Area from 1993. The new act replaced the *Energy Act* from 1967 and was grounded on new perspective in the electricity sector. It's main objective was to liberalize the market for generation of electricity and retail although having the transmission and distribution regulated as natural monopoly.

Many other acts affect the sector of geothermal energy exploration and utilisation. Mainly the *Environmental Impact Assessment Act* and the *Act on Master Plan for the Protection and Utilisation of Natural Resources*. Other acts relating to the sector are, among others, the *Nature Conservation Act* and the *Planning Act*.

7.2 The Act on Survey and Utilisation of Natural Resources

The ownership of resources in the ground is attached to a private land, while on public land resources in the ground are the property of the State of Iceland, unless others can prove their right of ownership. Even though the ownership of resources is based on the ownership of land, Orkustofnun can grant licenses anywhere for the research and utilisation of the resources according to the *Act on Survey and Utilisation of Natural Resources*, No. 57/1998 and the *Electricity Act*, No. 65/2003. Survey, utilisation and other development pursuant to these Acts are also subject to the *Nature Conservation Act*, No. 44/, *Planning and Building Act*, *Environmental Impact Assessment Act* and other acts relating to the survey and utilisation of land and land benefits.

The *Act on Survey and Utilisation of Natural Resour*ces covers resources in the ground, at the bottom of rivers and lakes and at the bottom of the sea within netting limits. The Act also covers surveys of hydropower for the generation of electricity. The term resource applies to any element, whether in solid, liquid or gaseous form, regardless of the temperature at which they may be found.

The State, municipalities and companies, entirely owned by them, are prohibited to sell directly or indirectly the ownership of geothermal and ground water more than for household or agricultural use. A landowner may exploit geothermal energy, without permission, on his or her private land for household and agricultural use, including for greenhouse cultivation, industry and cottage industry, up to 3,5 MW of thermal energy based on the heat extracted from the ground within private land.

Figure 7.2.1**. Ownership, Resource Control, Operation and the Grid**

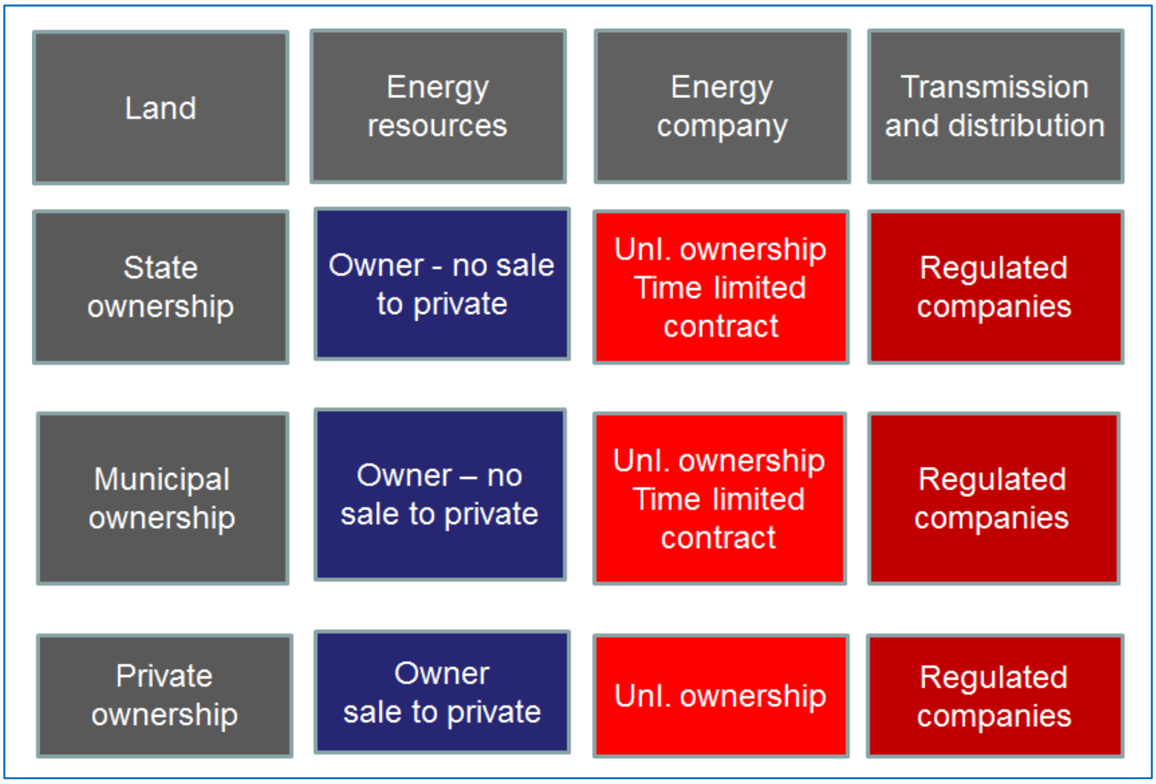
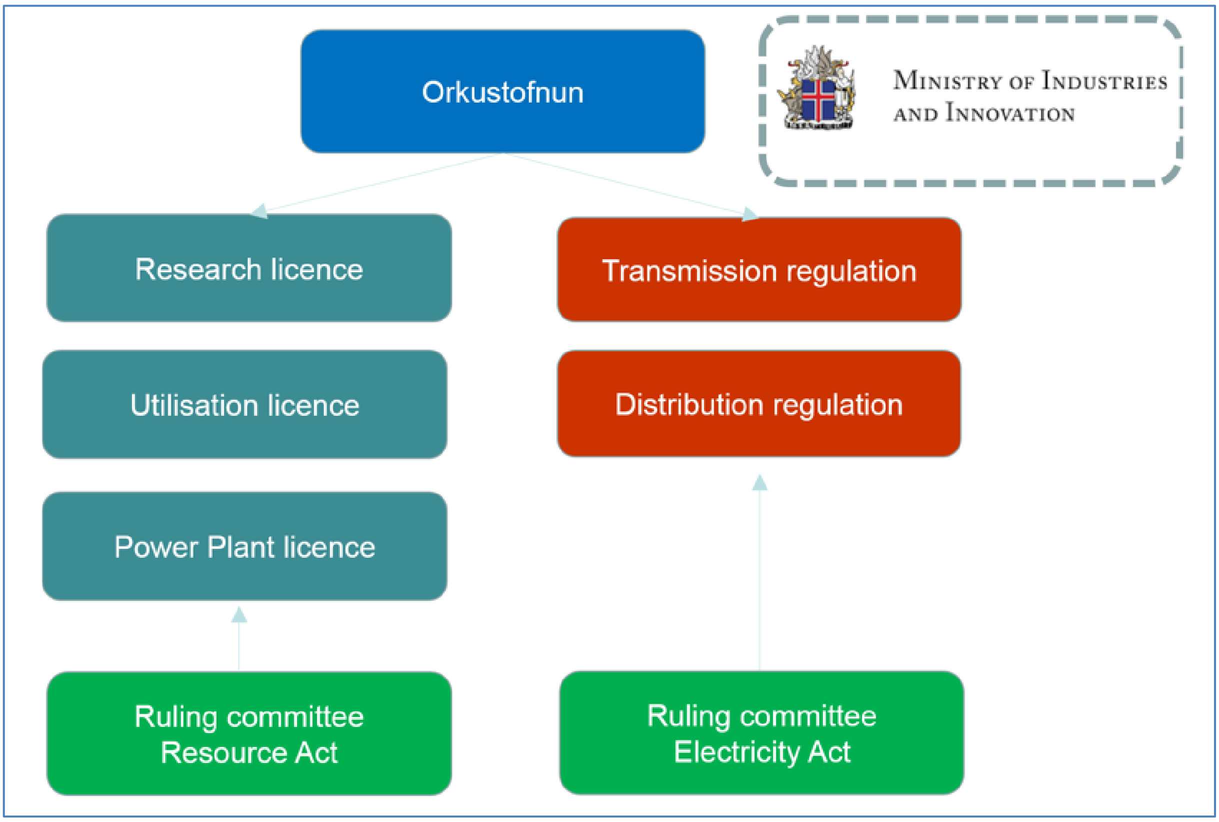


Figure 7.2.2. **Role of Orkustofnun as a Licensing Authority and the two Ruling Committees that can be appealed to.**



Research License

According to the Act Orkustofnun is permitted to take the initiative in and/or give instructions on surveying and prospecting for resources in the ground anywhere in the country, regardless of whether the owner of the land has himself or herself begun such surveying or prospecting or permitted other such surveying or prospecting, unless the party in question holds a valid research license pursuant to the Act. A research license confers the right to search for the resource in question within a specific area during the term of the license, survey extent, quantity and potential yield and to observe in other respects the terms which are laid down in the Act and which Orkustofnun considers necessary.

Therefore Orkustofnun can issue a research license even if the land owner has not agreed to it himself unless he has a valid research license himself. If the land owner, on the other hand, decides to prospect himself he does not need a license but is only required to inform Orkustofnun of the research scheduled. Before granting a license Orkustofnun must confer with the landowner, the Environment Agency of Iceland, The Icelandic Institute of Natural History and in some cases the Institute of Freshwater Fisheries. Only one person or legal entity can be granted a license in one area during the term of the license. More than one person or legal entity can be granted such a license if they have applied for the license jointly and have agreed upon dividing the prospecting cost.

Orkustofnun can grant a pre-emptive right to a utilisation license if the foreseen exploitation is for space heating. The pre-emptive right can last for up to 2 years after the research license expires which also prevents others to be granted research license in the respective area. In order to be granted a research license, the applicant must file the exploration scheme which he will then need to comply with, shall he be granted a license. In the case of non-compliance the license holder must ask Orkustofnun for an alteration in the scheme or Orkustofnun can cancel the license.

Utilisation License
The utilisation of resources in the ground is subject to a license from Orkustofnun, whether it involves utilisation on private land or public land, with the exceptions provided for in the Act. A landowner does not have the priority to an utilisation license for resources on his or her land, unless such an owner has previously been issued a research license. The utilisation license permits the license holder to extract and use the resource in question during the term of the license to the extent and on the terms laid down in the Act and regarded necessary by Orkustofnun.

Before the holder of an utilisation license begins extraction on private land the holder needs to reach an agreement with the landowner on compensation for the resource or obtain permission for expropriation and request assessment. In the event of neither an agreement made on compensation nor expropriation requested within 60 days immediately following the date of issue of an utilisation license, the license shall be cancelled. The same applies if utilisation on the basis of the license has not started within three years of the issuance of the license. This also applies to the utilisation of resources on public land. With these limitations, a license holder cannot reserve areas, and in the same manner withhold the exclusive rights to exploit the areas in question. Orkustofnun has therefore the power to cancel the license shall there be a non-compliance with the exploitation scheme presented in the application for the license.

If a landowner has himself explored the resources on his or her land or allowed it to others, but an utilisation license has not been granted, the land owner or the one who did the research, can demand that the utilisation license holder reimburses him the cost for the research useable to him or her.

Orkustofnun may revoke the above license if their conditions are not fulfilled. If a license holder does not comply with the conditions established in the license or contracts relating to the license, Orkustofnun shall issue a written warning and provide time limits for rectification. Should the license holder not comply with such a warning, the license shall be revoked.

Recent Amendments to the law
In 2008 the Parliament decided to prevent any further sale of water resources, including geothermal energy, to private entities. As of that same year, all natural resources that were not privately owned were guaranteed to remain in the possession of the State. As described previously the State can grant licenses for utilisation, for up to 65 years, according to the *Act on Survey and Utilisation of Natural Resources*. As of that same year the Parliament also decided to implement into the Act, a clause stating that the Minister of Energy could delegate the power to grant licenses to Orkustofnun. Prior to that time, the Minister himself granted such licenses.

The decisions made by Orkustofnun, deriving from the newly granted power, could be appealed to the Ministry for revision. In that way, the civilians had the possibility to have a decision revised in the administrative sector and without having to turn to the courts. Another amendment that same year dictates that CHP power plants are obliged to keep separate accounts for heat and power production to prevent cross subsidisation of electricity. Producers of electricity compete in an open market in Iceland whereas the heat is sold based on a natural monopoly license to sell heat within a certain area, hence, it is necessary to keep financial records separate in relation to e.g. the *Administrative Act*, No. 37/1993 as well as Act. 65 of the *Icelandic Constitution*. Later, or in 2012, the Parliament decided to move that same license granting power to Orkustofnun by amending the law, making Orkustofnun fully independent in its decision making. Such decisions can today be appealed to the Appeals Committee for Environmental and Resource Matters.

7.3 The Electricity Act

Power Plant License

According to the *Electricity Act*, No. 65/2003, a license issued by Orkustofnun is required to construct and operate a power plant. However, such a license is not required for power plants with a rated capacity of less than 1 MW electric, unless the energy produced is delivered into the distribution system of a distribution system operator or into the national transmission grid.

A power plant license shall expire after 10 years following its date of issue if the license holder has not begun development at such time and fifteen years after the date of issue if the power station has not then been taken into operation. The license holder may apply to Orkustofnun for a renewal of the license prior to its expiry. A power plant license is not limited in time in other aspects than the fore mentioned.

Before a license holder starts development on a property pursuant to such a license, an agreement must be concluded with the landowners and the owners of the energy sources concerning compensation, or, alternatively, a decision on expropriation needs to be obtained. In the event of neither an agreement nor an expropriation within 90 days immediately following the date of issue of the license, the license will be cancelled. This applies both to land in private ownership and State ownership.

Power plant licenses are granted to independent legal and taxable entities. Orkustofnun may establish conditions for the issue of the license that are designed to promote an adequate supply of electricity, security, reliability and efficiency of the electricity supply system and the utilisation of renewable energy sources. Also, conditions may be established in relation to environmental protection, land use and technical and financial capacity of the license holder. The conditions concerning environmental protection and land use do not derive from Orkustofnun as such. Prior to granting the license, Orkustofnun must make sure that the applicant has already acquired the opinion from the National Planning Agency concerning the environmental impact assessment and also a confirmation from the municipal authorities in question that the construction of the foreseen power plant is in accordance with the land use planned by the respective authorities.

Orkustofnun can, in such licenses, include a provision that a license shall be reviewed after a specific amount of time if the grounds for the conditions have changed materially. This gives Orkustofnun some power to alter a license or set new conditions even though a power plant license is not limited in time.

Transmission

There is only one transmission Company in Iceland, called Landsnet that has the obligations and rights of transmission of electricity and system management. It is an independent company and a taxable entity.

