Development of an assessment tool to evaluate the geothermal potential of countries

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of

Maximilian Trombitas, MSc

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AFFIDAVIT

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume.

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Date Signature

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Abstract

OMV is on its way to establish itself as one of Europeans major energy supplier. Therefore, the company is interested in green energy technology and likes to invest in that field of energy production in the future. OMV has already done research on geothermal energy technology and carried out one geothermal energy project in Austria. To be able and ready to increase their geothermal energy portfolio in the next few years, OMV was interested in developing an assessment tool for the geothermal energy potential of their E&P country portfolio.

In a first step, a research on all countries from the OMV E&P portfolio was done and based on the facts the countries were described shortly by their political, economic and geological aspects. As the OMV E&P portfolio consists of 17 countries which all have different geothermal energy potentials, it was decided to run a pre-screening upfront to filter out all countries with an economical meaningful geothermal energy production potential, to be able to achieve better results regarding the sensitivity of the needed data-packages. By conducting this step, the countries could be minimized to nine potential countries.

To establish the desired assessment tool, a system has been defined as framework for all further steps. However, multiple criteria decision analysis with a SWING weighting method was chosen. After the system evaluation step, all criteria with an influence on a geothermal energy production projects were defined. This process was accomplished with the aid of a top-down approach, a political-economic-social-technological-analysis and expert interviews.

After the assessment tool was established, experts weighted all criteria on their importance for the overall system, the criteria were assigned their appropriate key figure and the different countries were evaluated. To assess the plausibility of the results a sensitivity analysis was carried out.

An easy and understandable assessment tool to determine the geothermal energy potential of different countries was developed, what was proved on its functionality. The results of the tool show reasonable values, with Romania having the highest potential, as the two most interesting regions are based there.

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List of Abbreviations

AHP	Analytic Hierarchy Process
Cp	Compare
EBIT	Earnings before interests and taxes
E&P	Exploration and production
HDI	Human development index
HDR	Hot dry Rock
MAUT	Multi attribute Utility theory
MCDA	Multiple criteria decision analysis
OPEX	Operational expenditure
PEST	Political/Economical/Social/Technological
SMART	Simple multi attribute rating technique
TDS	Total dissolved solids
TVZ	Taupo Volcanic Zone
UAE	United Arab Emirates
UK	United Kingdom
VDI	Verein deutscher Ingenieure

1 Introduction

Since decades the worldwide energy consumption is rising and therewith the environmental impacts. Even if the industry countries from an ecological and economic point of view are already alerted and try to reduce these increasing emissions, the rising energy need especially of China, India and all other upcoming newly industrialized countries with their high population - and economy growth rate, cannot get satisfied. The growing demand of the fossil fuels oil, gas and coal in the future is accompanied by a shrinking supply. An increase of energy efficiency will not be enough to compensate this scenario. Therefore, the attention should be turned on renewable energy like wind, water, solar, biomass or geothermal energy.

The geothermal energy has worldwide a huge development potential. Geothermal energy has already a long and old story and was already known by early humans by using the natural pools and hot springs for cooking, bathing and to keep warm. The first commercial use to produce electricity is going back to the beginning of the 20th century, but since than a very small but constant development rate of geothermal resources started. Geothermal energy shows a lot of advantage compared to other renewable energy sources. It does not depend on the time of the day, the season or any climatic conditions and is therefore more or less available for 24 hours 365 days a year.

OMV recognized the potential of the geothermal energy already years ago and started to work on this field of renewable energy sources intensively. A whole range of projects in the field showed promising results and a handful of them are also in commercial use already. For further investigations, OMV is interested what are the geothermal potentials of all countries in their exploration and production (E&P) portfolio, to be ready and prepared to expand their geothermal business in this new countries.

1.1 Scope & Structure of Work

The main target of this work is to develop an assessment tool to define the geothermal potential of the OMV E&P countries and rank them by this criterion. For reaching this target, many different steps have to be carried out.

As a first step, a literature study has to be conducted, to get an overview about the problem and to collect all available and necessary information about the topic. After getting an overview, a pre-screening of the OMV E&P portfolio has to be done to check which countries even have a potential or are too risky to accomplish a geothermal project, to reduce the portfolio to a range of countries, which have a future commercial geothermal potential. To even be able to carry out a pre-screening process, meaningful and significant factors have to be defined in advanced, to screen with their aid all countries as a first step. After a successful screening process, the next step is to find in detail all relevant factors, which influence a geothermal energy project with all its aspects. Therefore, an analytical structuring and analysis of the whole project process has to be done with the objective to split the process in groups, which again are divided in their key elements. These key elements should be described and should be quantified by the findings of proper key figures. As next step a method has to be found and defined to combine the elements in a way to get a basic structure for further investigation. This structure should be used to develop a multi criteria decision analysis tool. To verify and weight the individual elements and groups, expert interviews are going to be conducted.

The verified multi criteria decision analysis tool has to be filled with data and the geothermal potential of all key countries should be calculated. The results should be analyzed.

2 Geothermal Energy

Geothermal energy is the heat, which is contained in the solid earth and its internal fluids. This sets it apart from other terrestrial energy sources such as

- Fossil fuels in the subsurface
- Biomass, solar energy, and hydropower on the surface
- Wind energy in the atmosphere

Geothermal energy is supplied by both external - and internal sources. It represents a vast supply, which is only started to be tapped by humankind for space heating, process heat, and generation of electric power. Geothermal energy is stored as sensible or latent heat. The challenges involved in turning this promising potential into operational, efficient, and economic technologies is the main issues for the future.

The following chapter will give an overview about geothermal energy fundamentals, like the definition of geothermal energy and where does it come from. Furthermore, different geothermal resources are described. As next point various types of geothermal energy use are discussed and the most common power generation techniques. In addition, a project process with all its key factors will be given. At a last point, the basics of multi criteria decision analyses systems will be announced.

2.1 Geothermal Energy Fundamentals

"Geothermal" originates from the Greek words geo, what stands for earth, and thermos, meaning heat. The Association of German Engineers (VDI) defines geothermal energy in Europe as the "energy stored in the form of heat beneath the surface of the solid earth"[1]. This comprises the heat stored both in the solid rock and in the fluids of its voids, and distinguishes it from heat stored in surface water bodies such as rivers, lakes and oceans. This definition disregards whether the heat stored in the Earth is generated by internal or external sources.

Geothermal energy was already used by the early humankind but the real first small scale application occurred in the ancient world for heating and bathing. Nevertheless, even today, hot springs are still used worldwide for bathing, and many people believe hot mineral waters have natural healing powers.

The production of electricity out of geothermal energy is a young industry. A group of Italians first utilized it in 1904. The Italians used the natural steam erupting from the earth to power a turbine generator. The first big scale and successful American geothermal plant began operating in 1960 at the Geysers in northern California. There are now about 60 geothermal power plants in five western states, with many more in development. Most of these geothermal power plants are in California with the remainder in Nevada, Hawaii, Alaska, and Utah. In 2010 there were power plants installed in 23 countries all around the world with an expected development rate to 35 countries in 2015 (see Figure 1).

[1] Cp. VDI (2000)

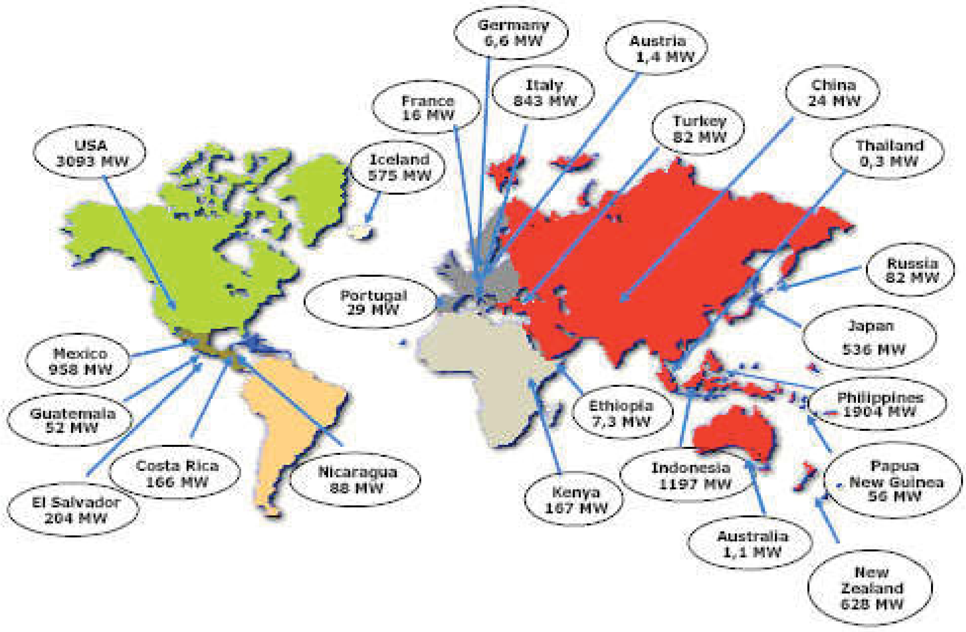


Figure 1: Installed geothermal power capacity 2010[2]

Geothermal energy comes from the natural generation of heat primarily due to external heat sources:

- The solar radiation of the sun
- The gravitational energy from the exchange between the earth, the moon and the sun

and internal heat sources:

- Radiogenic heat due to the decay of the naturally occurring radioactive isotopes of uranium, thorium and potassium
- Original heat from the beginning of the development process and phases of the earth which are still stored in the inner of the earth
- Potential energy which is liberated by the formation of the iron core of the earth and the enrichment of heavy metals in the earth mantle
- Frictional heat due the release of elastic energy in earthquakes

But the earth is also losing heat, mainly to three processes:

- Long-wavelength heat radiation
- Volcanism
- Global heat flow[3]

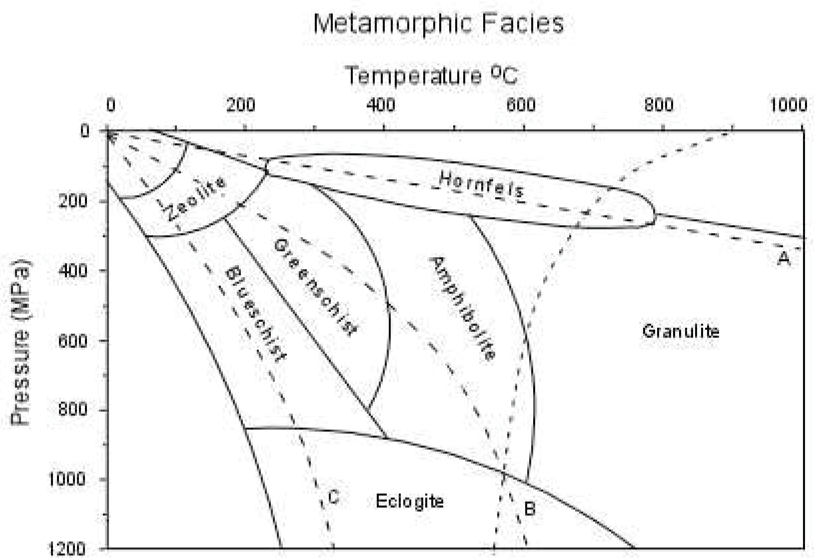
The temperature of the surface of the earth depends mainly on the solar radiation and has an influence down to a depth of around 20m. As soil has a very low heat conductivity property, 20m is pretty much the depth where an influence of this effect is measurable[4].

[2] Bertani, R (2010), p. 2
[3] Cp. Kaltschmitt et al (1999), p. 9ff
[4] Cp. Kaltschmitt et al (1999), p. 9ff

Under this described zone, the temperature starts to increase constantly. The different geological factors have a huge impact on this temperature gradient, is mainly driven by lithology and geodynamic effects. The gradient varies over a wide range, as every region has other characteristics (see Figure 2).

The constant rise of the temperature in the outer earth crust is in average 3°C/100m. It is also called the geothermal temperature gradient and can be used a rough guideline value for central Europe[5].