The transmission company is not to engage in any other activities other than those which are necessary for the performance of its obligations according to the *Electricity Act*. There are a few exemptions to that article that stipulate that they are only authorized if the accounts are kept fully separate from those relating to the main activities.
The transmission system operator must have a board of directors independent of other companies engaging in the generation, distribution or sale of electricity.

The transmission system operator is obliged to develop the transmission system in an economic manner, taking into account security, efficiency, reliability of supply and the quality of electricity. The company has the exclusive right to build transmission lines but is required to obtain a license from Orkustofnun prior to the construction, for all lines transmitting electricity at 66 kV or higher.

In the event of noncompliance with the *Electricity Act* Orkustofnun shall issue a written warning to the transmission system operator and allow a reasonable deadline to make amends. If amends are not made by the company, the Minister of Industry can terminate the agreement made between him and the transmission system operator for the operation of the transmission system.

Orkustofnun decides an income possibility curve that the transmission system operator has to comply with. The curve is set on the basis of expenses, profitability, depreciation and taxes. The transmission system operator can establish its tariffs in accordance with the income curve set for that time period. If the operator establishes a tariff that Orkustofnun sees as too high or too low compared to the curve, and therefore not in accordance to the law, Orkustofnun can demand that the operator changes its tariff. The transmission system operator must publish its tariffs.

Distribution
There are 6 distribution system operators in Iceland, each licensed in a specific distribution zone. A license is required from Orkustofnun, to construct and operate a distribution system in a specific zone and to cease such operation. These companies are required to be, like the transmission system operator, an independent legal and taxable entity. The distribution system must be connected to the transmission system with the possibility of exemption in special circumstances, e.g. in the case of a small, isolated area. The distribution system operators are not required to obtain licenses to construct a distribution line. All such lines are under the 66 kV limit.

The operator is responsible for the distribution of electricity and system management in a specific zone and shall maintain, improve and develop it in an economic manner, taking into account security, efficiency, the security of supply and the quality of the electricity. Similar to the transmission system operator, a distribution system operator is not allowed to engage in other activities than the distribution of electricity with the exemption of other subsidised operation such as space heating or water supply. The same rules apply to distribution system operators regarding the income possibility curve and tariff establishment.

Regulation and remedy
Orkustofnun shall regulate the compliance of companies operating under the requirements of *the Electricity Act*. Orkustofnun can request all information necessary to carry out the role of monitoring according to the Act, notwithstanding the parties obligation to maintain confidentiality. In the event that Orkustofnun is of the opinion that an operation subject to regulatory monitoring does not conform to the conditions thereof, Orkustofnun can require rectification subject to the imposition of daily fines. All decisions, based on the *Electricity Act*, can be appealed to the Appeals Committee on Electricity.

7.4 The Environmental Impact Assessment Act

Development consent is granted by the National Planning Agency if all conditions and requirements have been fulfilled according to the *Environmental Impact Assessment Act*, no. 106/2000. Projects can be subject to environmental impact assessment or not. Projects are categorized according to appendix 1 and 2 to the Act, either projects that are always subject to an assessment or projects for which the applicant must get the opinion of the Planning Agency whether they are subject to an assessment or not.

In order to prevent that application procedures get too long the Act specifies what time limit the Planning Agency has for each step of the procedure. In short, the procedure is as follows: The applicant notifies the Planning Agency of a project which may be subject to assessment. The Planning Agency has 4 weeks to decide upon its answer. If the project is subject to such an assessment, the applicant submits a scoping document proposal as early as possible in the preparatory stage of the project. Again the Planning Agency has 4 weeks to decide whether the proposal is approved or not. If the proposal is approved the applicant shall compile a report on environmental impact assessment of the proposed project.

The Planning Agency then has only 2 weeks to assess whether the report meets the criteria provided for in the act and is consistent with the scoping document. If it does meet the criteria it shall be publicised and subjected to written comments from anyone. The applicant shall then respond to the written comments, possibly by altering the document in accordance. Within 4 weeks of receiving the environmental impact statement, the National Planning Agency shall deliver a reasoned opinion on whether the report meets the criteria of the Act and regulations and whether the environmental impact is satisfactorily described.

Decisions on environmental impact assessments, based on the Act, can be appealed to the Appeals Committee on Environmental and Resource Matters.

7.5 Act on Master Plan for the Protection and Utilisation of Energy Resources

Earlier energy developments in Iceland were focused on meeting the basic energy needs of the society for space heating and electricity for the general market. Through the years it has become more and more evident that utilisation of energy resources (as other development) must take into account not only the energy needs and the economic aspects of the development, but also a range of other interests as well. This includes other use of land and the impact of the development on the environment and the cultural heritage. The first step towards such an evaluation was undertaken by a collaboration committee of specialists from the Ministry of Industry, the National Power Company, Orkustofnun and the Nature Conservation Council. This committee was active during the 1970's to the 1990's. It discussed plans for various electrical power plants with special emphasis on the natural conservation aspects of the projects.

A general view on the energy policy and the nature conservation policy was needed for the country. This became even more important by 1994 when the Parliament of Iceland passed the first *Act on Environmental Impact Assessment*. The Icelandic Government published a white paper on sustainability in the Icelandic society in 1997. There the need of the development of a long term Master Plan for energy use in Iceland was once again stressed. All proposed projects should be evaluated and categorized on the basis of energy efficiency and economics, as well as, on the basis of the impact that the power developments would have on the environment.

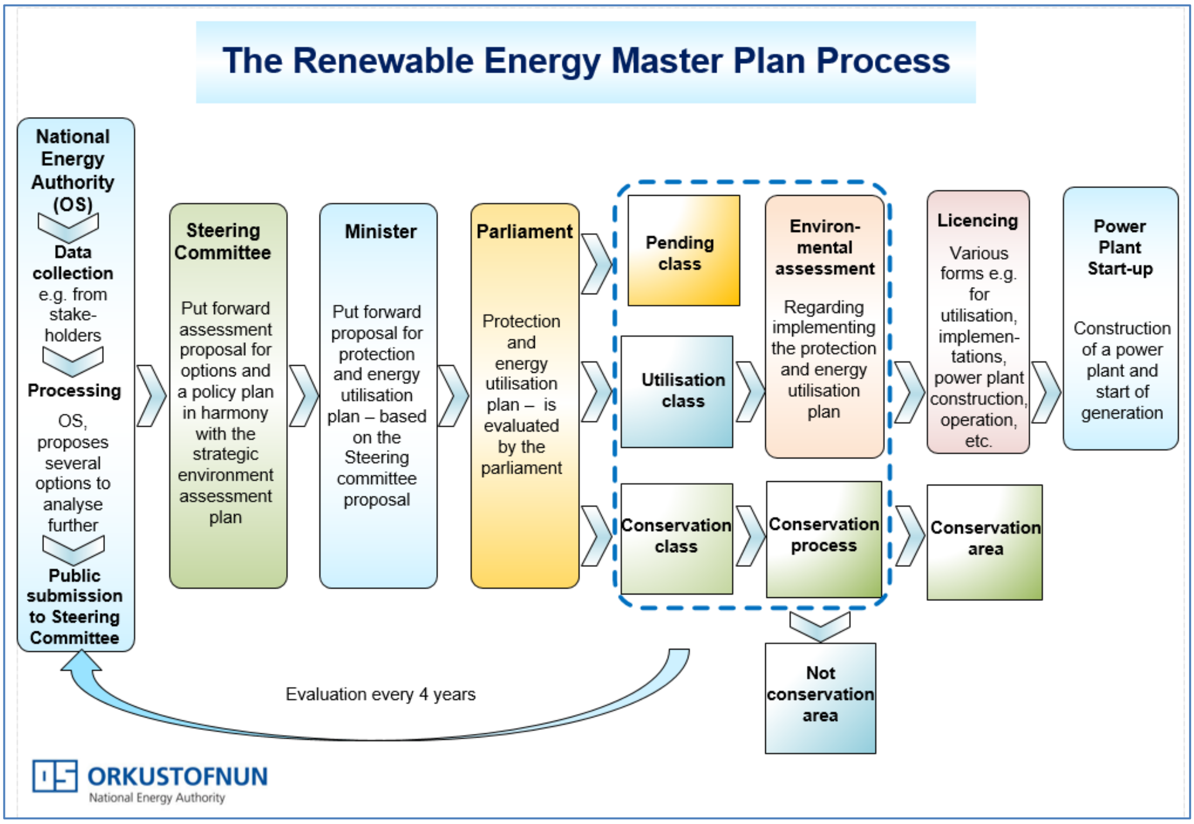
A master plan of this kind is comparable to the planning of land use and land protection. It is not supposed to go into the details required for environmental impact assessment (EIA). The vision is to prepare an overview of the various potential energy projects in hydro and geothermal and to evaluate and rank these based on their energy and economic potential, feasibility, national economy and the estimated impact that each project would have on nature, environment, cultural heritage and the society, as well as the potential for other uses of the areas in question.

The master plan should be based on the best available scientific information and conclusions should be transparent and reproducible and made available to the public. It was considered of vital importance to establish public confidence in the evaluation process.

The master plan aims to identify power projects that rank high from an economical point of view, have a minimum negative impact on the environment, and a positive impact on the society. Such a score card for the energy projects helps decision makers to filter out which of the proposed projects are likely to become controversial and disputed and which ones not. It also directs the attention to those project areas that might have protective value and should be left untouched by human development.

A method for evaluating and ranking energy alternatives based on impact upon the natural environment and cultural heritage was developed as part of the first phase of the master plan for the use of hydropower and geothermal energy in 1999 to 2003. The three step procedure involved assessing i) site values and ii) development impacts within a multi-criteria analysis, and iii) ranking the alternatives from worst to best choice from an environmental–cultural heritage point of view. The natural environment was treated as four main classes (landscape+wilderness, geology+hydrology, species, and ecosystem/habitat types+soils), while cultural heritage constituted one class. Values and impacts were assessed within a common matrix with 6 agglomerated attributes: 1) diversity, richness, 2) rarity, 3) size (area), completeness, pristineness, 4) information (epistemological, typological, scientific and educational) and symbolic value, 5) international responsibility, and 6) scenic value.

Fig. 7.5.1 Flow Diagram Illustrating the Processes around the Master Plan



The Government decided to use the work on the master plan to establish a permanent planning tool, with regular re-evaluation phases followed by subsequent confirmation of the master plan by Parliament. For that purpose, a new *Act on a Master Plan for Protection and Development of Energy Resources* was passed in Parliament in May 2011. According to the act the Minister for the Environment, shall in co-operation with the Minister of Industry, at least every four years, propose a Master Plan to the Parliament. The plan shall divide the different projects in three categories, projects for utilisation, projects awaiting further research or projects in areas appropriate for protection. A total number of 84 potential power projects was evaluated during the second phase in 2011 and a Master Plan ranking 28 hydropower projects and 38 geothermal projects was approved by the Parliament in 2012.

The Master Plan only covers projects that have the potential of at least 10 MW electric or at least a thermal potential of 50 MW. The plan is binding for all municipalities and is to be included in their general land use plans.

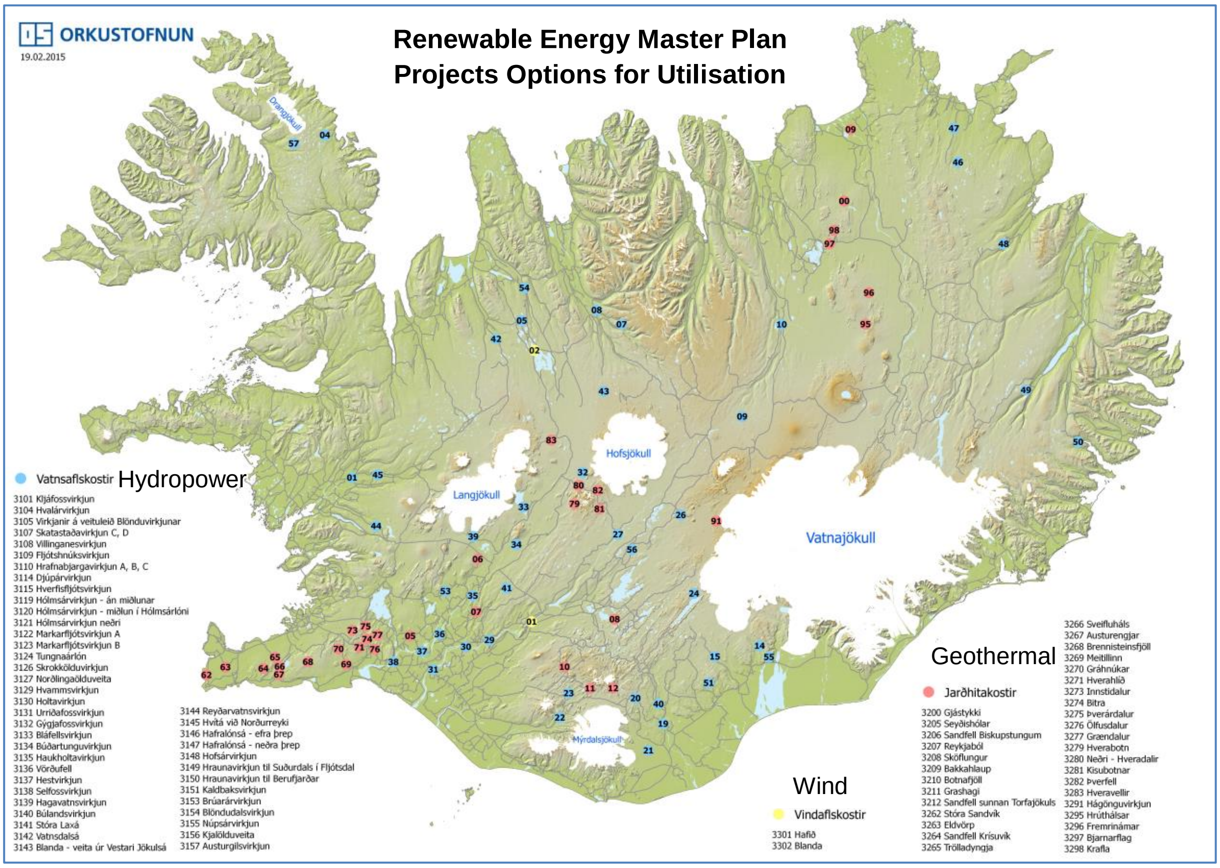
Administrative bodies can grant licenses relating to projects that are categorized for utilisation and all research that does not require licenses can be carried out. Administrative bodies cannot grant licenses for projects that await further research if the intended work requires assessment of environmental impact. Research that does not require licenses can be carried out in these areas with the same restriction. Administrative bodies cannot grant any licenses for projects that are in areas categorized for protection except for a limited research license for prospecting on surface without affecting the environment.