"The estimated total thermal energy above mean surface temperature to a depth of 10km is 1.3 x 10^{27}J what equivalents the burning of around $3*10^{17}$ barrels of oil. Since the global energy consumptions for all types of energy, is equivalent to the use of about 100 million barrels of oil per day, the Earth's energy to a depth of 10km could theoretically supply all of mankind's energy needs for six million years."[6]



A= High Geothermal gradient

B= Normal Geothermal gradient

C= Low Geothermal gradient

Figure 2: Geothermal gradient in dependency on depth (=pressure) and lithology[7]

2.2 Geothermal resources

Geothermal reserves are defined as the fraction of the accessible resource base or "heat in place" which are commercially recoverable. Geothermal resources, in contrast, are resources where viable markets or required technology under development[8] (see Table 1).

In principle, geothermal resource can be divided by their vertical position in surface-near - and deep resources and by their enthalpy[9].

[5] Cp. Kaltschmitt et al (1999), p. 102

[6] Cp Lundv (2007), p. 1

[7] Source:.Tulane Homepage (Access 08.02.11)

[8] Cp. Clauser et al (2006), p. 59

[9] Cp. Kaltschmitt et al (1999), p. 41

Table 1: Definition of geothermal resources and their estimated potential[10]

Resource category	Energy (EJ)
Accessible resource base (heat in place: amount of heat which can be produced theoretically from the topmost 5 km)	140,000,000
Useful accessible resource base	600,000
Resources (fraction of the accessible resource base which is expected to become economical within 40-50 years)	5,000
Reserves (fraction of the accessible resource base which is expected to become economical within 10-20 years)	500

2.2.1 Definition by vertical position

The surface-near resources will be only described shortly in this chapter and there will not be paid any more attention in any further chapters, as OMV is only interested on deep geothermal reservoirs, as only these resources can provide enough energy for a commercial application.

2.2.1.1 Surface-near resources

The surface-near geothermal resources play only few hundred meters a role, until they reach a temperature of around 20°C[11].

Shallow geothermal installations do not make use of higher temperatures in the underground, but of the steady temperature level throughout the year, and of the thermal storage capacity. Two approaches can be distinguished:

- Ground Source Heat Pumps:

  The low temperature from the ground is transformed into useful energy for heating and cooling by the heat pump

- Underground Thermal Energy Storage:

  The temperature in the ground is changed by injecting heat or cold, and this heat or cold can be retrieved later; usually seasonal storage (e.g. cold from winter to summer)

2.2.1.2 Deep geothermal resources

Deep geothermal resources can be differentiated in four sources:

- Hydrothermal resources
- Geo-pressurized resources
- Hot-dry-rock resources
- Molten rock or magma resources

Hydrothermal resources are characterised by water – and steam bearing formations. These resources can be differentiated in two further reservoirs:

- Liquid dominated reservoirs
- Steam dominated reservoirs

[10] Clauser et al (2006), p. 59

[11] Cp. Kaltschmitt et al (1999), p. 105

Liquid dominated reservoirs have warm-water-sources (temperatures up to 100°C) and hot-water-sources (temperatures over 100°C). Steam dominated reservoirs have wet steam, hot steam and dry steam sources (temperatures from 150°C to 250°C). Wet steam reservoirs contain pressurized water at temperatures above 100°C and a smaller amount of steam in the shallower, lower-pressure parts of the reservoir. Hot, pressurized water is the dominant phase inside the reservoir. Vapour dominated, dry steam fields produce dry saturated or slightly super-heated steam at pressures above atmospheric. This steam has the highest energy content. Dry steam fields are less common than wet steam fields, but about half of the geothermal electric energy produced worldwide is generated in the six vapour dominated fields at Lardarello and Monte Amiata in Italy; The Geysers (California) in the USA; Matsukawa in Japan; and Kamojang and Darajat in Indonesia[12].

Geopressurized resources bearing compared to hydrothermal reservoirs, hot water mixed with gas, which is mainly methane. This is the result of tectonic movements of parts of the formation. The geo-pressurized reservoirs consist of permeable sedimentary rocks, which are incorporated into impermeable strata. The reservoir contains pressurized water that remained trapped at the moment of deposition of the sediments.

Hot-dry-Rock (HDR) resources are defined as heat stored in rocks within about 10 km of the surface from which energy cannot be economically extracted by natural hot water or steam. These hot rocks have few pore space, or fractures, and therefore, contain little water and little or no interconnected permeability.

Molten rock and magma resources are found next to tectonic active zones and are found in depths from 3 to 10km under the surface. To produce such reservoirs, high technology is needed[13].

2.2.2 Definition by enthalpy

Geothermal fluid acts as carrier for heat from sub-surface to the surface. The enthalpy is the heat content of these fluids, which is proportional to the temperature of the fluid what, equals more or less the value of energy output. It can be differentiated between low -, intermediate - and high enthalpy resources. There are a number of different classifications from different authors (see Table 2).[14]

[12] Cp. Clauser et al (2006), p. 70
[13] Cp. Kaltschmitt et al (1999), p. 46f
[14] Source: IGA Homepage (access 08.02.11)

Table 2: Classification of geothermal resources by the definition of enthalpy (all values provided in °C)[15]

	(a)	(b)	(c)	(d)	(e)
Low enthalpy resources	< 90	<125	<100	≤150	≤190
Intermediate enthalpy resources	90-150	125-225	100-200	-	-
High enthalpy resources	>150	>225	>200	>150	>190

Source: (a) Muffler and Cataldi (1978).

(b) Hochstein (1990).

(c) Benderitter and Cormy (1990).

(d) Nicholson (1993).

(e) Axelsson and Gunnlaugsson (2000)

In this thesis, it will be only distinguished between low and high enthalpy, therefore the classification (d) from Nicolson (1993) will be used.

2.3 Types of geothermal energy production systems

The difference between deep and surface-near geothermal reservoirs is next to the depth, the higher temperature level. The utilization of the energy depends mainly on geological, hydro-geological and geophysical terms in the subsurface and can be produce with different techniques[16].

The following points are going to describe the different opportunities to produce geothermal energy. It will be distinguished between deep borehole heat exchanger, HDR technique and hydrothermal energy techniques.

2.3.1 Deep borehole heat exchanger

Deep borehole heat exchangers are deep wells in which are pipe bundles installed. Through the outer pipes of the bundle gets liquid or gaseous heat transfer medium pumped down what gets heated up down hole and is than again pumped upwards through the inner insulated pipes of the bundle to the surface. This technique is mainly used for heat production and can be applied nearly in every well[17].

This technique will not be discussed further in this thesis, as no special geological regions are needed to produce such energy. If this technique is used in deep enough wells, energy can be utilized in every country all around the world without any problems.

2.3.2 Hot Dry Rock

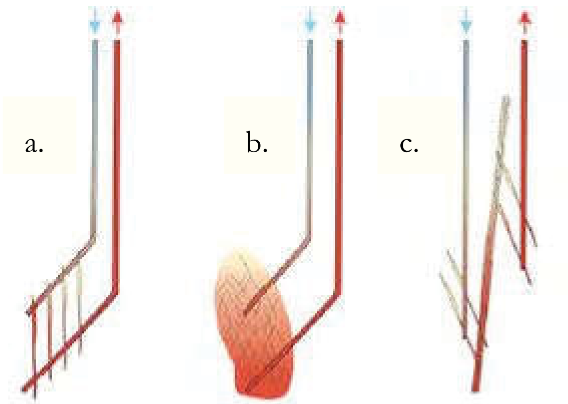
The HDR technique uses the stored heat in the formation. Therefore, the formation is artificially fractured and is then used as heat exchanger. A number of wells are drilled into the rock with a clearance of several hundred meters apart. Water is circulated down the injection wells and through the HDR reservoir. The fluid then returns to the surface

[15] Source: IGA Homepage (access 08.02.11)
[16] Cp. Kaltschmitt et al (1999), p. 47
[17] Cp Werner (2009), p.63

through the production well. This fluid transfers the heat to the surface as steam or hot water. Various concepts for generating different kinds of sub-surface heat exchangers have been proposed and studied.

2.3.3 Hydrothermal energy technique

In this case, wells are drilled in the formation, which is hot water, or steam bearing. These fluids are then produced through the wells (production wells) and the heat is used on the surface via a heat exchanger. The cooled water is pumped down through an injection well into the formation, to maintain the reservoir pressure and because of ecological issues[18].



a. Coinshaped vertical cracks
b. Network of micro-cracks, fissures and fractures
c. Interconnected large-scale fractures and faults

Figure 3: Different heat exchange systems for HDR techniques[19]

2.4 Electric power generation systems

There are three types of geothermal plants used to generate electricity. The type of plant is determined primarily by the nature of the geothermal resource at the site.

2.4.1 Direct steam plant

The so-called direct steam geothermal plant is applied when the geothermal resource produces steam directly from the well. Early geothermal systems made direct use of hot dry steam generated in hot aquifers and erupting from geysers with temperatures typically above 235°C. The steam, after passing through separators is fed to the turbine (see Figure 4). These were the earliest types of plants developed in Italy and in the U.S. Recent direct steam plants in the U.S., at the Geysers in California have been installed in capacities of 55 and 110MW. Unfortunately, steam resources are the rarest of the all geothermal resources and exist in only a few places in the world. Obviously, steam plants would not be applied to low-temperature resources[20].

In most plants, cooling water is circulated between the condenser and a cooling tower to reject this heat to the atmosphere. An alternative is to use so-called "dry coolers" or air cooled condensers, which reject heat directly to the air without the need for cooling water. This design essentially eliminates any consumptive use of water by the plant for cooling.

[18] Cp. Kaltschmitt et al (1999), p. 129
[19] Clauser et al (2006), p. 91
[20] Cp. Kaltschmitt et al (2005), p. 511

Liquid working fluid from the condenser is pumped back to the higher pressure preheater or vaporizer by the feed pump to repeat the cycle. This cooling system is also used and valid for the flash steam plant and the binary plant.

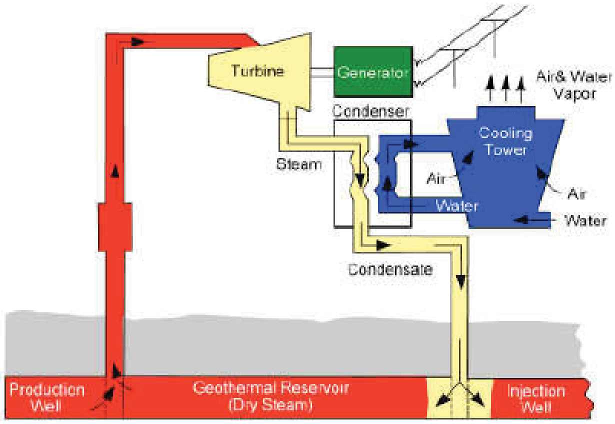


Figure 4: Direct steam plant[21]

2.4.2 Flash steam plant

Flash steam plants are employed in cases where the geothermal resource produces high-temperature hot water or a combination of steam and hot water. Superheated water pumped from the ground at temperatures of 175□C or more can be flashed to steam in a separator or flash tank to drive a turbine directly. The remaining water is directed to disposal (see Figure 5). Depending on the temperature of the resource, it may be possible to use two stages of flash tanks. In this case, the water separated at the first stage tank is directed to a second stage flash tank where more steam is separated. Remaining water from the second stage tank is then directed to disposal. The so-called double flash plant delivers steam at two different pressures to the turbine. Again, this type of plant cannot be applied to low-temperature resources[22].