The flow diagram in Fig. 7.5.1 illustrates the processes around the master plan before the feasibility of the geothermal system is analysed in detail. After the steering committee has decided that resources in a designated area should be utilized, protected or further studied, the projects themselves can be reevaluated and hence subject to review again by the master plan until the municipalities have adjusted their regional plans. The municipalities could also take the initiative to designate a certain area for protection and another area for reevaluation. This process of reevaluation is necessary because with increased understanding on the effects of these projects and with technological advancements assumptions can change. This reevaluation is relative until either the area has been formally protected or licenses for the power plant have been issued.

The projects in question can both be state owned and privately. Before presenting the proposal to Parliament the Steering Committee of the Master Plan must both ask for written comments and publicize the draft proposal. After the confirmation of the Parliament, the Master Plan is valid and binding for all parties for up to four years, unless the Parliament changes its resolution. The municipalities are required to adjust their regional plans accordingly within 15 years from the decision of the Parliament. In Fig 7.5.1 this process is illustrated.

Grant Support and financial mechanism

For regional purposes space heating of homes with either electricity or oil receive a subsidy so heating costs will not be higher than heating your house with geothermal. This reduces social and economic disparities within rural parts of Iceland. However, if the individual decides to invest in a heat pump or take part in installing a geothermal based district heating system and hence stop using electricity or oil for space heating the individual can receive a subsidy, in the form of a lump sum, for the equivalent of 12 years (now 8 years) accumulation (Act No. 78/2002 with recent amendments).



7.6 The Administrative Framework

The Ministry of Industries and Innovation
The Ministry of Industries and Innovation is the head organization of energy matters in Iceland. The Ministry has today two ministers, Minister of Industry and Commerce and Minister of Fisheries and Agriculture. The Ministry has authority of the *Act on Survey and Utilisation of Natural Resources* and the *Electricity Act* which are the two main legal acts that geothermal energy exploration and utilisation is based on in Iceland.

Orkustofnun (The National Energy Authority)
Orkustofnun is a government agency under the Ministry of Industries and Innovation. Orkustofnun works on the basis of the *Act on Orkustofnun* nr. 87/2003. The main responsibilities have been to advise the government of Iceland on energy issues and related topics, promote energy research and administrate development and exploitation of the energy resources. Orkustofnun is also responsible for gathering, guarding and mediating information on energy resources and their exploitation. It has been responsible for the regulation of the aforementioned Acts, among other acts such as the *Act on Prospecting, Exploration and Production of Hydrocarbons,* The *Water Act* and the *Act on the Ownership of the Icelandic State of the Resources of the Sea Floor*. More recently Orkustofnun has received the responsibility of granting licenses for exploration and exploitation of natural resources as well as all licenses according to the *Electricity Act*, thus acquiring full independence regarding the granting of licenses based on the Acts regulated by Orkustofnun.

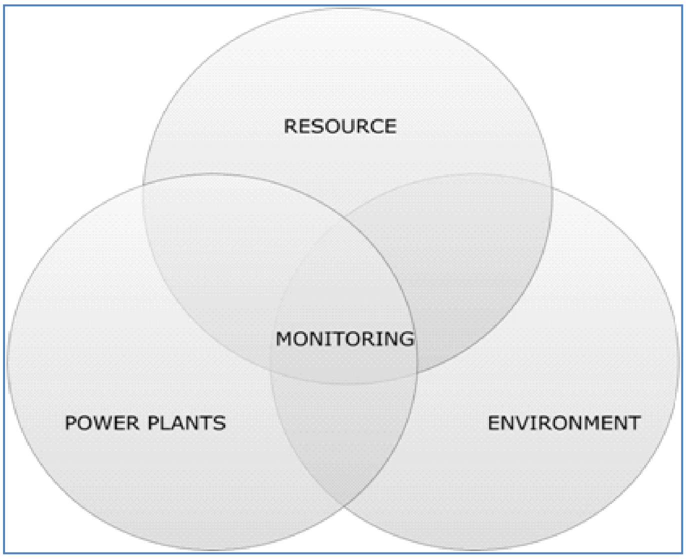
7.7 Official monitoring

In June 1999 the Icelandic Parliament passed Act No. 27/1999 on Official Monitoring in order to promote efficient yet beneficial monitoring praxis. The objective of this act is to ensure that official monitoring is conducted in the most economical way possible, both for the State and for those the monitoring is aimed at. The official monitoring rules have to be effective in order for it to serve its aims.

According to Art. 2, the objective of the Act is also to ensure that official monitoring rules promote the welfare of the Nation, safety and public health, safety of property, environmental protection, normal business practices and consumer protection. The Official Monitoring Act requires authorities to conduct an economic evaluation before new monitoring rules are passed as law, to ensure that the extent of the monitoring is reasonable in proportion to the objectives aimed for. The monitoring should not be more extensive or more complex in execution than is required to achieve the distinctive objectives.

The official monitoring of utilisation of geothermal resources in Iceland is rather extensive and is the responsibility of different public authorities, as will later be addressed. The monitoring of geothermal utilisation can be divided into three main sectors as shown in Fig. 7.7.1.

Figure 7.7.1. **Monitoring of Geothermal Utilisation can be divided into Three Main Sectors**



The objective of the monitoring for each sector is different, respectively: to protect the environment, to prevent overexploitation of the resource, and to secure occupational safety and safety of delivery at the power plants as outlined in the following sections.

Environmental monitoring

The objective of official monitoring of the environment surrounding geothermal projects in Iceland is reflected in the stated aims of Art. 1 of the Nature Protection Act No. 44/1999. The objective is to regulate the interaction of man with his environment so that it harms neither the biosphere nor the geosphere, nor pollutes the air, sea or water. The ultimate aim is to ensure that the Icelandic ecosystem can develop according to its own laws and to ensure the conservation of its exceptional or historical aspects. An important pillar in environmental protection according to Icelandic legislation is Act No. 106/2000 on Environmental Impact Assessment (EIA Act) as previously mentioned.

The objective of the EIA is to gauge the effects the project may have on the environment and to minimise as far as possible the negative environmental impact of projects. Furthermore, when resource utilisation and power plant licenses are issued, environmental factors should be taken into consideration. Surveying, utilisation and power plant licenses may be bound by specific conditions in order to safeguard environmental requirements, according to the Resources Act, Art. 17 and the Electricity Act, Art. 5. With the Strategic Environmental Assessment Act No. 105/2006 (SEA Act), Iceland adopted Directive

2001/42/EC from the European Parliament and the Council as previously mentioned. The objective of the Directive is to protect the environment and to encourage sustainable development by conducting an environmental assessment of plans which are likely to have an impact on the environment. In the Directive it is assumed that the impact of plans and programmes on the environment is assessed before they are passed and executed.

The Health committees are responsible for official monitoring of the operation license. These committees derive their power from the Hygienic & Pollution Act No. 7/1998. The Act divides Iceland into ten regulatory zones and each zone has one committee. The operation licenses for power plants are issued by these health committees. The objective of these licenses is to prevent pollution from e.g. run-off water and to promote a clean environment. The operation license is equipped with conditions and the health committees oversee that these conditions are met. Failure to do so can result in official warnings, daily penalties and termination of the license.

Resource monitoring

Another objective of official monitoring of utilisation of geothermal resources is to ensure that the most efficient exploitation of the resource is withheld in the long run and that extraction of geothermal fluid does not exceed levels deemed necessary, according to Art. 25 of the Act on Survey and Utilisation of Ground Resources. One way to ensure this is to have an effective official monitoring of the utilisation taking place at every geothermal project. Besides efficient monitoring it is also important that relevant institutions, municipalities and developers are aware of the fact that utilisation of geothermal energy in Iceland is to be conducted as stipulated in Art. 25 of the Act on Survey and Utilisation of Ground Resources. Some natural resources are exhaustible, therefore it has been considered necessary to apply rules to manage their utilisation, in order to ensure natural resources are protected and maintained for next generations.

Orkustofnun has the responsibility to monitor geothermal areas being researched or utilised, according to the Act on Survey and Utilisation of Ground Resources. Orkustofnun is also responsible for the official monitoring stipulated in the Electricity Act.

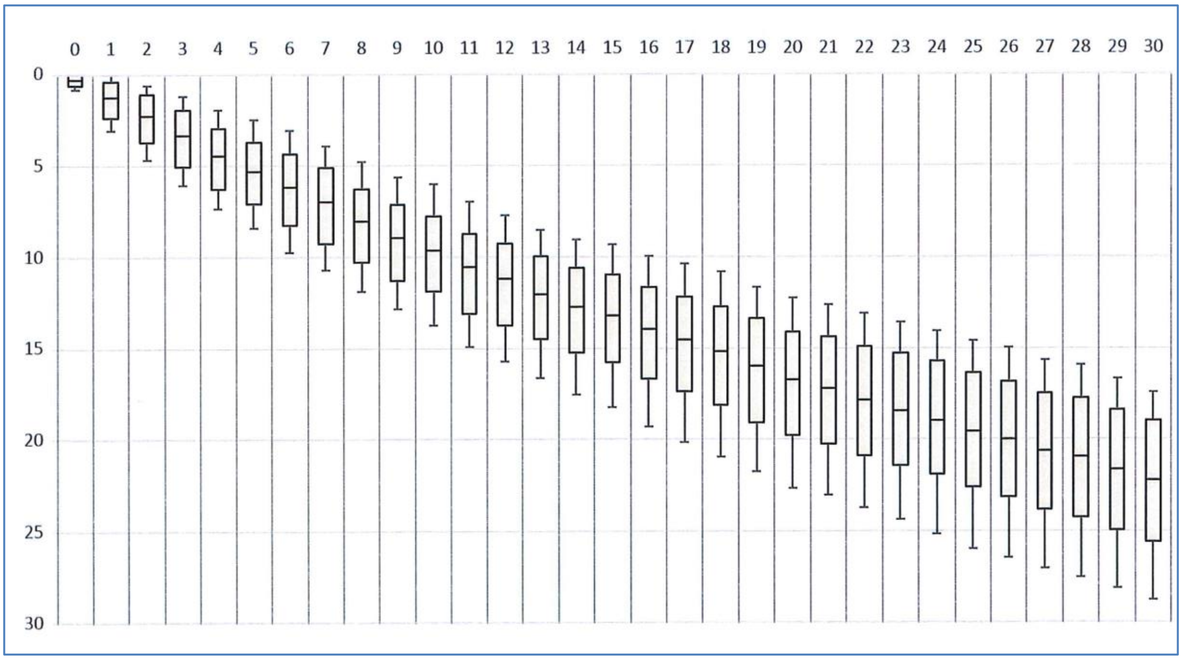
In an appendix with utilization licenses and power plant licenses it is stipulated what detailed information the developer is supposed to present once a year to Orkustofnun. The information required is as follows:

- The amount of fluid extracted or re-injected into each well in the geothermal field, each month.
- The temperature of the water re-injected into the geothermal reservoir each month.
- Results of water level measurements in wells in which the water level can be measured and are within the geothermal field.
- The pressure changes or drawdown determined in the geothermal reservoir.
- The results of measurements of the enthalpy of the fluid from every production well in the geothermal field.
- Chemical analysis of the geothermal water (and steam, if appropriate).
- Results from simulations of the geothermal reservoir.
- Results of measurements made to monitor changes in the geothermal reservoir.
- Information on drilling in the industrial area.
- A resume of improved understanding of the physical characteristics of the geothermal reservoir based on the results of the latest drilling.

The above mentioned items should provide all the necessary information for the monitoring authority to monitor the utilisation of the resource. Furthermore Orkustofnun has stipulated in the last three utilisation licenses for geothermal power plants that certain limitation is on drawdown within the geothermal system. This is done to maintain long term balance in water in place in order to secure the possibility of continuing carrying heat in place to the surface using water as the carrier.

An example is given in Fig 7.7.2 for actual drawdown limitations stipulated in the utilisation license of the Þeistareykir Geothermal Power Plant proposed by Landsvirkjun to be built in the next years. In addition to limitation of drawdown there are also limitations in terms of annual reduction in steam supply to be no more than 3%. If those limits the reached Landsvirkjun is required to take the necessary steps in mitigating the effects by calibrating the reservoir model and predict again whether the geothermal system can sustain enough yield through the lifetime of the power plant.

Figure 7.7.2. **Limitations of Drawdown to Ensure Long-term Utilisation of the Resource.** The vertical scale shows pressure drawdown from natural state in bars. The horizontal scale is in years of operation with an uncertainty margin



The graph shows predicted simulated drawdown from the natural state due to the extraction of fluids. The prediction is given with a calculated probability margin taking uncertainty into account. If the drawdown goes beyond the error margin the license holder needs to revaluate the reservoir model, change the extraction levels within the area or increase reinjection into the same geological formation to maintain long-term water balance.

Safety and management

The objective of monitoring of utilisation of geothermal energy does not only entail monitoring of the surrounding environment and the resource. A third objective of monitoring of geothermal projects is to ensure the safety and responsible management of the power plants which generate electricity from geothermal energy. Monitoring of a power plant starts before construction of the plant begins. First, the municipal authority in the area where the power plant is to be built issues a development license or a building license, according to the Planning and Building Act No. 73/1997.

According to paragraph 2 in Art. 38 it is the local authority's responsibility to monitor power plant development and its surroundings, according to the terms of the development or building license that it has issued for the power plant. The council is to make sure that all buildings are built according to the development plan, rules and regulations. Second, a power plant license is required in order to build and operate a power plant, according to Art. 4 of the Electricity Act. Orkustofnun is responsible for official monitoring of the conditions stipulated in the relevant license. The objective of monitoring after generation of electricity at the power plant has begun is to ensure that operations are conducted according to the requirements of the act. On-site monitoring at the power plant, quality of electricity, security of supply of electricity and the accounting should be as stipulated in the Electricity Act.

According to Act No. 27/1999 on Official Monitoring the objective is to ensure that official monitoring rules promote the welfare of the Nation, safety and public health, safety of property, environmental protection, normal business practices and consumer protection. In paragraph 4 in Art. 9 of the derivative Regulation of the Official Monitoring Act it is stipulated that the requirements of individual official monitoring authorities are to be harmonised and the monitoring implemented by one and the same party to the greatest possible extent.

The objectives formulated in the legislation concerning the arrangements for official monitoring of utilisation are in general being reached, especially regarding the preparation phase for utilisation, environmental protection and the construction phase.

Energy Statistics related to Geothermal Energy Utilisation

With the aim of decreasing duplication of efforts and increase reliability of energy statistics it is important that countries using geothermal energy report usage in a consistent manner. The main international agencies and offices have already joined forces in collecting energy statistics with annual questionnaires with historical revisions. Two of those questionnaires collect geothermal energy statistics, Annual Questionnaire on Renewables and Annual Questionnaire on Electricity and Heat in addition to a Mini-Questionnaire.

Those international agencies that collectively and consistently gather this data are; the Energy Statistics Division of the International Energy Agency (IEA), the Organisation for Economic Co-operation and Development (OECD), the Statistical Division of the United Nations Economic Division for Europe (UNECE), the Statistical Office of the European Communities (EUROSTAT) for the Commission of the European Communities (EC) and finally the Statistics Division of the United Nations (UN). Terminology of the questionnaires is outlined in a report (Energy Statistics Manual) published by IEA/OECD in collaboration with these international bodies (IEA/OECD, 2005). Recently the International Renewable Energy Agency (IRENA) has started to accumulate data which is somewhat linked to this joint work but has though not been formalized completely and hence is out of scope of this report. In this report the aforementioned recognised national energy statistics by the IEA, OECD, UNECE, EUROSTAT and the UN will be referred to as the official statistics.

The countries that are members to the aforementioned organisations and agencies are obliged to complete the questionnaires in accordance with the respective by-laws of the organisations. In addition non-member countries do also complete these questionnaires in relation to various joint activities they have with these organisations and hence these organisation are able to disseminate a world outlook on energy and predict future trends taking other parameters like population growth and gross domestic product, to name a few, with official data from all countries in the world for all energy sources.

European Union (EU) Member States together with EU Candidate Countries and EFTA Countries are required to complete these questionnaires in accordance with regulation (EC) No. 1099/2008 on energy statistics. The objective of the regulation is namely to establish a common framework for the production, transmission, evaluation and dissemination of these statistics to assist political decision-making by the EU and its Member States and to promote public debate on energy use and future trends. In order to do so the EU must afford guarantees of comparability, transparency, flexibility and ability to evolve with a greater focus on increased knowledge and monitoring of final energy consumption and renewable energy in particular as stipulated as the aim of the regulation. The regulation further defines and stipulates the responsibility of the countries and in two annexes of the regulation the terminology is clarified which is comparable to the before mentioned Energy Statistics Manual (IEA/OECD, 2005) and as previously mentioned is referred to as the official statistics.

One of the legal responsibilities of Orkustofnun is to gather energy statistics as stipulated for which the institution can enforce by means of fines on companies that are obliged to submit the data. In accordance with regulation No. 518/2006 Orkutofnun is required to gather and maintain energy statistics database that is coherent and meets the requirements of the relevant regulation which in this case is the aforementioned regulation (EC) No. 1099/2008 on energy statistics. Therefore Orkustofnun is obliged to follow the framework set out in the regulation and since that is done in collaboration with other institutions, it is required to complete the aforementioned joint questionnaires.

In addition, Directive 2009/28/EC stipulates that the countries are required to predict energy use in the near future. This can be seen in the respective National Renewable Energy Action Plans (NREAP) within EEA. The IEA also predicts world energy outlook for all countries which is partly based on these strategies. Therefore, it is important that when data gathering for energy statistics of geothermal, appropriate institutions familiarize themselves with the terminology used and adjust domestic data gathering accordingly.

Within the geothermal industry Orkustofnun participates in several associations and partnerships and collaborates with many other like the Implementation Agreement within the IEA (IEA Geothermal), International Geothermal Association (IGA), European Geothermal Energy Council (EGEC), Geothermal ERA NET, International Partnership for Geothermal Technologies (IPGT) to name a few. As part of the role of these organizations, data collection on geothermal energy statistics is often the focus of the work, in particular of the IEA Geothermal, EGEC and IGA. The data gathering done by these organizations is unfortunately not coherent with the official statistics. It is one of the aims of Orkustofnun to bring focus on this issue but care should be taken from the beginning of utilization.

7.8 Recommendations and Remarks on the Legal framework

Through the use of geothermal energy directly and as a means to produce electricity in Iceland, important know how and experience has been accumulated, regarding geoscience, engineering and finance as well as the administrative side to the sector. For the administrative bodies, the *Act on the Exploration and Utilisation of Natural Resources* has been very important. That law has now been applied for over 15 years. Alterations have been made in order to make the law as adequate as possible. Over 10 years of experience have accumulated regarding the *Electricity Act*, implementing directive 96/92/EC, concerning internal rules for the common market in electricity that replaced the *Energy Act* from 1967. Alterations have also been made to this act. It is of great importance that alterations are made possible while the act is fairly new or has only been applied to a certain extent.

Firstly, the existence of the aforementioned acts is necessary for countries that wish to establish a thriving sector for the exploration and utilisation of geothermal energy. Secondly, it is vital that the law is reasonable in the conditions to be granted licenses according to the acts. The licenses are for both the exploration and exploitation of the resource. Especially the conditions for granting of licenses to explore need to be of such a manner that the conditions can be met.

The administrative body, responsible for granting of licenses must have the power to grant licenses regarding a resource owned by others than the State, irrespective of the landowner’s opinion, unless he himself or herself has already been granted a license.

All conditions on the license holder’s duties must be mentioned in the act, followed by active monitoring of the administrative body.

Time limits are of essence in an effective law. They regard the duration of the license as well as disclosures in order to review the license in certain cases or disclosures on the approval of any alterations to the exploration or exploitation schemes approved before the granting of a license. It is also of high importance that the administrative body has means to intervene if the license holder does not comply with the time limits of the procedure of the project agreed upon in the application process, i.e. shall there be excessive delay to the project. In this same sense, means for the administrative body to intervene, shall the license holder not reach an agreement with the landowner in question or have requested expropriation of the resource. In such cases, a reasonable compensation must be paid for the utilisation of the resource or in the case of expropriation, a compensation for the land itself.

An appeals committee gives a certain discipline to the administrative body in question as well as the counterparties, giving them a possibility of having administrative decisions reviewed without the intervention of the courts.

As mentioned before, conditions for the granting of licenses must not be too large of a hindrance for a smaller entity to overcome. The granting of power production license falls under that same rule. The conditions must also be reasonable, measurable and transparent. Such a license should also ensure that other conditions are met such as regarding security of the system, security of supply and effectiveness of the system.

Regarding the transmission system operator there are many important things to keep in mind. One of them is access to the grid. The principle in Iceland is that the transmission system operator must connect anyone who requests it, provided for that he pays a connection fee according to the provisions of a tariff. In this way, equality among new customers is secured although new customers may be denied access on grounds pertaining to the transmission capacity, security and quality of the system.

One of the most difficult problems we have encountered in Iceland regards the setting and settling of the possible income curve and related subjects such as allowed expenses, profitability and efficiency requirements of the system operator. The articles regarding the methodology of both the setting and settling of the possible income curve as well as the article on tariff setting have been reviewed on several occasions.

In regard of the distribution system operator, experience has shown that the unbundling of these entities is the largest hindrance of an effective law. The demand that accounts be fully separated and the subsidized part of the company does not pay cost for the competition part is of great importance for an effective and open market with electricity.

The official monitoring must be active and visible in order to be effective. Orkustofnun can, as mentioned before, request any information and data needed for its monitoring. For data consistency it is important to review requirements of IEA/OECD and streamline data gathering so the effect of geothermal on world energy statistics is presented correctly.

Effective remedies for the administrative body are of essence. In the case of any non-compliance on the grounds of the *Electricity Act*, Orkustofnun can require rectification, subject to the imposition of daily fines, after a written warning. Orkustofnun can also revise or alter granted licenses or even revoke them. Again, this is only carried out if a written warning has been ineffective for rectification.

To conclude these recommendations it must be said, that it is vital for carrying out an effective law on the sector of geothermal energy, that the administrative body, responsible for the regulation and monitoring of the law, be active and visible to those subject to regulation. It is also very important that this same body has effective remedies to bring into actuality each article of the act. Lastly, an appeals committee is important to give the regulator the necessary restraint.

8 Competitiveness, Internationalisation and Clusters of the Icelandic Geothermal Sector

8.1 International Development Aid - Sustainable Development

The Icelandic International Development Agency (ICEIDA) is an autonomous agency under the Ministry of Foreign Affairs and is responsible for the implementation of official Icelandic bilateral development cooperation. It follows the Icelandic government's Act on Development Cooperation No 121/2008, which is in keeping with the UN Millennium Development Goals and other international commitments, such as the Monterrey Consensus on Financing for Development and the Paris Declaration on Aid Effectiveness.

In 2014 ICEIDA operates in three countries - Malawi, Mozambique and Uganda - in the areas of fisheries, education, energy, health, and water and sanitation. ICEIDA's cooperation with its partner countries is based on the partner countries' Poverty Reduction Strategy Plans and ownership is emphasised. ICEIDA's support mainly consists of strengthening infrastructure and the basic pillars of society, focusing on human capital, education and capacity building. In addition, ICEIDA is the Lead Agency in the Geothermal Exploration Project with joint co-financing of the Nordic Development Fund (NDF) in Eastern Africa.

ICEIDA operates in line with the DAC Guidelines on development cooperation and its implementation. All of ICEIDA´s development cooperation is based on mutual international agreements between the government of Iceland and the governments of the partner countries.

8.1.1 Iceland, WB and NDF - International Geothermal Cooperation in Africa

The Icelandic International Development Agency (ICEIDA) and the Nordic Development Fund (NDF) launched in 2012 a project to support geothermal exploration in East Africa. ICEIDA is the Lead Agency in the Geothermal Exploration Project with joint co-financing of NDF. The project is the initial phase of the Geothermal Compact partnership, initiated jointly by the Ministry for Foreign Affairs in Iceland and the World Bank. The World Bank's Energy Sector Management Assistance Program (ESMAP) serves as the focal point at the Bank for the Compact.

13 countries in East Africa Rift Valley
The geothermal potential in Africa is mainly in the East Africa Rift Valley States (EARS) covering 13 countries from Eritrea in the north to Mozambique in the south. The project aims to mitigate and distribute the risk associated with geothermal exploration thus contributing to the acceleration of geothermal development in the region.

The main objective of the Geothermal Exploration Project is to assist all EARS countries in completing the exploratory phase of geothermal development and build capacity and expertise in the field of geothermal utilization and related policy. The project support will extend up to the stages of exploratory drilling.

The project will be demand-driven and activities funded by the project will be based on specific requests from governments in the countries of the region. Project funding can cover the following activities:

1. Reconnaissance and geothermal exploration leading up to exploratory drilling
2. Technical assistance and capacity building
    a. Training, e.g. through the UNU Geothermal Training Programme
    b. Institutional capacity building
    c. Policy and legal framework for geothermal utilization

Five years

The financial framework for the project is estimated at USD 13 million over a period of five years. The project could extend to 13 countries in the East Africa Rift Valley: Burundi, Comoros, Djibouti, DR Congo, Eritrea, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda and Zambia.

At the end of the project it is expected that participating countries have 1) a realistic assessment of potential geothermal sites, 2) plans for further action where applicable, and 3) capacity to move forward on the basis of those plans and submit exploration drilling projects into funding pipelines. The Geothermal Exploration Project formally started in January 2013.

The Agreement – Key Elements

November 9th. 2012, an Agreement was made between Iceland, the World Bank and Nordic Development Fund (NDF. The agreement includes the development of a Global Geothermal Development Plan under the auspices of the World Bank, which could amount up to 500 million USD.

The agreement provided finance for geothermal feasibility assessments and test drilling. The collaboration between Iceland and the World Bank is the largest initiative so far for promoting the utilisation of geothermal energy in developing countries, and Iceland will effectively become the Bank's key partner in this field. Geothermal utilization in East Africa will transform positive conditions to further development and quality of life for millions of residents on the regions of 13 African countries. According to the agreement the Nordic Development Fund (NDF) and Iceland will co-finance of the first phase of the geothermal project. The Icelandic government and the Fund will contribute 5 million EUR each to the project during a five year period.

The Nordic Development Fund NDF has thereby teamed up with Iceland and the World Bank with a contribution towards primary geothermal exploration and research. The Icelandic International Development Agency, ICEIDA, will be the lead agency for this geothermal component. The objective is to advance geothermal utilisation in thirteen states of the Great Rift Valley in East-Africa; Djibouti, Ethiopia, Uganda, Eritrea, Kenya, South-Sudan, Tanzania, Malawi, Mozambique, Burundi, Rwanda, Zambia and Somalia.

Energy poverty in this area is high; however experts consider that the Great Rift Valley has 14,000 MW of geothermal potential that can provide up to 150 million people access to clean and renewable energy. Iceland will, with the support of the Nordic Development Fund, assist the respective states with geotechnical investigations of promising sites, detailed geophysical, seismic, environment and chemical tests including geothermal test drilling and assessments.

The World Bank will, on the other hand, collaborate with Iceland, other partners and funding agencies to establish a flexible financing facility that can in part share the costs and risks of specific geothermal drilling programs in the target countries.

The drilling is the most costly part of the exploration and the primary hindrance to the utilisation of geothermal energy. However, if the drilling yields positive results, it will be possible to harness geothermal energy for electricity production and utilise it to further economic development, with the active participation of the private sector.

World Class Geothermal Knowledge

Icelanders have for many years developed technology and research of geothermal resources. It has called for need of a group of highly skilled specialists from a number of disciplines of science and engineering. Part of this was to establish a knowledge base through the UNU-GTP which was established 1975 in the shadow of the oil crisis, when nations were looking for new and renewable energy sources in order to reduce dependence on hydrocarbons, in particular oil with its rapidly escalating prices.

The current situation is somewhat similar in that the international community is looking towards renewable energy sources as an alternative for the hydrocarbons in order to reduce the emissions of greenhouse gases.

The first official statement on establishing a UNU geothermal institute in Iceland was made in 1975 when the United Nations University (UNU) had just been established. After a first proposal in 1976 and an international workshop in 1978, the Government of Iceland decided in October 1978 to ask Orkustofnun, the National Energy Authority (NEA), to sign an Agreement on Association with the UNU and establish the UNU Geothermal Training Programme (UNU-GTP). The UNU-GTP has been hosted by the NEA since then.