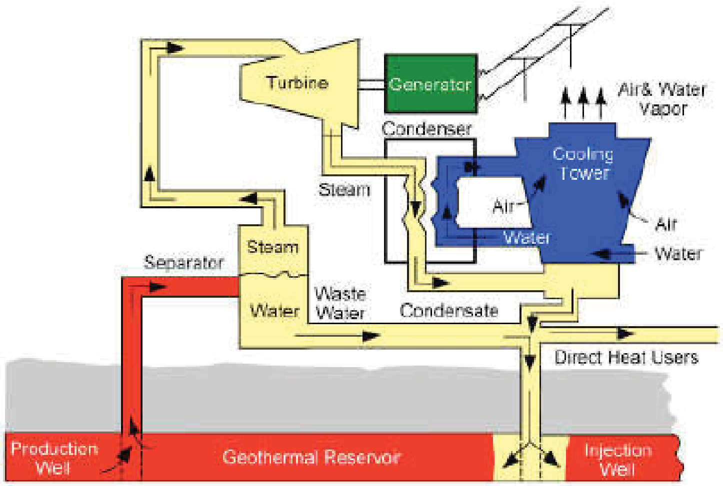


Figure 5: Flash steam plant[23]

[21] Lundv (2007), p. 5
[22] Cp. Kaltschmitt et al (2005), p. 512ff
[23] Lundv (2007), p. 5

2.4.3 Binary plant

The third type of geothermal power plant is called the binary plant. The name derives from the fact that a second fluid in a closed cycle is used to operate the turbine rather than geothermal steam. Geothermal fluid with temperature between 100□-175□C is passed through a heat exchanger called a boiler or vaporizer where the heat in the geothermal fluid is transferred to the working fluid causing it to boil. Past working fluids in low temperature binary plants were chlorofluorocarbon (Freon type) refrigerants. Current machines use hydrocarbons (isobutene, pentane, etc.) of hydro-fluorocarbon type refrigerants with the specific fluid chosen to match the geothermal resource temperature.

The working fluid vapour is passed to the turbine where its energy content is converted to mechanical energy and delivered, through the shaft to the generator. The vapour exits the turbine to the condenser where it is converted back to a liquid.

The binary cycle is the type of plant, which would be used for low temperature geothermal applications. Currently, off-the-shelf binary equipment is available in modules of 200 to 1,000kW[24].

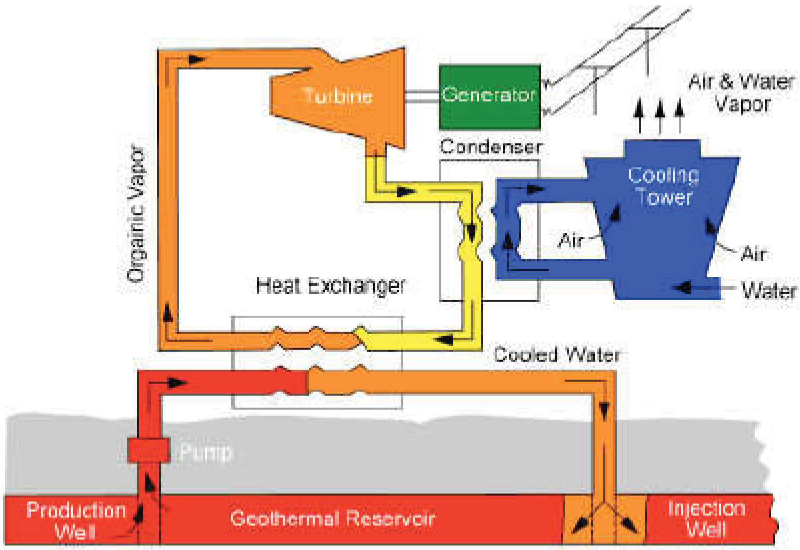


Figure 6: Binary plant[25]

[24] Cp. Kaltschmitt et al (2005), p. 514ff
[25] Lundv (2007), p. 5

3 Development of a geothermal energy assessment tool

In this chapter the theory and basics for an assessment tool which should have the target to evaluate the geothermal potential of different countries based on various key figures, should be given.

At first, the main process of a geothermal energy project with all its stakeholders and all factors, which influence a geothermal project, will be described, to get a better understanding of the key factors that will be the main drivers for the assessment tool. The second part will then describe multiple criteria decision analysis (MCDA) systems with a detail description of the different MCDA methods. With the aid of this knowledge, a method will be chosen what will be used as framework for the assessment tool. This method should work as decision-making tool to be able to identify the geothermal potential of different countries.

3.1 Geothermal Project key factors

General statements about geothermal project processes are difficult, as the range of projects is huge and every project can vary a lot from all others. The problem starts already when it has to be differentiated between electricity and heat generation project, the technologies are totally different. Next to these characteristics projects depend on the location, the power output of the plants, natural conditions and surface requirements

The quality and quantity of the geothermal resources are the necessary requirements for a successful geothermal project. Compared to other renewable energy technologies, have geothermal projects very high preproduction costs due the fact of high exploration costs which are mainly seismic surveys and drilling costs. On the other hand, the operational expenditures (=OPEX) are low. The OPEX varies from project to project through the fact that it depends on factors like size, quality of the geothermal fluids, etc.. However, all these factors are good known and can be determined upfront[26].

In this thesis, only electricity generation projects will be considered, as OMV is only interested in this kind of applications.

[26] Cp GEOFAR (2009), p.9

3.1.1 Phases of a geothermal project

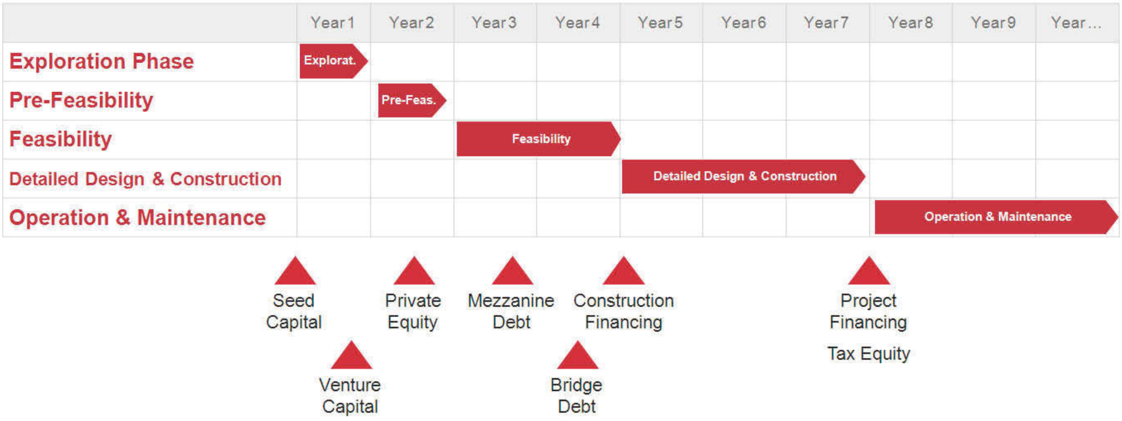


Figure 7: Typical project timeline and financing options[27]

3.1.1.1 Site identification phase

The site identification phase is also called exploration phase (see Figure 7). The main target of this phase is to find interesting geological sites for the geothermal projects. Therefore an evaluation of existing geological and geochemical surveys is conducted. The outcome of this evaluation should be a recommendation for the site selection to apply for exploration concessions.

In addition, an exploration concept has to be developed on the known facts, as this is part of the application proposal for the exploration permit.

Site identification costs range up to US$ 10,000[28].

3.1.1.2 Pre-feasibility phase – surface exploration

As next step, surface exploration has to be done. In most of the time the existing surveys are not enough or too old. To overcome this problem new data has to be gathered. The most important or interesting surveys are following:

- Remote sensing

  Remote sensing provides important coverage, mapping and classification of land cover features, such as vegetation, soil, water and forests by using satellite and digital imagery.

- Geological survey

  For the geological survey, rock samples are taken and geological features are mapped and investigated in detail.

- Geochemical survey

  For the geochemical survey, representative samples are taken from hot and cold fluids, gases and rocks for chemical and isotopic analyses to determine their composition.

- Geophysical survey

  The geophysical survey should locate the up flow zones in depth and determine the lateral extension of the geothermal reservoir.

[27] GEOFAR (2009), p.11
[28] Cp FORSEO (2008), p. 22

- Geo-scientific synthesis

  For the geo-scientific synthesis, geological, hydrological, geochemical and geophysical data are combined in a conceptual model of the geothermal system with the aim to locate sites for promising exploration wells.

Further this phase comprehends, reaching the acceptance of the local authorities and population, receiving all missing permits and to establish a feasibility study which assesses the risks of the project, to develop strategies to overcome these risks

The costs for this phase will sum up to several hundred thousand to one million US$[29].

3.1.1.3 Feasibility phase – exploration drilling

In this phase the productive area within the geothermal field should be determined and next to it, as much information as possible should be gathered from e.g. cores or logs. The results are the main decision tools for a go or no-go decision for the next phases.

Before drilling, the drilling site has to be prepared, the equipment has to be brought on site and safety installations have to be done (blowout-preventer).Usually three exploration wells are drilled in high-enthalpy field and only one exploration well in low-enthalpy fields[30].

The costs depend on the number of drilled wells and conditions governing the location, like the depth to the target formation. Therefore, the drilling cost can vary between US$ 1,500 and US$ 3,000 per drilling meter[31].

3.1.1.4 Resource development phase

This phase is already a part of the detailed design and construction phase (see Figure 7). The field gets developed in the best way. Production and injection wells are drilled and pipelines get installed. In addition, the efficiency of the individual wells can get enhanced by stimulating the formations by hydraulic fracturing.

The costs for the development phase can sum up to several US$ 10 to US$ 100 million, depending on the size of the field and the number of drilled wells[32].

3.1.1.5 Power plant construction phase

The power plant construction phase is the second part of the design and construction phase (see Figure 7). In this phase, a suitable power plant for the kind of resource is constructed. The three leading plant types are single-flash plant followed by dry steam and double flash-plant and account for 90% of the worldwide installed capacity (see 2.4) [33].

The costs for these power plants vary depending on the power plant size. A small power plant (<5MW) costs between US$ 1,100 and US$ 1,400 per installed KW capacity. A medium power plant (5-30MW) costs between US$ 850 and US$ 1,200 per installed KW capacity. A big power plant (>30MW) costs between US$ 750 and US$ 1,100 per installed kW capacity[34].

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[29] Cp FORSEO (2008), p. 23ff

[30] Cp FORSEO (2008), p. 28ff

[31] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2007), p. 20

[32] Cp FORSEO (2008), p. 33

[33] Cp FORSEO (2008), p. 34ff

[34] The World Bank Group: Geothermal Energy

3.1.1.6 Operation and maintenance phase

The most plants are remotely controlled what has many advantages like fast control or more reliable. Via the remote control, all relevant operation parameters are monitored and indicate upcoming maintenance.

Make-up wells have to be drilled in this phase because of the production decline in the individual wells. The costs of these wells have to be considered as well.

The cost of the operation and maintenance phase vary strongly because of the different types of power plants, the quality of the geothermal fluids, the decline rate of the production wells, etc.[35]. But as a rough estimate, a small power plant (<5MW) costs between US cent 0.8 and US cent 1.4 per kWh. A medium power plant (5-30MW) costs between US cent 0.6 and US cent 0.8 per kWh. A big power plant (>30MW) costs between US cent 0.4 and US cent 0.7 per kWh[36].

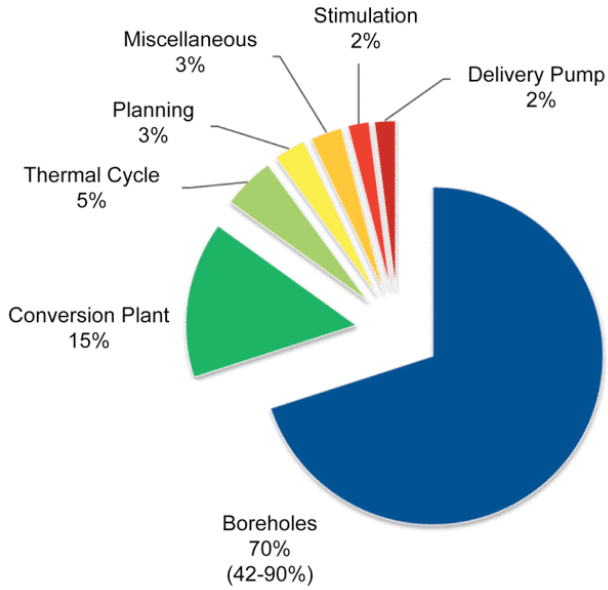

Figure 8: Overview about the costs of an average geothermal energy production project in Germany[37]

3.1.2 Project key factors

There are four major groups of key figures:

- Geological factors
- Legal factors
- Economic factors
- Area specific factors

All four groups of factors can be crucial for a successful geothermal project.