The Main elements of the Agreement

In a report on the Geothermal Exploration program it is stated that "the preparation of this project was initiated following a visit of a World Bank Mission to Iceland in early November 2011. During the visit cooperation between the World Bank and Iceland was discussed, in particular how it would be possible to accelerate the geothermal development in Africa by utilizing the expertise and experience of Iceland in the field of renewable energy and combine that with the Bank's convening power and financial resources. The outcome of this visit was that the World Bank and the Ministry of Foreign Affairs (MoFA) in Iceland decided to continue the cooperation and formulate a plan to advance this concept. This entails that Iceland and Icelandic agencies will advance their work in order to bring the countries towards exploration drilling.

The approach two-phase cooperation.

- Firstly, a generic partnership program has been sketched between Iceland and the World Bank, based on an exchange of letters, with invitation to other partners to join. The World Bank will play a lead role in providing general guidance for the direction of the Geothermal Compact partnership.

- Secondly, under the umbrella of the Compact partnership individual or groups of agencies are invited to develop sub-programs/projects, which, for instance, may be implemented in the form of parallel co-financing. The World Bank has already invited the Nordic Development Fund (NDF) to join the partnership. The Icelandic bilateral development agency, ICEIDA, will be the key actor on the Icelandic side.

- Subsequently, ICEIDA and NDF decided to embark on a joint project under the Geothermal Compact, with a focus on the earlier stages of geothermal development, mainly the stages leading up to significant exploration drilling. In addition, funding will be available for technical assistance and capacity building, including training through the United Nations University – Geothermal Training Programme.

The cooperation between ICEIDA and NDF is based on joint co-financing, with each agency primarily financing costs in specific countries, but under a joint program. ICEIDA will be the Lead Agency for NDF's participation.

The implementation of the project is demand-driven, responding to requests from the governments in the countries of the African rift valley. The project will seek good cooperation with other agencies supporting similar exploration activities and notes in particular the presence of BGR of Germany in certain ARGeo countries and the AUC/KfW Geothermal Risk Mitigation Facility (GRMF) which entails elements of potential support to surface exploration activities in Ethiopia, Kenya, Rwanda, and Tanzania.

In 2011 The World Bank and Iceland started discussions on the possibilities of accelerating the geothermal development in the countries of the East African Rift Valley (EARS) by combining forces, and inviting other actors to join the cooperation. To this end a Geothermal Compact program has been formed, which includes a staged approach to research and investments, combined with parallel activities for institutional strengthening and capacity building in the respective countries and supporting institutions.

The main objective of the Geothermal Compact program is to assist the East African Rift Valley countries to increase their access to green and renewable energy through geothermal energy development. In 2012, The World Bank started to explore with other donors the possibility of mobilizing additional concessional resources to fund test drilling programs, after the activities of the Geothermal Exploration Project are successfully completed. This initiative, the Global Geothermal Development Plan (GGDP) is led by ESMAP. Iceland supports the GGDP.

The Geothermal Exploration Project aims at assisting all EARS countries in completing the exploratory phase of geothermal development and build capacity and expertise in the field of geothermal utilization and related policy. The project will thus contribute to the overall objective of the Geothermal Compact. At the end of the project it is expected that: 1) All participating countries have a realistic assessment of potential geothermal sites, 2) plans for further action where applicable, and 3) capacity to move forward on the basis of those plans and submit drilling projects into funding pipelines.

The Geothermal Exploration Project is the initial phase of the Geothermal Compact partnership program, initiated jointly by Iceland and the World Bank. The Icelandic International Development Agency (ICEIDA) will act as the Lead Agency with joint co-financing from the Nordic Development Fund (NDF) and participation of others, as the case may be. The implementation of the project is demand-driven, responding to requests by governments and appropriate authorities. In addition to supporting and funding reconnaissance and geothermal exploration the project will also cover technical assistance and capacity building, as needed and requested within the scope of the project, including training through the UNU-Geothermal Training Programme.

The financial framework for the Geothermal Exploration Project is estimated at USD 13 million. The project could extend to all 13 countries in the East Africa Rift Valley. A separate project document will be prepared for activities in each country, including plans for geothermal exploration and capacity building". (ICEIDA, 2011)

8.1.2 Main Objectives and Strategy

The main objective of the overall partnership program, the **Geothermal Compact**, is to assist the East African Rift Valley countries to increase their renewable energy access through low emissions geothermal energy development. The ambition for an outcome is to see 200 MW of electricity or more added to the energy production in the EARS countries as a result of actions supported by the Compact within a time span of 7-15 years.

The project support will extend up to (and possibly through) the stages of exploratory drilling, after which major infrastructure financing agents and/or commercial developers would step in to work with governments on further steps. An important aspect of the project includes support to the respective governments to move forward from positive exploration results and submit potential geothermal projects into funding pipelines for exploration drilling.

The specific objective (outcome) of the project is: *Enhanced geothermal knowledge and capacity that enables further actions on geothermal utilization in EARS countries.* The expected outputs are the necessary scientific data, reports and human resources to enable governments to take further actions on geothermal utilization. Where sufficient geothermal energy is discovered, such data will have significant market value in and of itself. Certain value is also attached in those cases where the explorations may eliminate fields previously thought to have potential. In both cases, an objective understanding of the geothermal potentials will be established in all participating countries, creating the necessary foundations for informed decisions regarding energy production.

Project Strategy
A nine stage process is proposed for the geothermal development cycle discussed under the Geothermal Compact, which is a slight variation on the stages described in the World Bank Aide Memoire. The Geothermal Exploration Project will mainly cater to stages 1 and 2. If required, the project

could potentially contribute towards stage 4 if funding allows. In parallel to the described stages the Project will offer financial support to parallel activities, mainly technical assistance and capacity building.

Stage 1: Reconnaissance – Gathering of existing data
Stage 2: Exploration
Stage 3: Exploration drilling of 1-3 wells
Stage 4: Prefeasibility report
Stage 5: Further drilling of wells – as needed
Stage 6: Feasibility report
Stage 7: Concept design and tender documents
Stage 8: Detailed design and construction
Stage 9: Testing, training and operations start-up

To facilitate the drive towards the objectives of the Compact and the Exploration Project, the parties will provide financing and technical assistance to governments and their agencies, join hands in resource mobilization, and work together to strengthen the capacity within all participating institutions, for instance through the formation of a Community of Practice on geothermal development, as outlined in the Aide Memoire from the World Bank. Parallel to the stages of geothermal exploration, the following activities, aimed at strengthening sector governance and capacity, will be carried out throughout the whole project period:

1. Policy development and updates. Legal and development framework for geothermal projects, business modelling, engagement of developers/sponsors, investors and financiers, with guidance from WB and technical support provided by the National Energy Authority of Iceland (OS) and other organizations.

2. Capacity Building in the participating countries. This includes training by UNU-GTP and other capacity building by the National Energy Authority of Iceland (OS). A geothermal human resource strategy should be prepared in each respective country which will guide these activities. The Reconnaissance study in each country will entail a human resource needs assessment. Regional capacity building efforts may also be considered for instance in cooperation with AUC and ARGeo.

3. Strengthen the ability of development and financial institutions to engage and support the geothermal development process. Various supporting initiatives will be launched, notably the creation of a Community of Practice on geothermal development for dialogue, learning and information sharing.

The 13 countries in the East Africa Rift Valley that this project covers are listed in enclosed table together with an indication of the geothermal potential and the status of geothermal development in each country, based on an assessment report by ISOR for ARGeo.

Table 8.1.2.1. **Matrix of Geothermal Project Options in the East Africa rift Valley**

Countries					Stages	1	2	3	4	5	6	7	8	9
		A	B	C	Potential	Recon.	Exploration	Exploration drilling	Pre-feasibility	Drilling	Feasibility	Design	Constr.	Operation
1	Eritrea	A			High	X	X							
2	Djibouti	A			High	X	X	X	X					
3	Ethiopia	A		N	High	X	X	X					X	X
4	Uganda	A	I	N	Med	X	X							
5	Kenya	A		N	High	X	X	X		X	X	X	X	X
6	Rwanda			N	Med/ High	X	X		X					
7	Burundi				Med	X								
8	Tanzania	A		N	Med	X	X							
9	Zambia			N	Low/ Med	X	X							
10	Malawi		I	N	Low/ Med	X								
11	Mozambique		I	N	Low	X								
12	Congo				Unknown									
13	Comoros				Low/ Med	X								

The Geothermal Compact and the Exploration Project envision a cooperation of several partners. In the table below the main agents are shown as well as the anticipated role of each agent. The core partnership concerning this project includes the World Bank, ICEIDA and NDF – in dialogue with the African Union and ARGeo, with input regarding training and capacity building from UNU-GTP and OS.

The World Bank provides the overall leadership for the Geothermal Compact. In the countries in which the World Bank has ongoing energy sector dialogue, implementation of the Geothermal Exploration Project will be aligned with this dialogue. The main actors and their role in geothermal development in the region are summarized in table below. (ICEIDA, 2011).

In Annex 1 there is an example of part of a Logical Framework Matrix, used in this case for planning.

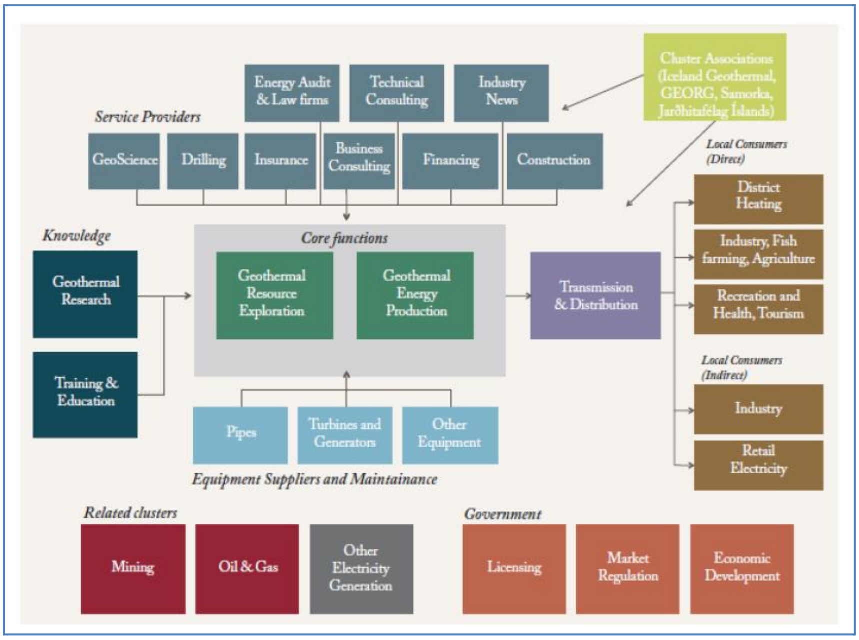
Table 8.1.2.2. **Matrix of Geothermal Project Financial Options in the East Africa Rift Valley**

Agents	Roles Stages	1	2	3	4	5	6	7	8	9
		Recon.	Exploration	Exploration drilling	Pre-feasibility	Drilling	Feasibility	Design	Constr.	Operations
African Union	Political Guidance	X	X	X	X	X	X	X	X	X
ARGEO	Facilitator and coordin.	X	X	X	X	X	X	X	X	X
World Bank	Funding			X	X	X	X	X	X	X
MFA Iceland	Facilitator and funding	X	X	X	X					
ICEIDA	Lead agency Exploration	X	X		X					
NDF	Funding	X	X	X	X					
UNEP	Technical Assistance					X	X	X	X	X
OFID	Funding					X	X	X	X	X
BADEA	Funding					X	X	X	X	X
KfW	Funding					X	X	X	X	X
Other funds	Funding					X	X	X	X	X
BGD	Geological research	X	X	X	X					
IEA Iceland	Framework and capacity	X	X	X	X	X	X	X	X	X
UNU-GTP	Capacity building	X	X	X	X	X	X	X	X	X

8.2 Clusters and Competitiveness of the Icelandic Geothermal Sector

In 2010, Dr. Michael Porter and Dr. Christian Ketels performed an analysis of the Icelandic geothermal cluster in cooperation with Gekon, an Icelandic consulting firm. Nearly 60 different stakeholders within the cluster were involved in the project. According to the results Iceland is naturally uniquely situated in terms of access to a quality resource.

Figure 8.2.1. **The Icelandic Geothermal Cluster**



The term cluster is defined as a geographical group of companies and associated institutions in a particular field, linked by commonalities and complementarities. In a cluster there is a system of interconnected firms and institutions whose value as a whole is greater than the sum of its part. The cluster policy has been part of the structure of the Icelandic economy for two decades. So far, such work has mainly been formed by local conditions and initiated by the government. In recent years this development has grown towards more private governance of clusters, and now several clusters in Iceland are governed by private partners, e.g. the Geothermal Cluster, Ocean Cluster, the Tourism Cluster and the Health Cluster. (Institute, 2014) [7]

Table 8.2.2. **Some of the Icelandic Geothermal Cluster Expertise**

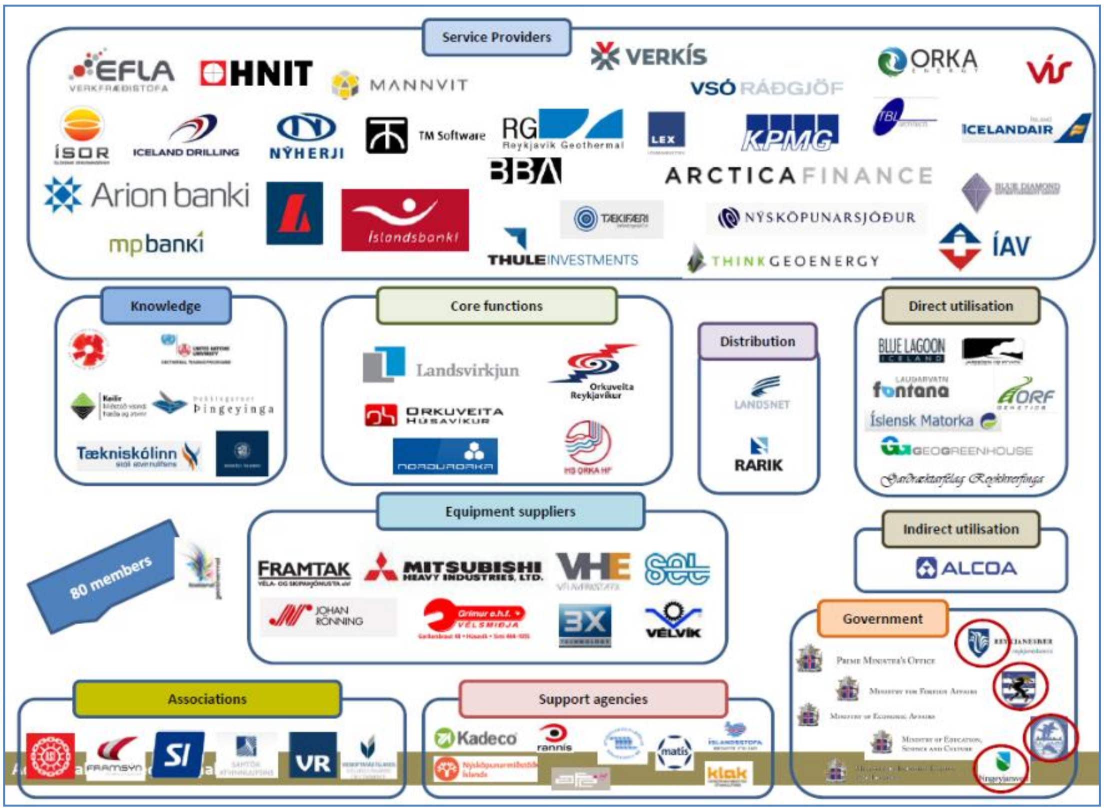
GeoScience	ISOR, Mannvit, Vatnaskil
Technical Consulting	Mannvit, Verkís, Efla, Reykjavík Geothermal, Landsvirkjun Power, Reykjavík Energy Invest
Business Consulting	KPMG, Capacent Corporate Finance, Íslandsbanki
Drilling	Jarðboranir, Ræktunarsamband Flóa og Skeiða
Construction	ISTAK, ÍAV and Loftorka
Energy Audit & Law Firms	KPMG, Pricewaterhouse Coopers, Deloitte, Lex (law firm), Logos (law firm)
Financing	Arionbanki, Íslandsbanki, Landsbankinn
Geothermal Research	ISOR, Mannvit, Vatnaskil, Utilities, Universities
Research Funding	Orkusjóður, Geothermal Research Group, Landsvirkjun´s Energy Fund, OrkuveitaReykjavíkur Energy Fund, Rannís
Training and Education	University of Akureyri , University of Iceland, Reykjavík University, Reykjavík Energy Graduate School of Sustainable Systems, Keilir – Atlantic Center of Excellence, United Nations University – Geothermal Training Programme

The high percentage of geothermal energy as proportion of Iceland's total primary energy consumption is unique in the world. Most of the development of geothermal utilization in Iceland has occurred for the last one hundred years or so, especially in the latter half of the 20th century. Iceland is a strong player in the global geothermal market, enjoying the benefits of a powerful geothermal cluster. The cluster's strength consists of a developed system for using geothermal energy in multiple ways, experienced specialists, and a strong international reputation and network. The cluster's weaknesses include poor access to capital, a lack of critical mass of companies, a complex domestic market environment, and fragmented educational activities. (Hákon Gunnarsson, 2011)

[7] Geothermal Cluster - http://www.gekon.is/,
Ocean Cluster - http://sjavarklasinn.is/en/,
Regional Clusters - *http://www.byggdastofnun.is/is/verkefni/vaxtarsamningar*

A cluster can contribute to national competitiveness efforts that include policy reform, trade capacity building, a private-public dialogue, regional economic development, workforce development, technology and trade development, drive export etc. Competitive Clusters may well be one of the most effective tools in a broader context of policy reform and other private sector development initiatives.

Figure 8.2.3. **Main Parts of the Geothermal Cluster in Iceland**



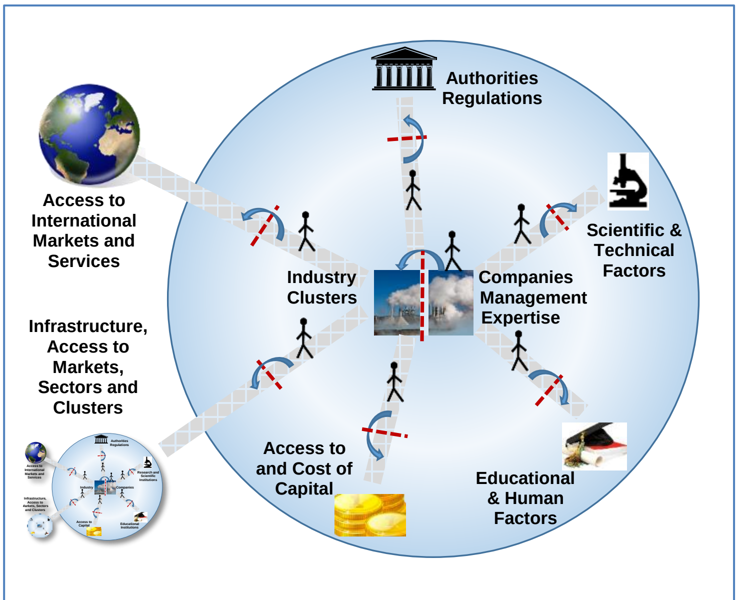
Sources: The Icelandic Geothermal Cluster

The importance of clusters has grown rapidly in recent years to increase competitiveness, growth and productivity, as a reaction to increased competition in all areas and sectors, more globalisation, and rapid changes in technology, services and trade. The cluster competitiveness model can be used in many different ways to increase competitiveness and growth of companies. One possibility is to use the enclosed model to analyse the seven main framework conditions in the geothermal sector;

1. authorities and regulation,
2. scientific & technical factors,
3. education & human factors,
4. access to capital,
5. infrastructure and access to markets, sectors and other clusters,
6. access to international markets and services, and finally,
7. the company, management, expertise & industry, clusters assessment.

By evaluation of these seven factors of the geothermal competitiveness in the concerning country, it is possible to highlight the key weaknesses and strengths of the frameworks conditions as a base for the formulation of a better competitiveness policy for the geothermal sector; to increase competitiveness, growth, jobs, productivity and quality of life.

Figure 8.2.4. **Competitiveness of the Geothermal Cluster**

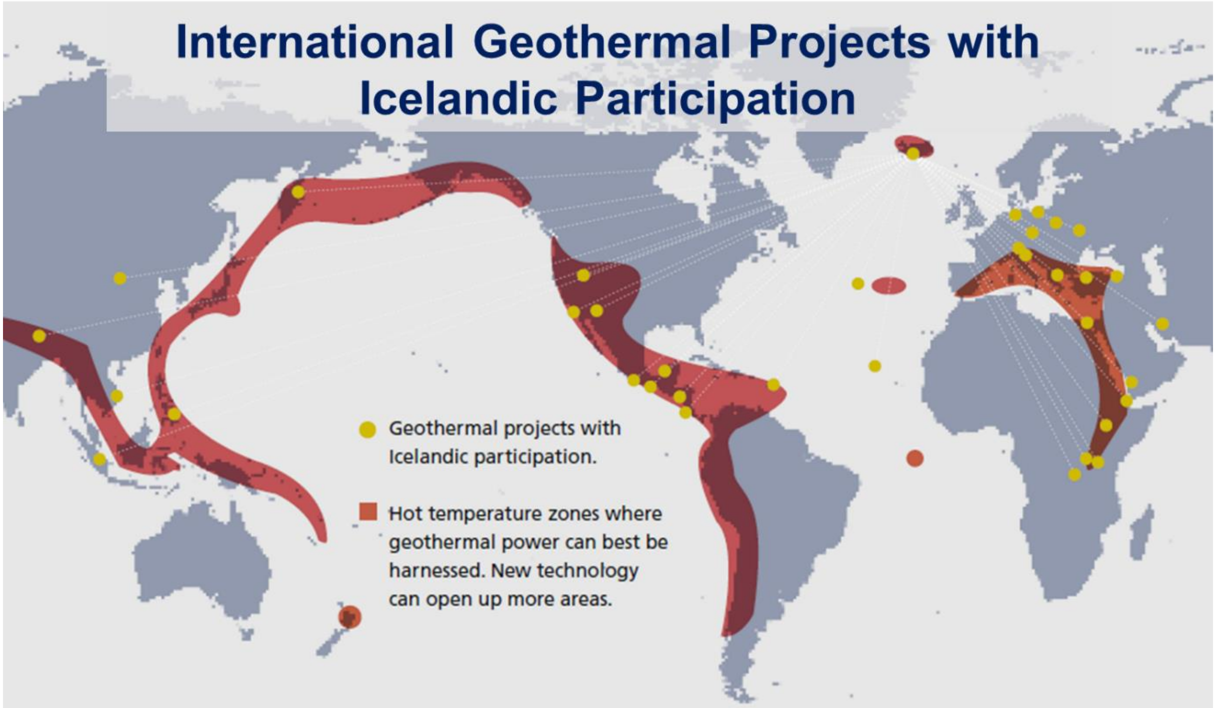


Source: Sölvell & Lindquist 2012, Amended, B. Petursson, National Energy Authority, 2014

8.3 International Cooperation of the Icelandic Geothermal Sector

8.3.1 International Work and Projects of the Business Sector

As global warming poses a threat to the world, it is now mostly acknowledged that an increased use of renewable energy could play a key role in reducing this development. Geothermal energy can play a significant role in the electricity production of countries and regions rich in high-temperature fields which are associated with volcanic activity.



Capacity building and transfer of technology are key issues in the sustainable development of geothermal resources. Icelandic emphasis in bi-lateral development assistance has therefore focused on geothermal energy and cooperation with countries that have unexploited geothermal resources. The objective is to assist them in developing their renewable energy resources. In addition, several Icelandic companies make it their business to export geothermal and hydropower know-how and experience. Icelandic experts participate in geothermal projects worldwide, and have contributed to the world's best known geothermal projects. Geothermal experts from Iceland are now at work in the United States, China, Indonesia, the Philippines, Germany, Hungary, Djibouti, Eritrea, Nicaragua, and El Salvador to name but a few examples.[8]

[8] **Examples of Engineering and Consulting Companies:**

- Icelandic Geosurvey – www.isor.is
- Mannvit – www.mannvit.is
- Verkís – www.verkis.is
- Efla – www.efla.is
- Reykjavik Geothermal, www.rg.is/

Energy and Contracting Companies:

- Iceland Drilling – www.iceland-drilling.com
- Icelandic State Electricity – www.rarik.is
- HS Orka – www.hsorka.is
- Landsvirkjun Power – www.lvp.is
- Reykjavik Energy – www.or.is

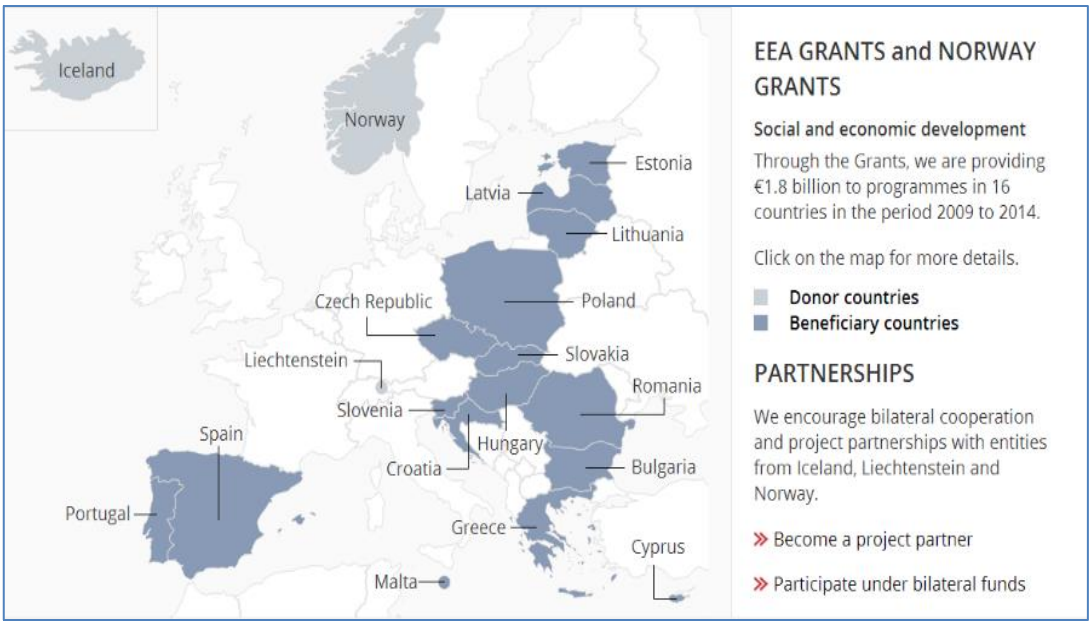
Energy Institutions / Cooperation Platforms

- Orkustofnun, (National Energy Authority) – www.os.is
- Iceland Geothermal Cluster http://www.icelandgeothermal.is/

8.3.2 EEA Grant Cooperation in Eastern Europe

Through the European Economic Area (EEA) Agreement, Iceland, Liechtenstein and Norway are partners in the internal market with the 28 EU member states. Ever since the establishment of the EEA Agreement in 1994, Iceland, Liechtenstein and Norway have provided funding to reduce social and economic disparities in the EA. The expansions of the EU in 2004 and 2007 brought a 20% increase in the EU's population, but only a 5% increase in GDP. The EEA and Norway Grants, are helping to reduce disparities. The funding is targeted on areas where there are clear needs in the beneficiary countries.

Fig. 8.3.2.1. **The EEA Grants and the Beneficiary and the Donor countries**



Orkustofnun (National Energy Authority), work as EEA Donor Program Partner

Funded by the EEA Grants, Hungary, Portugal and Romania will work together with the National Energy Authority of Iceland to develop and exploit the potential of geothermal energy in their countries. With its expertise in securing long-term sustainable use of geothermal resources, the National Energy Authority in Iceland will, as a Donor Programme Partner, offer assistance in creating, implementing and monitoring geothermal resource management plans in these three beneficiary states. This cooperation aims at securing long term sustainable yield of the geothermal resource.

Fig. 8.3.2.2. The launch of the EEA Grants in Hungary 2013. The Hungarian State Secretary for Energy, Attila Imre Horváth, the Icelandic Foreign Minister Gunnar Bragi Sveinsson, the Norwegian Ambassador Tove Skarstein and Guðni A. Jóhannesson, Director General of the Icelandic Orkustofnun.