3.1.2.1 Geological key factors

The overall geological key factor is the amount of available resources in the area, what is the heat stored in the formation and how much of it can be produced. If there is not enough heat or energy stored to produce it in a commercial way, the area is not interesting

[35] Cp FORSEO (2008), p. 49ff
[36] The World Bank Group: Geothermal Energy
[37] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2007), p. 21

for a geothermal project. Nevertheless, the resources are also driven or influenced by other factors. As the resources only give an answer about how much energy is stored in the area initially, it gives either no information about the time span to produce these resources in an economical way nor is the heat even producible due the different geological characteristics.

Reservoir depth and formation

The depth is next to the amount of resources the key driver of a geothermal project. The depth of a well has a huge impact on the drilling costs, as with increasing depth the cost increase exponentially because of a more powerful drilling rig is required, the well will take longer to drill, a bigger drilling pad is needed, etc.. This higher costs influence the profitability of the whole project. Next to the increasing costs the risk is also rising, what can jeopardize the profitability of a project in case that the drilling phase is not successful.

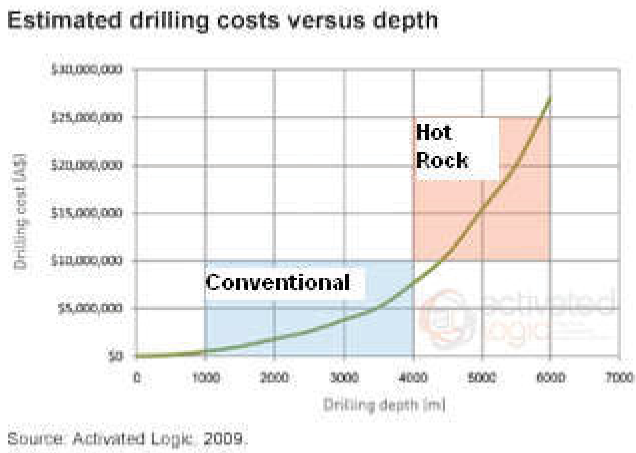

Figure 9: Drilling costs vs. depth[38]

Formation properties

The influence of the lithology and the formation depends on the type of the energy production system. HDR and hydrothermal reservoirs have different requirements on the formation as also the production system framework technology differs a lot.

HDR reservoirs get fractured and fluid is pumped through the fractures. The formation is more or less used as a heat exchanger. As fracturing is an important step in this production system, the lithology has a big influence on the success of the fracturing. The lithology and formation are the main drivers on the fracture gradient of the formation. High fracture gradients bear high risk of failures. This fracturing process involves also other risks, fracturing can cause earthquakes. This can be an issue if the fracture is done in a high-populated area or near a city. To lower the risk there must be a high acceptance in the population. Another point is the heat conductivity of the formation. As the formation is cooled all the time by pumping cool fluids through the fracture, the heat flow from the surrounding formation has to be high enough to provide enough energy to heat the fluid.

Hydrothermal reservoirs are influenced by different formation properties as HDR reservoirs. The main drivers for this kind of reservoir are the lithology and type of matrix. It has to be mentioned that the lithology and matrix are more or less depending on each other. It has to be differentiated between:

[38] Source: Activatedlogic Homepage (11.02.11)

- Porous matrix
- Fractured/jointed matrix
- Karst matrix

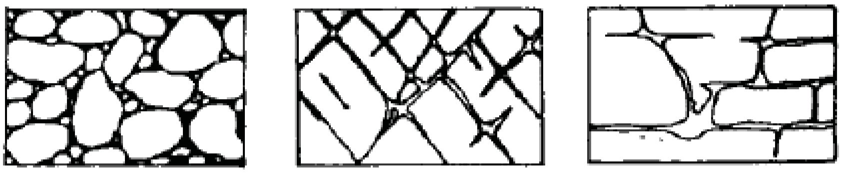

Figure 10: Porous, fractured/jointed and karst matrix (from left to the right)[39]

The porous matrix is a primary porosity (=porosity preserved from deposition through lithification) while fractured/jointed and karst matrix have a secondary porosity (=porosity created through alteration of rock, commonly by processes such as dolomitization, dissolution and fracturing). The secondary porosity shows normally a higher permeability what means that the productivity of the geothermal fluid is higher too and therefore the more favourable matrix for a hydrothermal project.[40] The lithology is related to the type of matrix as usually dolomites and chalks have a karst matrix, which is the most favourable matrix. Plutonites with a fractured/jointed matrix and the sandstone with a porous matrix follow these lithologies. The worst lithology for a hydrothermal project is schist. Next to the lithology and matrix another question is what kind of recharge area is the reservoir The recharge area just determines if the reservoir is open or closed and therefore if the reservoir gets steadily refilled by fluids from other formations. As last point, influences the type of brine the efficiency the hydrothermal production system. A high amount of total dissolved solids implies higher risk of deposits too.

3.1.2.2 Legal key factors

To achieve or to conduct successfully a geothermal project a punch of different permits and concessions are needed in advance. At first, permits to explore and exploit the geothermal resources are necessary and further, permits to build geothermal power plants are essential. Next to these key permits, all additional requirements under public law have to be met. The main requirements and permits are:

- Zoning and land use security
- Water -, mineral – and mining rights
- Environmental reviews
- Well constructions permits
- Drill exploration and production permit
- Building permit
- Power purchase agreement

In addition, should all possible long-term questions be solved, like environmental impact assessments, as these legal conditions have to be met before a project can be conducted. It is also important to check the regulatory framework regarding taxes and royalties.

[39] Cp. Kaltschmitt et al (1999), p. 42
[40] Cp. Kaltschmitt et al (1999), p. 42

Another legal key factor is the power purchase agreement. It is a legal contract between the electricity producer and the purchaser of the energy. It plays a big role in the price finding of the energy, as this determines the profitability of the project[41].

3.1.2.3 Economical key factors

The main drivers of the economical key factors are costs and risks on the one hand and financing, energy prices and subsidies on the other hand. Every phase contains a range of risks, which normally decreases with the time as the uncertainties are getting smaller too (see Figure 11). However, every risk is accompanied to a portion of costs and to control or keep these costs with its implied risk in an appropriate range is the key to a successful project.

The financing also depends on risk and is usually hard to get in the early phases of a project. The financing is a tool to provide money and to cover the expenses for the costs and capital expenditures. The financing solution also changes with time, as not every phase is appropriate for every financing type (see Figure 7). The selling price of the produced energy is the only real source of income and depends on the life span of the project. Subsidies can also help to achieve a profitable geothermal project. Subsides can reduce the capital expenditures dramatically.

Costs and risks

Normally the main investment costs for hydrothermal geothermal projects are:

- 15% construction of power plant
- 15% miscellaneous
- 70% drilling costs[42]

The individual costs can vary as they are depending on local conditions, work procedures and global market factors. Next to the investment cost also production costs have to be considered. Figure 12 shows that the costs are in a range of 0.045 – 0.091€/kWh, what is comparable to other renewable energy sources[43].

The costs for HDR project are mainly depending on the drilling costs, which are driven by the depth of the wells. A detailed cost distribution cannot be done, as there are not enough projects carried out until now but the technology is on a good way to become economical, especially by focusing on learning curves in the future and also up-scaling effects[44].

The biggest risk is involved in the exploration and drilling phase. While in the exploration phase the expenditures are low, it changes in the drilling phase where the risk and the expenditures are very high. It can be distinguished between risks:

- Going into the well (drill string, drilling tools, mud, casing, cement, etc.)
- Coming from the well (geological risks, drilling behaviour, influx, lost circulation, etc.)[45]

[41] Cp FORSEO (2008), p. 20
[42] Cp. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2007), p. 21
[43] Cp. Clauser et al (2006), p. 96
[44] Cp. Clauser et al (2006), p. 97ff
[45] Cp FORSEO (2008), p. 31ff

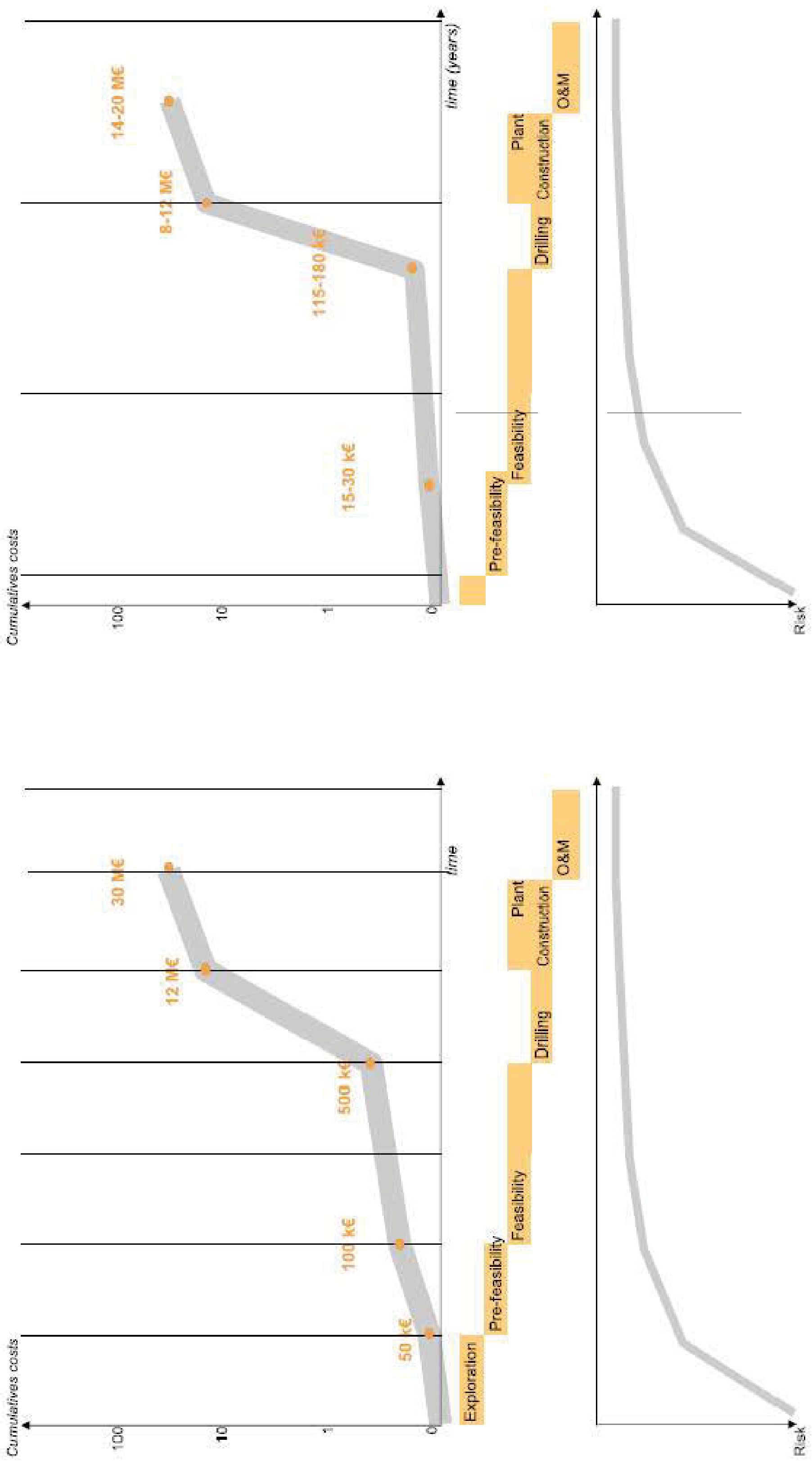

Figure 11: Cumulative costs vs. time and cumulative risk vs. time of two different geothermal projects (left: hydrothermal project with one well to 2750m and a 4MW power plant, right: hydrothermal project with a doublet to 2000m for district heating)[46]