Renewable Energy Supported by EEA Grants

In the EEA Grants scheme, €135 million has been set aside in eight countries for projects that promote energy efficiency and the share of renewable energy in the energy mix, in line with the EU/EEA, Europe 2020 targets. Renewable energy comes in many forms. Both Iceland and Norway have had great success with hydroelectric energy and Iceland is a pioneer in harnessing geothermal energy. Geothermal energy sources account for 68% of Iceland's primary energy use.

Fig. 8.3.2.3. The launch of the EEA Grants in Romania 2013. Jónas Ketilsson, Project Manager from NEA Iceland, the Icelandic Minister of Industry and Commerce, Ragnheiður Elín Árnadóttir and Adrian Gearap, President of EFA.

Fig. 8.3.2.4. The launch of the EEA Grants in Azores Islands (Portugal) 2013. The Icelandic Minister of Industry and Commerce, Ragnheiður Elín Árnadóttir and others from Azores and Iceland.

Example of a Renewable Program within the EEA Grant Programme – the RONDINE
On Tuesday, November 26, 2013, the RONDINE (RO 06) Renewable Energy Program was launched in Romania. The aim of the RONDINE Program, which is based on the EEA Grants 2009 - 2014, is to promote sustainable use of natural resources and reduce emissions of greenhouse gases through the use of renewable energy, by hydro- and geothermal projects. The program is operated by the Romanian Environmental Fund Administration, EFA.

What will the programme achieve and who are the beneficiaries?
The programme will increase the share of renewable energy in energy generation in Romania. This will be done by way of financially supporting the construction or refurbishment of three or more small scale hydropower plants in order to make them more efficient. Moreover, the programme will support the construction of one or more geothermal heat plants in areas where there already is a heat distribution system in place. The new or refurbished plants, will contribute to the replacing of fossil fuels with renewable energy. The programme will benefit local public administration, local institutions, enterprises and households.

Example of one Geothermal Project in Romania
An example is the geothermal project in the city of Oradea, which is one of the biggest city in western Romania with 200.000 inhabitants. One of the biggest universities in Romania (with 20.000 students) is located in the city. The aim of the project is to install pumps in an existing borehole, as well drilling injection wells, to utilize hot water for heating. The additional geothermal fluid that will be extracted will be used for the city district heating system to reduce the use of coal, the current fuel being used.

Figure 8.3.2.5. **The City of Oradea, in Romania**

Orkustofnun
http://www.nea.is/the-national-energy-authority/international-relations/
Ministry of Foreign Affairs
http://www.utanrikisraduneyti.is/verkefni/evropumal/verkefni/nr/4582
EFTA / FMO / EEA Grants
http://eeagrants.org/

8.3.3 UNU – GTP Programmes

The Geothermal Training Programme of the United Nations University (UNU-GTP) is a postgraduate training programme, aimed at assisting developing countries in capacity building within geothermal exploration and development.

The annual programme consists of six months training for practicing professionals from developing and transitional countries with significant geothermal potential. Priority is given to countries where geothermal development is under way, in order to maximize technology transfer.

The programme has operated in Iceland since 1979. It is a cooperation between the United Nations University and the Government of Iceland and is hosted by the National Energy Authority (Orkustofnun).

The UNU-GTP has three main activities:

- The Six Month Training Programme
- MSc and PhD Fellowships
- Workshops and Short Courses

The core focus of the UNU-GTP is an annual six month specialized training programme initialized in 1979. New countries are continuously added in the training but care is taken not to spread the efforts too thin. Experience strongly suggests that it is necessary to build up groups of ten or more geothermal specialists in a given country in order for technology transfer to be successful and sustainable.

In association with the Six Month Training Programme a leading specialist in geothermal energy is invited every year to give a series of lectures over a duration of one week on a specific geothermal subject. The lectures are open to all interested in geothermal sciences.

The UNU-GTP also offers an opportunity for outstanding fellows to pursue their MSc and/or their PhD degree through a cooperation with the University of Iceland (UI) and Reykjavík University (RU). The Six Month Training Programme counts 25% towards the MSc degree.

Furthermore the UNU-GTP plans and executes annual workshops and short courses in geothermal development in selected countries in Africa (in Kenya which started in 2005), Central America (El Salvador which started in 2006), and Asia (in China in 2008). The courses are set up in cooperation with the energy entities in the respective regions. A part of the objective is to increase cooperation between specialists in the field of sustainable use of geothermal resources. (Iceland, 2014)

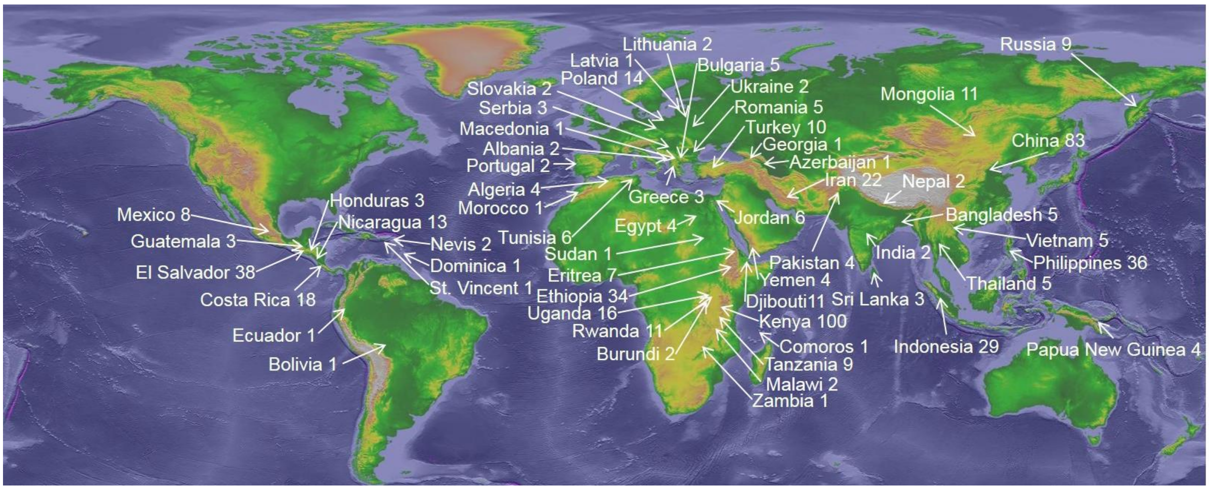
The United Nations University Geothermal Training Programme (UNU-GTP) can support the ANDEAN countries in strengthening the skills of experts who are tasked with the responsibility of carrying out geoscientific exploration, utilizing and managing geothermal resources. Since its inception in Iceland in 1979, the programme has graduated 515 fellows from 53 countries. The fellows have obtained both a broad overview of the major geothermal disciplines as well as committing to in-depth studies in one or more of the nine available lines of specialization, which are: Geothermal geology, reservoir engineering, geophysical exploration, borehole geophysics, reservoir engineering, environmental studies, chemistry of thermal fluids, geothermal utilization, drilling technology and project management and finances.

Many of the fellows bring with them data from home to analyze during the nearly three month long project work, which entails the writing of a report that is included in the annual publication Geothermal Training in Iceland. The individual reports are available on the UNU-GTP website (www.unugtp.is). In this way, strong groups of geothermal experts have been established in many developing countries over the years. A selected number of fellows who have shown outstanding performance in their six month studies have been offered the opportunity to further their geothermal studies at the University of Iceland towards an MSc degree, and a few have been enrolled in PhD programmes.

Since 2006, the UNU-GTP has offered semi-annual Millennium Short Courses in cooperation with LaGeo S.A. de C.V. in El Salvador for the Latin America region. The courses are the contribution of the government of Iceland towards the United Nations Millennium Development Goals and are intended to strengthen the skills of participants in specific geothermal disciplines, as well as providing a venue for experts in the region to meet and compare books. These Short Courses are often the first step for candidates towards further studies at the UN University Geothermal Training Programme.

Figure 8.3.3.1**. UNU-GTP Fellows in Iceland 1979-2014 – 583 from 58 Countries**

In



2010 and 2012, the University of El Salvador offered a geothermal diploma course in cooperation with LaGeo S.A. de C.V. and the Italian Cooperation of the Italian Ministry of Foreign Affairs, which funded the courses. The diploma courses have continued in 2013 and 2014 with support from the Nordic Development Fund and the Inter-American Development Bank and the hope is that they will provide a foundation for a permanent regional geothermal training centre that can offer Spanish speakers the opportunity to study the geothermal disciplines in their native language. (Haraldsson, Geothermal Activity in South America, 2013).

Cooperation with other Universities

University of Iceland
University of Iceland is an active coordinative partner in the programmes of UNU-GTP and Keilir, but offers also in-house graduate studies in the field of Renewable Energy Engineering: an interdisciplinary study on the technical and environmental aspect harnessing, distributing and consuming energy in a sustainable manner. http://english.hi.is/

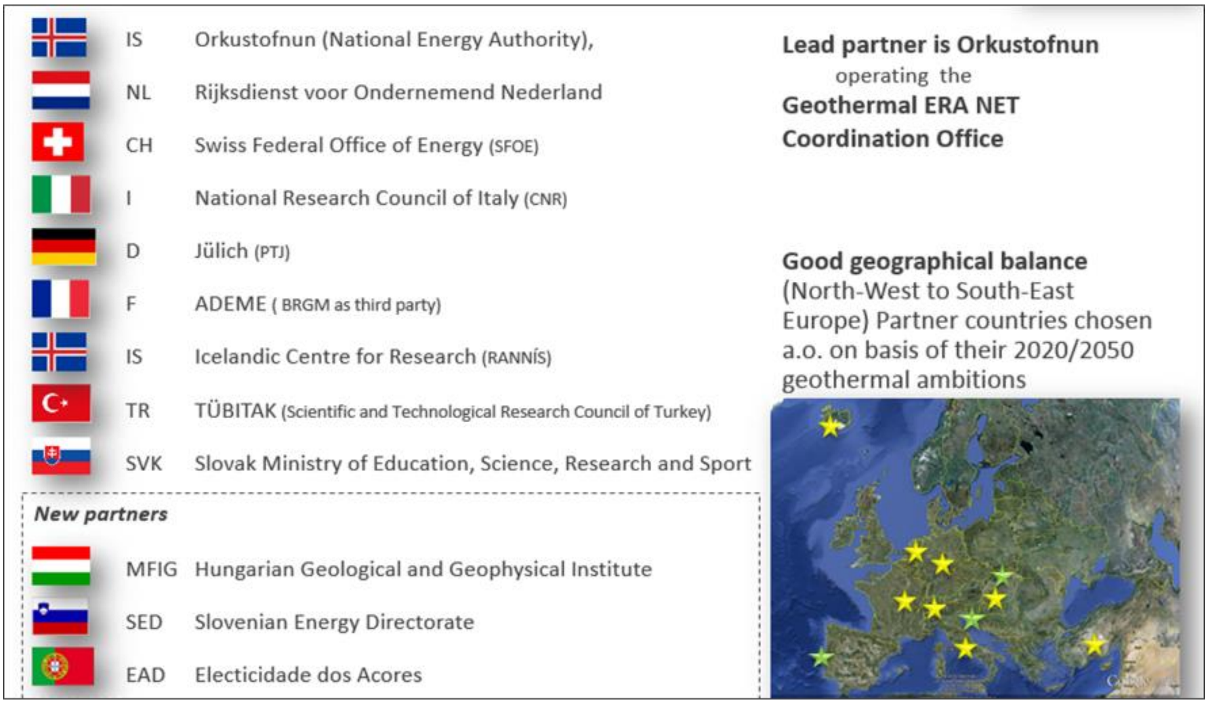
Reykjavik University
Reykjavik University offers a BSc programme in Mechanical and Energy Engineering with a strong tradition of practical orientation in cooperation with the industry. The research focus is on applied research in cooperation with specialized companies and institutions in the energy field.

All these programmes are supported by the leading energy companies, providing access to expertise and facilities. More information can be seen on website: http://www.unugtp.is/

8.3.4 ERA Net Cooperation

The Geothermal ERA-NET is a cooperation started on May 1st 2012 within the EEA Agreement, and will last for four years. It is estimated that the project will support geothermal research in Europe - that could lead to greater cooperation between energy agencies and ministries in Europe and make it possible for them to work on common goals. The Geothermal ERA NET focuses on direct use and higher enthalpy uses of geothermal energy. The general vision of the Geothermal ERA NET is as follows:

- Minimize the fragmentation of geothermal research in Europe
- Build on European know-how and know-who to utilize geothermal energy
- Contribute to a framework to realise large opportunities in the utilization of geothermal energy through joint activities.

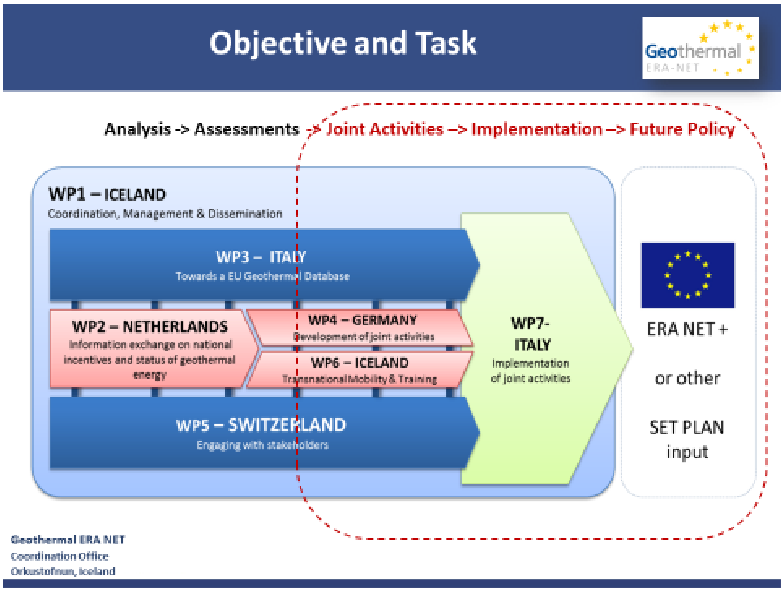


Geothermal energy utilisation accounts for 68% of energy consumption in Iceland, and one could say that the potential that this energy source holds for this country is largely deployed. Italy also has a significant geothermal production and ranks fifth in the world for geothermal electricity production. After Turkey, Iceland and Italy, Hungary is ranked at 4th place regarding geothermal direct use in Europe. For all other participating countries, geothermal energy is an energy source with potential.