[46] Cp GEOFAR (2009), p.10

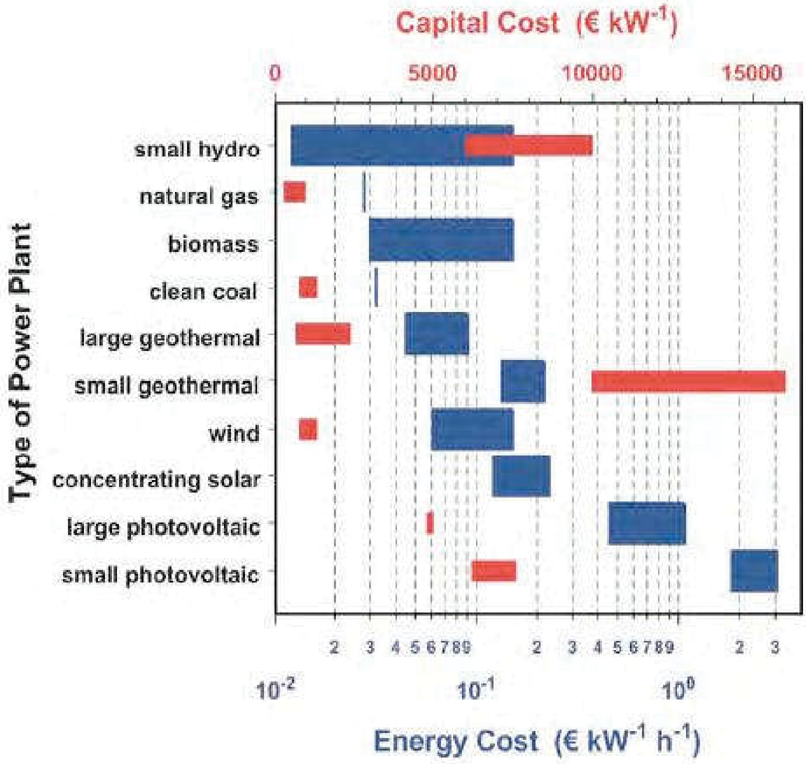

Figure 12: Capital costs and energy costs of different energy sources[47].

As going-into-the-well-risk can be controlled to a certain degree, depends the coming-from-the-well mainly on the geology and only a little prevention can be done upfront to control it. The costs, which are associated with these risks, can quickly develop from a few ten thousand to several million US$[48].

Financing, energy prices and subsidies

The financing depends mainly on the local energy market, public and political support. Geothermal project imply huge risks until the resources are proven. All the risks exacerbate the financing process. In average, it takes around 5-7 years until a geothermal power plant can go on stream and profits are made. As the risk changes with time, also the financing types change (see Figure 7). The first phases are the riskiest, so it is normally financed with venture capital or private equity and subsidies. When the drilling phase is over and the resources are known, it is easier to find investors. [49]

The energy prices are negotiated at the power purchase agreement and stay more or less constant over longer periods, so that long-term calculations can be done.

Today nearly, every country has a type of subsidy for renewable energies and most of them have even programs for geothermal energy. All other countries, which have not invented any programs until now already, think about these steps. In the next future, the subsidy landscape for geothermal project will change in a positive way, especially as a lot of project depending in the early stages on the money from the countries to finance the risky part of the project. This positive change will make a lot of project profitable in the future.

[47] Cp. Clauser et al (2006), p. 95
[48] Cp FORSEO (2008), p. 32
[49] Cp FORSEO (2008), p. 44

3.1.2.4 Area specific key figures

As this thesis should provide an overview about geothermal potentials of whole countries, it is necessary to split the country up in the regions, which can be considered as geothermal potential zones. Every region has different circumstances, which will influence the project.

Key factors therefore are the population density in the area and the vicinity of cities. These factors drive the economics of projects like for example, if the geothermal zone is in a high dense population area or near a city, the waste heat can be sold as district heat. Furthermore, the probability of a developed infrastructure in this area is higher too, what makes it easier to develop the field and to feed in the electricity in an already established power network. Another factor is the chance of natural disasters, which can disrupt the production or even damage the asset. This factor has also to be considered as many geothermal potential zones are near tectonic plate boundaries.

3.2 Multiple criteria decision analysis (MCDA)

„Decisions are often complex, multi-faceted, and involve many different stakeholders with different priorities or objectives - presenting exactly the type of problem that behavioral decision research shows humans are typically quite bad at solving, unaided. Most people, when confronted with such a problem will attempt to use intuitive or heuristic approaches to simplify complexity until the problem seems more manageable. In the process, important information may be lost, opposing points of view may be discarded, elements of uncertainty may be ignored - in short, there are many reasons to expect that, on their own, individuals (either lay or expert) will often experience difficulty making informed, thoughtful choices about complex issues involving uncertainties and value tradeoffs“[50].

MCDA is also called Multi Criteria Decision Making and is the general field of study, which includes decision-making in the presence of two or more conflicting objectives and involving two or more attributes. The general objective of MCDA is to assist a decision maker to choose the best alternative from a range of alternatives in an environment of conflicting and competing criteria[51].

To evaluate the geothermal potential of countries many different criteria are involved which influence the overall "problem". Out of these criteria, a decision should be then made about the geothermal potential of a country. Therefore, the MCDA is definitely the right tool as it helps to find out of multiple criteria a way to make a decision, which is in this case the geothermal potential of a country.

The basic structure and organization of MCDA framework follows mainly the same steps. In the first step the problem has to be defined to be sure what even is the goal and target of the whole process, it is base of the whole structure, if somebody makes a mistake in the definition also the result will not show the right result. As next step constraints can get defined, but normally first the evaluation criteria are defined and therefore the boundaries will be described. These criteria are arranged in a decision matrix and the decision rules will be applied to receive a result. With this result, a sensitivity analysis will be conducted to assess the results to check that the decision-makers preference matches with the results or the evaluation criteria assess the whole spectrum. If the sensitivity analysis is satisfying, a

[50] Cp. Linkov et al (2004), p. 2
[51] Source: Referenceforbusiness Homepage (Access: 14.02.11)

recommendation can be done[52]. An overview of the MCDA framework is given in Figure 13.

Several methods have been developed to deal with MCDA problems. To find out which methods is the best tool to answer the problem, the methods will be discussed in detail in the following pages.

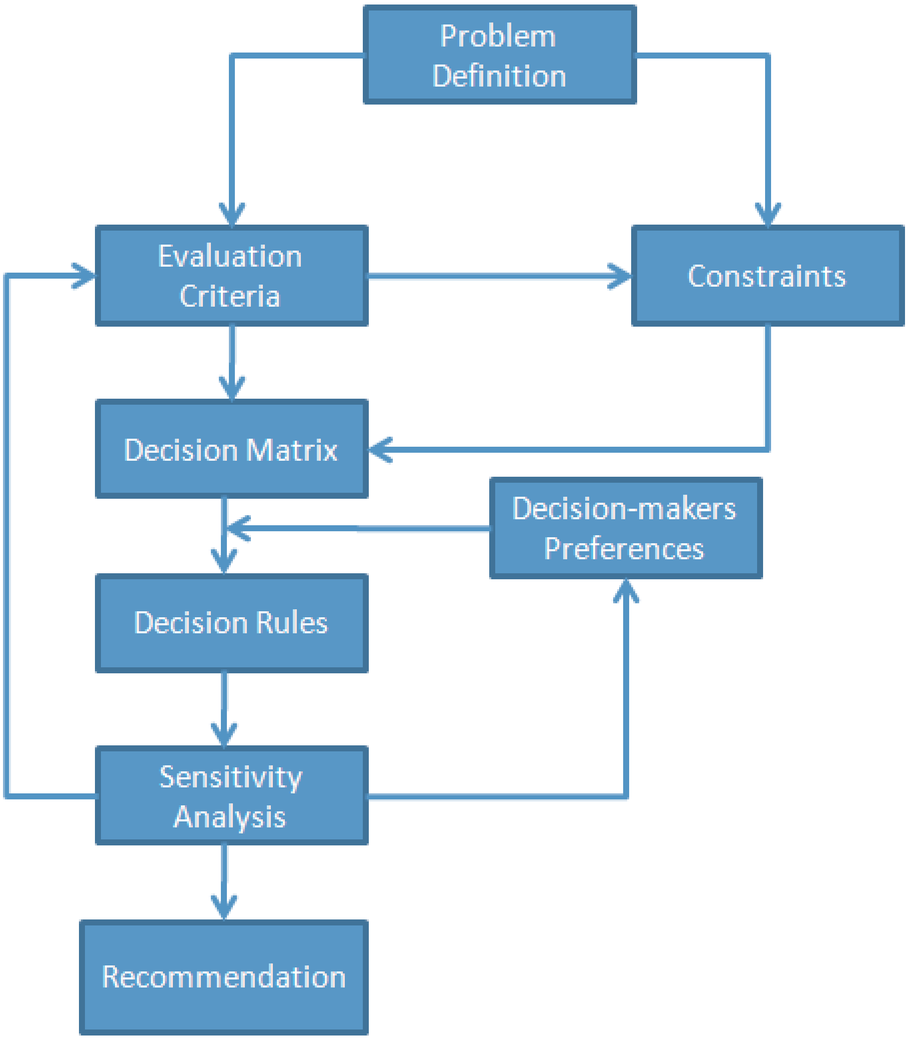

Figure 13: MCDA framework[53]

3.2.1 MCDA methods

MCDA methods differ, in the way the idea of multiple criteria is considered, the application and computation of weights, the mathematical algorithm utilized, the model to describe the system of preferences of the individual facing decision-making, the level of uncertainty embedded in the data set and the ability for stakeholders to participate in the process. The MCDA technique selected will typically need to:

[52] Cp. J. Bortz (2002), p. 346

[53] Source: Geoinformatics Homepage (Access: 14.02.11)

- Deal with complex situations or criteria, which consider different scales and aspects like geographical scales, micro-macro-links, social or technical issues and type of data with its uncertainties.
- Involve more than one decision maker, e.g. stakeholder participation, actors, communication, and transparency
- Inform stakeholders in order to increase their knowledge and change their opinion and behaviour

A typical flowchart of MCDA methods is presented in Figure 13 or can get summarized in following eight steps:

1. Establish the decision context. What are the aims of the MCDA and who are the decision makers and other key player?
2. Identify the options.
3. Identify the objectives and criteria that reflect the value associated with the consequences of each option.
4. Describe the expected performance of each option against the criteria. (If the analysis is to include steps 5 and 6, also "score" the option, i.e. assess the value associated with the consequences of each option).
5. Weighting: Assign weights for each of the criteria to reflect their relative importance to the decision.
6. Combine the weights and scores for each of the options to derive and overall value.
7. Examine the results.
8. Conduct a sensitivity analysis of the results to changes in scores and weight[54].

3.2.1.1 Optimization methods

The optimization methods synthesis assessments of the performance of alternatives against individual criteria, together with inter-criteria information reflecting the relative importance of the different criteria, to give an overall evaluation of each alternative indicative of the decision makers preference.

3.2.1.2 Goal aspiration methods

In the goal, aspiration method the decision maker specifies some goals, which have to be achieved. If they are achieved, the decision maker is assumed to be satisfied; if not the method seeks to get as "close as possible" to the goals.

3.2.1.3 Outranking methods

The outranking methods attempt pair wise or global comparison among alternatives. An "alternative a" is said to outrank another "alternative b" if, taking into account all the available information regarding the problem and the decision maker's preferences, there is a strong enough argument to support "alternative a" conclusion that "alternative a" is at least as good as "alternative b" and no strong argument to the contrary[55].

3.2.2 Method description

Optimization methods are some of the more widely applied MCDA methods and have benefited from the long-standing interests of psychologists, engineers and management scientists who have been nurtured through a continuing awareness of behavioral and social

[54] Cp. Department for Communities and Local Government (2009), p. 31
[55] Cp. Linkov et al (2004), p. 3ff

issues as well as the underlying theory. The methods are able to deal with complex issues, can accommodate the involvement of multiple stakeholders and allow processes to be facilitative and transparent.

Outranking models are appropriate when criteria metrics are not easily aggregated, measurement scales vary over wide ranges, and units are incommensurate or incomparable. Like most MCDA methods, outranking models are partially compensatory[56].