All the countries have ambitious agendas for an increase of the market for geothermal energy.

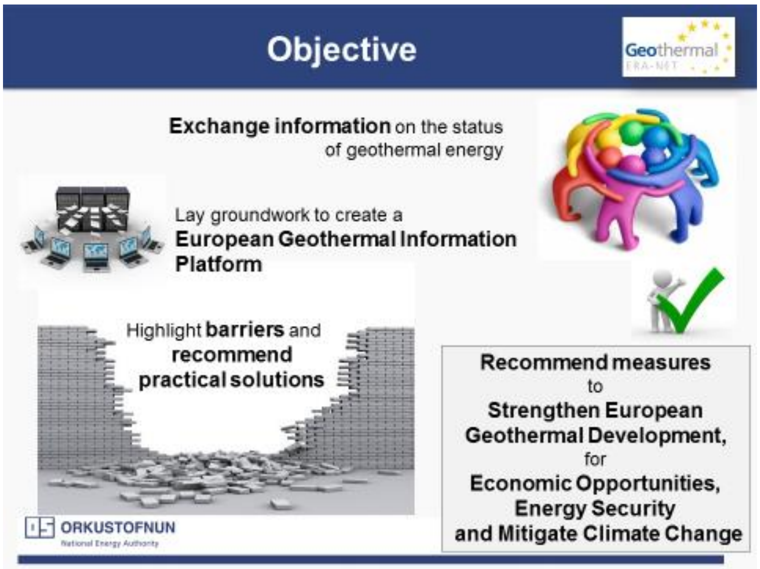
In all the ERA NET countries except for the Netherlands and Slovenia, this includes a significant growth in electricity production using geothermal energy.

Up to 2020, the Netherlands will focus on direct use. In all participating countries, there are policy instruments in place to forward geothermal energy utilisation. This includes R&D efforts, but in some countries also soft loans or guarantee funds.



The Geothermal ERA NET program is split into a 7 Work Package:

1. Coordination and Management
2. Information exchange on national incentives and status on geothermal energy
3. Towards a European Geothermal Database
4. Development of Joint Activities
5. Coordination with Stakeholders
6. Transnational Mobility and Training
7. Implementation of Joint Activities



"It is important for policymakers and others to recognise the great opportunity geothermal heating gives regarding savings for countries, as it is estimated that geothermal heating in Iceland is saving equal to 7% of GDP or 3000 US$ per capita or close to 1 billion US$ for the economy only for 2012. It has also been estimated that renewables for heating and cooling could save EUR 11.5 billion per year within EU, improve the energy security and mitigate climate change", says Guðni A Jóhannesson Geothermal ERA NET coordinator.

More information regarding the program and progress can be seen at the website.
www.geothermaleranet.is/

8.3.5 Additional International Geothermal Promotion

For many years the authorities in Iceland e.g. the **Ministry for Industry and Commerce and its ministers,** has strongly supported the geothermal sector in various forms, at domestic level by highlighting the importance of the sector in policy making as well as implementation for harnessing the geothermal resources both for electricity generation and district heating.

Fig. 8.3.5.1. Left - Ragnheiður Elin Árnadóttir, Minister for Industry and Innovation and Daniel Ortega President of Nicaragua. Right – the Icelandic Delegation in Nicaragua.

The Icelandic authorities have also supported various events on renewables and seminars at international level, with conferences trade missions etc. For example Ragnheiður Elin Árnadóttir, Minister for Industry and Innovation, chaired an Icelandic delegation on a visit to Nicaragua in November 2014, focusing on geothermal and hydro where she signed a Memorandum of Understanding (MoU) on Renewables Cooperation with Mr. Daniel Ortega, President of Nicaragua. http://eng.atvinnuvegaraduneyti.is/

The **Ministry of Foreign Affairs and its ministers** have also supported the geothermal sector, especially in the form of international aid, by helping several developing countries to harness geothermal renewable resources, by education and capacity building in cooperation with United Nations University Geothermal Training Programme (UNU-GTP), International Financial Institutions (IFI) and various countries. It has also be done by meetings and conferences at international level. http://www.mfa.is/

Fig. 8.3.5.2. Mr. Gunnar Bragi Sveinsson, Minister for Foreign Affairs, with United Nations Secretary-General Mr. Ban Ki-moon, at Hellisheiðarvirkjun in Iceland.

The presidents of Iceland have also highlighted the importance of the geothermal renewable resources at various occasions at domestic and international levels, at meetings, conferences and other occasions, especially in recent years. http://english.forseti.is/

Íslandsstofa, Promote Iceland offers the business community various marketing and trade promotional services, including the organisation of trade fairs and business delegations, in-depth consulting, training programmes and market information. http://www.islandsstofa.is/en

Fig. 8.3.5.3. Mr. President, Ólafur Ragnar Grímsson, at the World Future Energy Summit.

Such policy support and awareness raising through the years for the harnessing the geothermal resources by ministers, ministries and the presidents, is valuable awareness building at domestic and international level. This has also assisted concerning countries, regions and stakeholders to further utilisation of geothermal resources, to mitigate climate change and increase energy security, economic opportunity and savings, and quality of life.

9 Capacity building in Iceland

To promote and build up confidence in geothermal development it is essential that a governmental institute leads the regional survey for promising geothermal fields and evaluates the geothermal potential. This institute is required to encourage and supervise the first steps in exploration and demonstrate the methodology and value of the first geothermal development.

After this initial phase of encouragement confidence in geothermal development may have reached the stage that private investors and entrepreneurs are willing to take over projects. Then the role of the governmental institute changes to supervision and administration of the development like what has occurred in Iceland in the last few decades. For the initial phase of the regional survey for promising geothermal fields and evaluation of the geothermal potential, an institute with a staff with specialized training in geothermal exploration and sustainable development is needed. The main disciplines required are:

- **Geological exploration**
  Practical training in basic geological and geothermal mapping, which is commonly the first step in the geothermal exploration of an area.

- **Geophysical exploration**
  Practical training in conducting geophysical surveys of geothermal areas and/or interpretation of such data.

- **Chemistry of thermal fluids**
  Thermal fluid chemistry in geothermal exploration and exploitation, including sampling, analysis of major constituents and the interpretation of results.

- **Drilling technology**
  Selection of drilling equipment, well design, casing programs, cementing techniques, cleaning and repairs of production wells.

- **Borehole geology**
  Training in making geological logs, analyses of drill cuttings and cores. Identification of alteration minerals (microscope and x-ray diffraction) and interpretation of the alteration mineralogy.

- **Borehole geophysics**
  Geophysical measurements in boreholes used for geothermal investigations, with an emphasis on temperature and pressure measurements.

- **Reservoir engineering**
  Hydrological characteristics of geothermal reservoirs and forecast of the long term response of the reservoirs to exploitation

- **Environmental studies**
  Environmental impact assessments (EIA), laws and policies, the planning and execution of EIA projects and environmental auditing. Environmental monitoring, biological impact, pollution and occupational safety.

- **Geothermal utilisation**
  Civil, mechanical and chemical engineering aspects of geothermal fluids in pipes, equipment and plants. Feasibility of projects and environmental factors.

- **Law**
  Legal and institutional framework. Laws on survey, protection and utilization of natural resources, environmental impact assessment.

- **Financial analysis and planning of geothermal projects.**

- **Project Management.**

- **General geothermal framework assessment, evaluation and development.**

Training in these disciplines is offered at the United Nations University Training Programme (UNU-GTP) in Iceland and at many universities in other countries that have pursued geothermal development. The candidates for UNU-GTP must have a university degree in science or engineering, a minimum of one year practical experience in geothermal work, speak English fluently, and have a permanent position at a public energy agency/utility, research institution, or university. In selecting the participants the UNU-GTP sends representatives to the countries requesting training.

The potential role of geothermal energy within the energy plans of the respective country is assessed, and an evaluation made of the institutional capacities in the field of geothermal research and utilisation. Based on this, the training needs of the country are assessed and recipient institutions selected. The directors of the selected institutions are invited to nominate candidates for training in the specialized fields that are considered most relevant to promote geothermal development in the respective country. Further information on the UNU-GTP is attached in an Appendix.

When confidence in the geothermal development has reached the level that private investors are willing to take over in projects the role of the governmental institute changes to supervision and administration of the development along the lines defined in laws like the Act on Survey and Utilisation of Natural Resources in Iceland. At this stage the institute will require staff trained in legal affairs, economy and business administration. The exploration and appraisal of geothermal fields would then be carried out by specialized consultants but the institute would still require staff members with expertise in geothermal development to handle issues of granting licenses and supervision of the operating holders of licenses.

10 Conclusions and Lessons Learned in Iceland

Ownership, pricing and financing

In Iceland the energy sector has been built up by companies owned by the State or communities where the aim has been to utilize the natural energy resources for development and offer energy to the public at favourable prices, both electricity and hot water for space heating. In financing larger projects the owner of the respective energy company has given its guarantee and provided long term loans on favourable terms from development banks and commercial banks.

Profitability and savings for economy and citizens

The energy companies have not returned much profit on their equity, but companies and the public have enjoyed a relatively low energy price and a tremendous development has taken place in energy intensive industries and related services. The economic savings from using geothermal energy in space heating in Iceland are substantial, and have contributed significantly to Iceland’s prosperity, especially in times of need. The electricity price in Iceland is among the lowest in Europe.

Risks

Geothermal projects require considerable initial capital and investment long before the stream of income. The risk involved in new geothermal projects is generally a major barrier for the development as well as the difficulty persuading independent power producers (IPP) and investors to accept the risk and complete the total financing.

Cooperation

Geothermal development requires balanced cooperation of many disciplines such as geosciences, engineering, law and finance. This balance has though not always been reached. In many countries the legal framework and regulatory directives are incomplete or not existing. Conferences are held on science and technology but the discussion of finance, contracts and legal framework is often limited. As a result scientists and engineers have limited understanding of finance and the financial experts know little of the nature of resources and the applied technology. A description of the financial aspects gives decision makers basic understanding of the assumptions and risk involved in geothermal projects and aids in finding methods to reduce the risk and utilize opportunities in the geothermal development.

Administration

To promote and build up confidence in geothermal development it is essential that a governmental institute leads the regional survey for promising geothermal fields and evaluates the geothermal potential. This institute is required to encourage and supervise the first steps in exploration and demonstrate the methodology and value of the first geothermal development. When the geothermal development reaches the stage that private investors and entrepreneurs are willing to take over projects, the role of the governmental institutes changes to supervision and administration of the development. It is vital for carrying out an effective law on the sector of geothermal energy, that the administrative body, responsible for the regulation and official monitoring of the law, be active and visible to those subject to regulation. It is also very important that this same body has effective remedies to bring into actuality each article of the act. Lastly, an appeals committee is important to give the regulator the necessary restraint.

Due to uncertainty it is important that planning process for utilization takes above mentioned factors into account as well as the fact that the environmental effects can sometimes be difficult to predict. Hence, the licenses issued need to take that into consideration and active cooperation is needed between the developer and the authority to mitigate unforeseen effects. The licensing authority also needs to make sure that the economic model of the plant takes into account the uncertainty of reinjection strategies, gas emissions and rate of make-up well drilling to ensure that the developer will be able to run the facilities properly and within requirements stipulated in the legal framework and the licenses issued.

Lessons learned from Icelandic GeoDH Policy
Benefits of Geothermal District Heating

GEOTHERMAL ENERGY – Offers Major Opportunities

1. Harnessing Natural Resources
2. Economic opportunities and savings
3. Improve energy security
4. Reducing greenhouse gas emissions
5. Reducing dependence on fossil fuels for energy use
6. Improving industrial and economic activity
7. Developing the low-Carbon and Geothermal technology industry, and create employment opportunities
8. Improving quality of life

Financial Factors

The risk involved in new geothermal projects is generally a major barrier for the development as well as the difficulty persuading independent power producers (IPP) and investors to accept the risk and complete the total financing. Geothermal projects require considerable initial capital and investment long before the stream of income.

The World Bank, development banks, and development agencies have examined how they can best assist new geothermal projects in developing countries.

To explain this complicated problem one must present clearly the basic assumptions and results of financial analyses. It must be clear what matters most and which assumptions are essential. Case histories from countries which have attained successful development may be of help in that respect.

The case of Iceland is a good example, since in many countries the conditions for development may be similar to those in Iceland some 40 years ago. For comparison it may also be worth to examine why countries that have most of the natural conditions required have not succeeded in their development.

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Annex 1 – Logical Framework Matrix

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Assumptions/Risks
Overall Objective (Impact) (Geothermal Compact)			
Increased access to renewable energy through low emissions geothermal energy development in East African Rift Valley countries.	• 200 MWs of geothermal energy produced in „EARS" countries as a result of activities under the Geothermal Compact (10-15 years).	• Installed capacity of geothermal power plants.	
Specific Objective (Outcome) (The Geothermal Exploration Project)			
Enhanced geothermal knowledge and capacity enables further actions on geothermal utilization in EARS countries. *(Completing the exploratory phase of geothermal development)*	• Plans in place (drill permits prepared) for exploratory drilling in (4-7) respective countries. • Funding proposals submitted to relevant financial institutions for exploratory drilling in (4-7) countries.	• Documentation for drilling permits • Funding applications	• Requests for assistance • Agreements for rights and privileges • Geothermal potential • Favorable funding policies • Political commitment for geothermal energy development • Political stability
Expected Results (Outputs)			
1. Scientific data and reports on geothermal resources produced.			
1.1. Reconnaissance studies conducted in respective EARS countries with recommendations for further action.	• Reconnaissance reports with recommendations on further studies. • External appraisals	• Final reports for Reconnaissance studies • Appraisal	• Requests made for assistance • Required research permits available
1.2. Geothermal explorations conducted and reported.	• Exploration report with recommendations on potential exploration drill sites, if warranted. • External appraisals	• Exploration reports • Appraisal	• Positive results from Reconnaissance study
2. Improved and increased level of knowledge and capacity on geothermal utilization.			
2.1. Strengthened policy and legal framework for geothermal utilization in respective countries.	• Updated policy and legal framework for geothermal utilization in each country.	• Updated policy and regulations.	• Political will and support for geothermal energy development.
2.2. Capacity building in the participating countries, including UNU-GTP training.	• # number of participants trained by the UNU-GTP (by country, gender, field, and level of training).	• Training reports, diplomas, papers published.	• Human resources with required qualifications are available.