As these two methods fit best to the requirements of the needed MCDA system, both methods will be analyzed in more detail, to be able to find the right technique for the assessment tool.

3.2.2.1 Optimization methods

The optimization methods imply a lot of different techniques, but in this thesis only the relevant techniques will be discussed as the range of techniques will go beyond the scope.

Multi attribute utility theory (MAUT)

The Multi-attribute Utility Theory (MAUT) is very common approach. The criteria are weighted what reflects the relative importance of the criteria MAUT is based on the usage of utility functions. Utility functions can be applied to transform the raw performance values of the alternatives against diverse criteria, both factual and judgmental, to a common, dimensionless scale. In the practice, the intervals 0-1 or 0-100 are used for this purpose. Utility functions play another very important role: they convert the raw performance values so that a more preferred performance obtains a higher utility value. A good example is a criterion reflecting the goal of cost minimization. The associated utility function must result in higher utility values for lower cost values. [57, 58].

The MAUT seems to be the perfect tool to assess the different criteria, as every criterion can be evaluated with the aid of its utility. That seems to be the best and easiest way to evaluate the score of every criterion, especially as the rang of criteria will be big. Experts can define the utilities.

Simple multi attribut rating technique (SMART)

The MAUT has different techniques and the simplest form is SMART. The ranking value x_j of alternative a_j is obtained simply as the weighted algebraic mean of the utility values associated with it, i.e.

$$x_j = \sum_{i=1}^{m} w_i a_{ij} / \sum_{i=1}^{m} w_i, \quad j = 1, \ldots, n.$$

Equation 1: SMART calculation equation[59]

Therefore, the criteria are ranked in order of their importance, followed by assigning points to the least important criterion. The next step is to assign more points to the next-least-important criterion and so on. This procedure should reflect the importance of the criteria. The final step is to normalizing the sum of the points to one value to obtain the final weights. The comparison of attributes makes no sense if it does not reflect the range of the utility values of the alternatives as well. The method SMARTS (Simple multi attribute rating

[56] Cp. Eisenführ (2003), p 111ff
[57] Cp. Linkov et al (2004), p. 7ff
[58] Schäfer, R., p. 1ff
[59] Fülöp, J., p. 6

technique using swings) compares the importance of the criteria and considers the amplitude of the utility values[60].

SMART is an easy technique to rank criteria in a simple way and will be used because of these properties.

SWING

The swing weight method requires specifying hypothetical changes (swings) in the level of performance against different objectives and then obtaining judgments of the relative preferences for obtaining those swings, typically using a 0 to 100 scale. For example, if the most desirable swing is given a swing weight of 100 points, how many points would be assigned to obtaining the next most desirable swing? Although the swing weight method is not necessarily the most accurate method for eliciting weights, it provides much more reliable results than assigning weights based on abstract "importance" of each criterion. The strength of the swing weight method is that most people find it relatively quick and easy[61].

$$w_i = \frac{r_i}{\sum_{k=1,m} r_i} \quad , i = 1, 2, \ldots, m,$$

$$\text{where } 0 \le w_i \le 1 \text{ and } \sum_i w_i = 1$$

Equation 2: SWING calculation equation[62]

3.2.2.2 Outranking methods

The Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process is a quantitative comparison method used to select the optimal alternative by comparing project alternatives based on their relative performance on the criteria of interest. After accounting for the decision-makers relative preference or weighting of these criteria. Similar to MAUT, AHP completely aggregates various facets of the decision problem into a single objective function. The goal is to select the alternative that results in the greatest value of the objective function. Like MAUT, AHP is a compensatory optimization approach. However, AHP uses a quantitative comparison method that is based on pair-wise comparisons of decision criteria, rather than utility and weighting functions. Evaluators' express the intensity of a preference for one criterion versus another.

All individual criteria must be paired against all others and the results compiled in matrix form. If criterion A is strongly more important compared to criterion B, i.e. a value of 5, then criterion B has a value of 1/5 compared to criterion A. Thus for each comparative score provided, the reciprocal score is awarded to the opposite relationship. The priority vector is calculated for each criterion using the geometric mean of each row in the matrix divided by the sum of the geometric means of all the criteria. The AHP technique thus relies on the supposition that humans are more capable of making relative judgments than absolute judgments[63].

[60] Fülöp, J., p. 6
[61] Cp. Wang,J. (2009), p. 2271
[62] Cp. Jia, J. (1993), p. 6
[63] T´kindt (2002), p 305

3.2.2.3 Method decision

The optimization methods with the SWING meet exactly the requirements of the needed properties to develop a functional assessment tool to evaluate the geothermal potential of a country. The future assessment tool will also involve different criteria that have different importance and have to be weighted, with the target to evaluate different alternatives. It is a very easy and uncomplicated system, which is easy to understand. Research has demonstrated that simplified MAUT decision analysis methods are robust and replicate decisions made from more complex MAUT analysis with a high degree of confidence[64]. This will be also the case for this assessment tool.

3.3 Evaluation Process

After the establishment of the MCDA system, the system has to be tested on its plausibility.

3.3.1 Delphi method

As first step, the weighting process has to be reassessed. The weighting will be conducted with the aid of expert interviews. Therefore, a deviation between the weightings can appear. To overcome this variance, the Delphi method will be used.

3.3.1.1 Delphi methodology

The Delphi method is based on structural surveys and makes use of the intuitive available information of the participants, who are mainly experts. Therefore, it delivers qualitative as well as quantitative results and has beneath its explorative, predictive even normative elements. There is not the one Delphi methodology but the applications are diverse. There is agreement that Delphi is an expert survey in two or more rounds in which in the second and later rounds of the survey, the results of the previous round are given as feedback. Therefore, the experts answer from the second round on under the influence of their colleagues opinions. Thus, the Delphi method is a relatively strongly structured group communication process, in which matters, on which naturally unsure and incomplete knowledge is available, are judged upon by experts. It is believed that during this process the range of the selected criteria will decrease and the group will converge towards the "correct" criteria. Finally, the process is stopped after a pre-defined stop criteria[65].

3.3.2 Sensitivity analysis

The last check to assess the MCDA system is a sensitivity analysis. This analysis should show how stable the MCDA system is when parameters are changed and what are the influences on the results.

3.3.2.1 Sensitivity analysis methodology

The sensitivity analysis is used to determine how different values of an independent variable will affect a particular dependent variable under a given set of assumptions. This technique is used within specific boundaries that will depend on one or more input variables. Sensitivity analysis is a way to predict the outcome of a decision if a situation turns out to be different compared to the key predictions.

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64 Cp. J. Bortz (2002), p. 357

65 Cp. Wang, J. (2009), p. 2270

Sensitivity analysis is very useful when attempting to determine the impact the actual outcome of a particular variable will have if it differs from what was previously assumed. By creating a given set of scenarios, the analyst can determine how changes in one variable will affect the target variable[66].

3.4 OMV Portfolio countries

This chapter should give an overview about the OMV portfolio. Every country will get described by the mean of the OMV activities in the country and also a few key data will be given regarding the political situation and the overall geology which also includes the geothermal potential zones. This step should give a rough overview about the whole portfolio to get a better understanding and furthermore that everybody has the chance to make him/her-self a picture about the general conditions in the countries.

Based on this analysis a pre-screening was accomplished.

- **Australia**

Australia is a highly developed, stable democracy with a federal-state system. Australia's economy is dominated by its services sector, yet it is the agricultural and mining sectors that account for the bulk of Australia's exports.

Australia has an alert system for possible terrorist attacks. The threat levels range from “low” to “high”. The level nowadays is low.

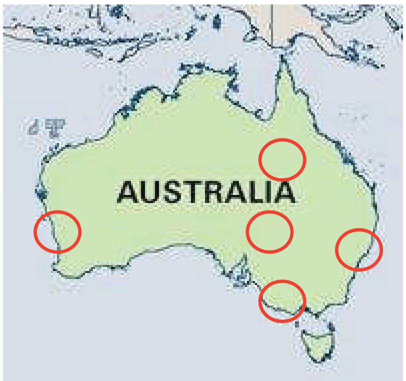

Figure 14: Australia map with OMV E&P licences (dark blue) and the geothermal potential areas (red circles)[67]

Since 1998 is OMV active in Australia. It acquired 1999 Cultus Petroleum, which has a significant portfolio in Australia and New Zealand. The exploration phase is mainly concentrated on the Carnarvon Basin on the North West Shelf offshore of the western coast of Australia. OMV holds around 40,000km^2 of mostly deep-water exploration licences. 2008 a 7,840km^2 seismic survey was done in the Carnarvon Basin and an appraisal well was drilled in the Browse Basin. 2010 a 4,000km^2 3D seismic survey was conducted what should follow 2011 and 2012 drilling activities. OMV is operator of the licences.

Australia has a huge hot rock and hydrothermal resources potential. Extensive radiogenic basement at modest depths are the heat source what results in many high enthalpy resources. 29 different companies have awarded 187,000km2 in Australia split in 204 licenc-

[66] Cp. Staber, S. (2010)

[67] Source: OMV Homepage (Access 14.02.11)

es. Around 80% of these permits are located in South Australia, but there also promising prospects in New South Wales, Victoria, Queensland and Western Australia[68].

- **Austria**

Austria is a highly developed, stable democracy with a modern economy. It has a well-developed social market economy with a high standard of living and close ties to other EU economies.

Austria remains largely free of terrorist incidents and has a very high safety standard.

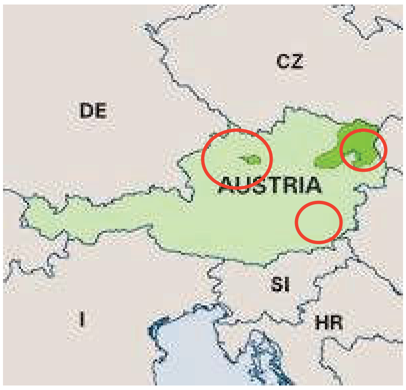

Figure 15: Austria map with OMV E&P licences (dark green) and the geothermal potential areas (red circles)[69]

Austria is the home country of OMV where also the headquarter is based. OMV is over 50 years active in exploration and production in this country. OMV is the main player in the oil and gas industry in Austria and is operator of the licences.

Austria is mainly focused on thermal water exploitation, but also has two small binary plants. Geological interesting zones with higher geothermal gradients can be found in the Vienna basin, the Styria basin and in the Molasse basin in Upper Austria. All the resources are considered as hydrothermal low enthalpy resources[70].

- **Egypt**

Egypt is a republic with a developing economy.

The south-western desert region, close to the Sudanese border should be avoided. In addition, the Egyptian-Gaza border, which has been re-opened on a permanent basis since June 2010 after being closed for three years, is declared as high-risk zone. Crowded tourist areas have been the target of terrorist activities over the last years. There have been instances of instability and public disorder in some other areas of Egypt, most notably in the Nile Valley governorates of Assiut and Sohag, located between Cairo and Luxor. These governorates, along with the adjacent governorates of Minya and Qena, have been areas of extremist activity in the past.

[68] Cp. Goldstein B. et al (2008)
[69] Source: OMV Homepage (Access 14.02.11)
[70] Source: Regioenergy Homepage (Access 14.02.11)

Figure 16: Egypt map with OMV E&P licences (dark blue) and the geothermal potential areas (red circles)[71]

In January 2011 the Egyptian population started a revolution against the regime which is still ongoing and the therefore the safety standard is decreased too.

OMV is since 2006 active in Egypt. It holds offshore licences for the Obaiyed block and runs there exploration. OMV is highly interested to enlarge their upstream business in this region in the near future what makes Egypt to one of the North African core regions for OMV. OMV is operator of the licences.

Egypt's geothermal potential is mainly located around the costal parts of the Gulf of Suez and in few parts of the western desert. The geothermal activity is limited to low enthalpy resources, which are recognized as small hot springs. Their existence is driven by tectonic or volcanic heating associated with the opening of the Red Sea rift[72].

As Egypt is rich on oil and gas resources the chance of an increasing demand for alternative energy in the country is questionable, therefore the chance to enforce geothermal energy in an economical way in the next decade is very low.

- **Faroe Islands**

The Faroe Islands are a constituent country of the Kingdom of Denmark, but they are not part of the European Union.

Faroe Islands remain free of terrorist incidents and has a very high safety standard.

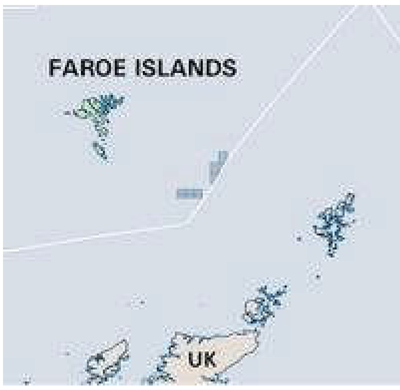

Figure 17: Faroe Islands map with OMV E&P licences (dark blue)[73]

[71] Source: OMV Homepage (Access 14.02.11)
[72] Cp. Lashin A. et al (2010), p. 1
[73] Source: OMV Homepage (Access 14.02.11)

Since 2005 OMV is active in the Froe Islands and is participating in two offshore licences. OMV is not the operator of these licences.

The origin of the Faroe Islands is volcanic. The presence of hydrocarbons is very likely[74]. No information about geothermal potential is stated.

- **Iraq**

Iraq faces many challenges. Those challenges include overcoming three decades of war and government mismanagement that stunted Iraq's economy; sectarian and ethnic tensions that have slowed progress toward national reconciliation; and on-going, albeit decreasing, criminal and terrorist violence. Iraq's economy is dominated by the oil sector, which currently provides about 90% of foreign exchange earnings. Iraq is seeking to pass and implement laws to strengthen the economy, including a hydrocarbon law that encourages development of the oil and gas sector and a revenue sharing law that equitably divides oil and gas revenues among the central government, the provinces, and the Kurdistan Regional Government implementing structural reforms, such as bank restructuring and private sector development, while simultaneously reducing corruption, will be the key to Iraq's economic growth.

The situation in Iraq has to be considered as highly dangerous. In the south part of Iraq, terrorist acts can appear on a daily order, the region can be considered as civil war region. In the north parts of Iraq, the safety standard is higher but still attention has to be paid on a daily basis. Terror attacks can also happen in these parts.

Figure 18: Iraq map with OMV E&P licences (dark green)[75]

OMV operates since 2007 in Kurdistan in the northern parts of Iraq. OMV holds two exploration blocks, Mala Omar and Shorish and owns 10% on the Pearl Petroleum Company Limited. OMV was running a 2D survey for its two blocks and started 2009 with exploration drilling.

Iraq has big oil and gas reserves, but no information about geothermal potential. Regarding the rich oil and gas resources in the country, it is questionable if a renewable energy has a change to enforce in an economical way in the next decade.

- **Ireland**

Ireland is a highly developed democracy with a modern economy.

Ireland remains largely free of terrorist incidents.

[74] Source: Visitfaroeislands Homepage (Access 12.02.11)
[75] Source: OMV Homepage (Access 14.02.11)

Figure 19: Ireland map with OMV E&P licences (dark blue)[76]

Since 2001 OMV is active in Ireland and hold licences on deep water, high pressure and high temperature prospects. Ireland is one of the core regions in the North Sea portfolio of the OMV. The OMV North Sea portfolio includes all offshore licences in the North Sea and the Atlantic.

Ireland has a large low temperature potential between 50 – 100C in parts of Ireland's subsurface, but it is unlikely that it will ever generate electricity from geothermal energy[77].

- **Kazakhstan**

Kazakhstan is a constitutional republic with an authoritarian system and a market economy. Kazakhstan's monetary policy has been largely well managed. Oil and gas is the leading economic sector.

Kazakhstan is comparatively safer than other countries in Central Asia, supporters of extremist groups such as the Islamic Jihad Union, the Islamic Movement of Uzbekistan, al-Qaeda, and the Eastern Turkistan Islamic Movement remain active across Central Asia and therefore also in Kazakhstan.

Figure 20: Kazakhstan map with OMV E&P licences (dark green) and the geothermal potential areas (red circles)[78]

2004 OMV acquired Petrom, which held exploration, and production licences in Kazkhstan. OMV produces oil and gas from the fields: Turkmenoi, Aktas, Tasbulat und Komsomolskoe. In 2009 OMV acquired a fifth licence, the Kultuk field which was explored over the last year and the development of the field will start 2012.

[76] Source: OMV Homepage (Access 14.02.11)
[77] Cp CSA Group (2004), p. 20
[78] Source: OMV Homepage (Access 14.02.11)

Kazakhstan has many low enthalpy resources but their also a few high enthalpy potential areas. These areas are not proved but expected from data of oil wells[79].

- **Libya**

Officially known as the Great Socialist People's Libyan Arab Jamahiriya, Libya has a developing economy. Islamic ideals and beliefs provide the conservative foundation of the country's customs, laws, and practices,

As Libya has taken steps to cooperate in the global war on terrorism, the Libyan government's designation as a state sponsor of terrorism was rescinded on June 30, 2006. The borders and remote areas are still considered as dangerous. In February 2011 the Libyan population started a revolution against the regime which is still ongoing and the therefore the safety standard is decreased too.

OMV is since 1975 active in Libya and expanded its business by acquiring 25% of interest from Occidental Petroleum. In 2008 OMV signed a contract for the redevelopment of the old fields of Libya. Hundreds of wells are planned and the newest technology will be used on these fields what makes Libya to one of the North African core regions for OMV.

Figure 21: Libya map with OMV E&P licences (dark green)[80]

Libya has big oil and gas reserves, but no information about geothermal potential. As Libya is rich on oil and gas resources the chance of an increasing demand for alternative energy in the country is questionable, therefore the chance to enforce geothermal energy in an economical way in the next decade is very low.

New Zealand

New Zealand is a stable parliamentary democracy, which recognizes the British monarch as head of state. It has a modern economy, which has been historically based on a foundation of exports from its very efficient agricultural system.

New Zealand remains largely free of terrorist incidents and has a very high safety standard.

[79] Boguslvsky, E et al. (1999)
[80] Source: OMV Homepage (Access 14.02.11)

Figure 22: New Zealand map with OMV E&P licences (dark blue) and the geothermal potential areas (red circles)[81]

OMV is operator in the Great South Basin and produces since 2009 oil from the Maari-field and gas from 2 other licences. OMV applied high technology to develop this field.

New Zealand has huge fields with high enthalpy resources mainly on the north island, but also a few promising low enthalpy resources on the south island[82].

- **Norway**

Norway is a highly developed stable democracy with a modern economy. Norway is one of the world's richest countries in per capita terms.

Norway remains largely free of terrorist incidents and has a very high safety standard.

Since 2006 OMV is active in Norway. It holds since 2010 10 offshore licences where OMV is operator in seven licences. OMV is in the exploration phase and will start with exploration drilling in the Barents Sea in the beginning of 2011. Norway is one of the core regions in the North Sea portfolio of the OMV.

Figure 23: Norway map with OMV E&P licences (dark blue)[83]

Norway has only a very low geothermal potential on low enthalpy energy.

- **Pakistan**

Pakistan is a parliamentary federal republic in South Asia and is a developing country. The World Bank considers Pakistan a low-income country. Pakistan remains dependent on the

[81] Source: OMV Homepage (Access 14.02.11)
[82] Cp. White, B. (2009)
[83] Source: OMV Homepage (Access 14.02.11)

International monetary fund and other international assistance for budgetary support and to keep the country more or less solvent.

The presence of Al-Qaida, Taliban elements, and indigenous militant extremist and sectarian groups poses a potential danger to foreigner throughout Pakistan, especially in the western border regions of the country. Continuing tensions in Muslim majority countries and territories also increase the possibility of violence against Westerners. Although the Pakistan government has heightened its security measures, particularly in the major cities, terrorist groups continue to seek opportunities to attack locations where Westerners are known.

Figure 24: Pakistan map with OMV E&P licences (dark green) and the geothermal potential areas (red circles)[84]

Since 1990 OMV is active in Pakistan and is the biggest foreign petroleum producer in Pakistan.

Pakistan is situated over the junctions of the tectonic plates of the sub-continents and is therefore considered as quite rich in geothermal resources. Exploration has to be conducted to proof the resources[85].

Regarding the rich oil and gas resources in the country, it is questionable if a renewable energy has a change to enforce in an economical in the next decade.

- **Romania**

Romania is a republic and has a market-oriented economy. Romania is a country of considerable potential: rich agricultural lands, diverse energy sources (coal, oil, natural gas, hydro, and nuclear), and a substantial industrial base encompassing almost the full range of manufacturing activities, an educated work force, and opportunities for expanded development in tourism on the Black Sea and in the Carpathian Mountains.

Romania remains largely free of terrorist incidents

[84] Source: OMV Homepage (Access 14.02.11)

[85] Cp. Bukhari, S. (2010)

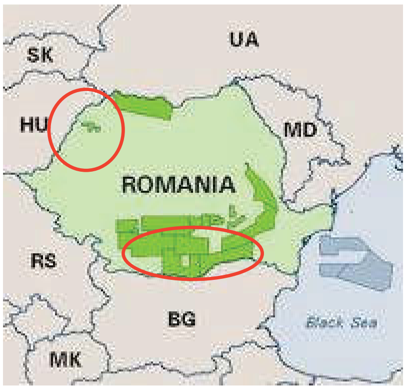

Figure 25: Romania map with OMV E&P licences (dark green and dark blue) and the geothermal potential areas (red circles)[86]

With the acquiring of 51% interest on Petrom in the year 2004 started OMV its activities in Romania. The main activities are work-over operations on the old wells. 2009 the biggest 3D survey in the history of Romania was conducted in the Black Sea. For the future, many development and production wells are planned. Romania is therefore next to Austria the core region in the central Europe for OMV.

Since the 60's over 250 geothermal exploration - and production wells were drilled. The main geothermal reservoirs in Romania are located in Oradea, Bors, Beius, Ciumeghiu, Olt Valley and Otopeni. The resources are all classified as low enthalpy resources[87].

- **Slovakia**

Slovakia is a democratic and rapidly developing European nation.

Slovakia remains largely free of terrorist incidents.

Figure 26: Slovakia map with OMV E&P licences (dark green) and the geothermal potential areas (red circles)[88]

OMV is since 2007 active via a joint venture with the Slovakian company Nafta. The two companies are holding two exploration licences in the west of Slovakia. The exploration phase has already started and the first exploration well was drill in spring 2010. Slovakia is therefore a core region in the central Europe for OMV.

[86] Source: OMV Homepage (Access 14.02.11)
[87] Cp. Antal, C. (2008),p. 2ff
[88] Source: OMV Homepage (Access 14.02.11)

Slovakia is rich on low enthalpy resources because of its favourable geological conditions. There are many developing projects running and the most important and biggest project is based in Kosice[89].

- **Tunisia**

Tunisia has an authoritarian system with a developing economy. Tunisia's economy has emerged from rigid state control and is now partially liberalized.

There have been no instances in which foreigners or their facilities in Tunisia have been subject to terrorist attacks. The borders and remote areas are still considered as dangerous. In December 2010 the Tunisian population started a revolution against the regime which is still ongoing and the therefore the safety standard is decreased too.

Figure 27: Tunisia map with OMV E&P licences (dark green)[90]

Since 1970 OMV is present in Tunisia. The company holds seven onshore and seven offshore licences. In 2009 OMV acquired a production concession in Nawara, 2011 OMV signed a contracted to buy the exploration, and production business from Pioneer Natural Resources what makes Tunisia to one of the North African core regions for OMV.

The geothermal energy is limited to low enthalpy resources what makes direct utilization hard. The main resources can be found in the southern part of the country in the regions of Gabes[91].

As Tunisia is rich on oil and gas resources the chance of an increasing demand for alternative energy in the country is questionable, therefore the chance to enforce geothermal energy in an economical way in the next decade is very low.

- **United Arab Emirates**

The United Arab Emirates (UAE) is a federation of seven emirates, each with its own ruler. The federal government is a constitutional republic, headed by a president and council of ministers. Islamic ideals and beliefs provide the foundation of the country's conservative customs, laws and practices. The UAE has a modern and generally well-developed infrastructure.

There have been no instances in which foreigners or their facilities in UAE have been subject to terrorist attacks but because of geographical position, it has to be considered as tensioned situation.

[89] Cp. Benovsky, V. (2000)
[90] Source: OMV Homepage (Access 14.02.11)
[91] Cp. Mohamed, M. (2002)

Figure 28: United Arab Emirates with OMV office (Abu Dhabi)[92]

OMV runs since 2007 only an office in Abu Dhabi to increase the influence in this region. No operations regarding exploration and production are conducted.

UAE has big oil and gas reserves, but no information about geothermal potential. Regarding the rich oil and gas resources in the country, it is questionable if a renewable energy has a change to enforce in an economical way in the next decade.

- **United Kingdom**

The United Kingdom (UK) of Great Britain and Northern Ireland is a highly developed constitutional monarchy composed of Great Britain (England, Scotland, and Wales) and Northern Ireland. The United Kingdom has the sixth-largest economy in the world, is the second-largest economy in the European Union, and is a major international trading power. A highly developed, diversified, market-based economy with extensive social welfare services provides most residents with a high standard of living.

The United Kingdom is politically stable, with a modern infrastructure, but shares with the rest of the world an increased threat of terrorist incidents of international origin, as well as the potential for isolated violence related to the political situation in Northern Ireland.

Since 1987 OMV is active in the UK and holds a big portfolio of licences western of the Shetland Islands. Since 2004 OMV is operator on these licences. UK is one of the core regions in the North Sea portfolio of the OMV.

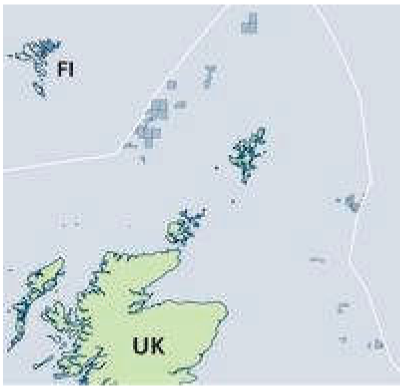

Figure 29: United Kingdom map with OMV E&P licences (dark blue)[93]

The geothermal energy is limited to low enthalpy resources what makes direct utilization hard. A bigger potential can be found in the Scottish granites, but exploration work has to be conducted to proof it[94].

[92] Source: OMV Homepage (Access 14.02.11)
[93] Source: OMV Homepage (Access 14.02.11)

- **Yemen**

The Republic of Yemen was established in 1990 following unification of the former Yemen Arab Republic (North) and the People's Democratic Republic of Yemen (South). Islamic and traditional ideals, beliefs, and practices provide the foundation of the country's customs and laws. Yemen is a developing country

Al-Qaida in the Arabian Peninsula is actively engaged in terrorist activities in Yemen and the other Gulf countries. In parts of Yemen, conditions are similar to civil war. In January 2010 the Yemen population started a revolution against the regime which is still on-going and the therefore the safety standard is decreased too.

Figure 30: Yemen map with OMV E&P licences (dark green)[95]

OMV is since 2003 active in Yemen. It owns three exploration and production licences. Further exploration and production wells are drilled in future to develop the promising block S2.

Yemen has promising locations near the most active plate boundaries of the world. The east African Rift and Afar Triangle show recent volcanic and tectonic activities. Preceding Studies indicate high enthalpy resources near Dhamar but further exploration has to be conducted[96].

[94] Cp. Busby, J (2010)
[95] Source: OMV Homepage (Access 14.02.11)
[96] Cp. Al-Kohlani, T. (2010)

4 Screening process

The following pages will describe the individual steps of the development process for an assessment tool, which is based on a MCDA system with the target to determine the geothermal energy potential of the countries from the OMV portfolio.

As not every country has a geothermal potential and especially there are countries that have absolutely no potential, it has to be done a pre-selection of countries where detailed investigations make more sense. Therefore a pre-screening will be done, to sort out the countries with no initial and future geothermal potential. For this screening only a few basic key figures will be used which are easily available. This step is conducted to minimize the portfolio to a range of countries, which have an economical potential. The step should also ease the information search in the future phases.

The next step is the development of the assessment tool. Therefore it has to be established a decision context, to find out what even is the aim of the tool. With this knowledge, all criteria and objectives that are associated with the question have to be defined. The criteria will be described in detail, to show which broadband of influences every factor has on the overall system. As next step every criteria or also called key figure, will be assigned a score or value. For this step, a detailed analysis of every country is necessary to be able to evaluate every key figure. Not every criterion is as important as the others are, so a weighting has to be assigned for each key figure to reflect their relative importance to the decision. Experts, with the aid of interviews, should rate the weightings. The last step is to combine the scores and weighting to get an overall result. The result of this step should be a working assessment tool what yields realistic values to differentiate between the countries sharply.

A sensitivity analysis will show the range of changes in the results by manipulating the individual key figures. The results get analysed, ranked and discussed. Therewith should be the target reached to find out which countries of the OMV portfolio have a geothermal energy production potential. It should also be possible to rank the countries by their results to provide OMV recommendations, which should be undertaken as future steps in their geothermal energy strategy.

4.1 Pre-Screening

The target of the pre-screening is to reduce the OMV portfolio to countries, which have a commercial and serious potential to produce energy out of their geothermal resources. Therefore a quick and easy process should be run through, to assess only the countries with a geothermal potential.

The screening should be based on a few significant criteria that allow sorting out the negligible countries. In addition, an applicable framework is needed for the evaluation or screening process. This framework should be easy to understand and allow a quick implementation in the screening process.

4.1.1 Screening framework

As explained above the target is to find an easily and quickly understandable framework. Therefore the most basic MCDA tool can be used, the performance matrix, as this tool is also the simplest MCDA system. This tool consists of a matrix in which each row describes an option and each column describes the performance of the alternative criterion.

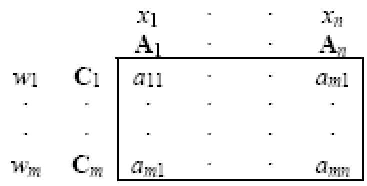

Figure 31: Performance matrix(C=option, A=alternative performance, w and x= possible weighting factors)[97]

The performance is described by a numerical value. These values have to be defined upfront by a scale, which is valid for all options[98]. Usually the criteria are weighted too, but in this case, criteria were found which have all the same importance for the definition of the geothermal potential of a country. The defined criteria are more or less the key criteria or knock out criteria for a geothermal project. Furthermore, frameworks are used which are easy and not struggling around with defining weightings in an appropriate way. As this defining of weightings also has to be based on a plausible method, which normally includes expert interviews, it is easier to use criteria with the same weight.

4.1.2 Screening criteria

At first, criteria were defined and as a second step, a scale was developed which reflects the performance. This scale was divided in three groups: 0, 1 and 2 in which 0 is the worst performance and 2 the best. The rest of the performance scale was defined as linear. The options in the performance matrix are all countries from the OMV E&P portfolio.

All criteria and performance scales were approved with the aid of Prof. Dipl.-Ing. Dr.mont. Schmid, from the Joanneum Research Leoben, Austria. Prof. Dipl.-Ing. Dr.mont. Schmid is geologist and works since many years in the geothermal energy industry, he carried out many geothermal energy projects in Europe as head of the projects and is therefore one of Austria's leading geothermal experts.

4.1.2.1 First Criterion

The first criterion is based on following question: Which systems are in the best case able to produce electricity from geothermal energy (only out of hydrothermal- and petrothermal systems <5,000m)?

This criterion should evaluate if there is even a potential to produce electricity and furthermore how big is the potential. Thereby the system, which is used to produce electricity, reflects indirectly the geothermal potential. As high temperature systems should be able, by assuming the same fluid production, to produce more energy and therefore have a bigger geothermal potential. It also shows if there are low or high enthalpy resources. Only resources will be considered which are not deeper than 5,000m, as on the one hand, this projects count as deep borehole heat exchange project (see 2.3.1) and on the other hand, the most projects are not accomplishable in an economical way. This assumption is also valid for the second criterion.

The scale is defined as following:

0 = no possibility to produce electric energy out of the geothermal resources

1 = binary plants (85°-150°C)

[97] Cp. Fülöp, J., p. 4
[98] Cp. Department for Communities and Local Government (2009), p. 21ff

2 = flash steam systems or dry steam systems (>150°C)

4.1.2.2 Second Criterion

The second criterion is based on following question:

What is the maximal possible future installed electric power potential (only consider hydro-thermal- and petrothermal systems <5,000m)?

This criterion should evaluate on the one hand if there even is a potential to produce electricity and on the other hand, what is the maximum expected producible electricity. As higher electricity output reflects the overall geothermal potential of a country.

The scale is defined following:

0 = no possibility to produce electric energy out of the geothermal resources

1 = 0.1-100MW

2 = >100MW

4.1.2.3 Third Criterion

The third and last criterion is defined by following question:

What is the political situation in the country?

This criterion aims on the issue that the political situation plays a big role in the feasibility of any project. There can be more than enough geothermal resources in a country but if they are not accessible because of war or other problematic situations in a country which can involve high risk operation with dangerous and fatal outcome, the potential of this country has to be counted as not available.

The scale is defined as following:

0 = whole country unstable (war, civil war)

1 = parts of the country unstable, dangerous (terrorism)

2 = safe country

4.1.3 Evaluation of Screening

At first, the screening tool was evaluated with the aid of literature research and in a second step, Dr. Schmidt evaluated the criteria. In the last step, the results of both evaluations were discussed with Dr. Schmid to approve the screening tool results.

It has to be noted that the screening was done already in the beginning of December 2010 what was before the start of the revolutions in Libya, Tunisia and Yemen. Therefore, the results do not pay attention in Question 3.

Following results were achieved:

Table 3: Result criterion 1 from the pre-screening process (X marks the alternative)

Which systems is in the best case able to produce electricity from geothermal energy (only out of hydrothermal- and petrothermal systems

0 = No possibility to produce electricity
1 = binary system is maximum (85°-150°)
2 = flash steam systems or dry steam systems (>150°C)

Conutries	0	1	2
Austria	-	X	-
Australia	-	-	X
Egypt	-	X	-
Faroe Islands	-	X	-
Iraq	X	-	-
Ireland	X	-	-
Kazakhstan	-	X	-
Libya	X	-	-
New Zealand	-	-	X
Norway	X	-	-
Pakistan	-	X	-
Romania	-	X	-
Slovakia	-	X	-
Tunisia	X	-	-
United Arab Emirates	X	-	-
United Kingdom	X	-	-
Yemen	-	X	-

Table 4: Result criterion 2 from the pre-screening process (X marks the alternative)

What is the maximal possible future installed electric power potential (only consider hydrothermal- and petrothermal systems <5000m)?

0 = No possibility to produce electricity
1 = 1-100 MWe
2 = >100 MWe

Conutries	0	1	2
Austria	-	X	-
Australia	-	-	X
Egypt	-	X	-
Faroe Islands	-	X	-
Iraq	X	-	-
Ireland	X	-	-
Kazakhstan	-	-	X
Libya	X	-	-
New Zealand	-	-	X
Norway	X	-	-
Pakistan	-	X	-
Romania	-	-	X
Slovakia	-	-	X
Tunisia	X	-	-
United Arab Emirates	X	-	-
United Kingdom	X	-	-
Yemen	-	X	-

Table 5: Result criterion 3 from the pre-screening process (X marks the alternative)[99]

What is the political situation in the country?			
0 =	whole country unstable (war, civil war)		
1 =	parts of the country are unstable, dangerous (terrorism)		
2 =	safe country		

Conutries	0	1	2
Austria	-	-	X
Australia	-	-	X
Egypt	-	-	X
Faroe Islands	-	-	X
Iraq	X	-	-
Ireland	-	-	X
Kazakhstan	-	-	X
Libya	-	X	-
New Zealand	-	-	X
Norway	-	-	X
Pakistan	-	X	-
Romania	-	-	X
Slovakia	-	-	X
Tunisia	-	X	-
United Arab Emirates	-	X	-
United Kingdom	-	-	X
Yemen	X	-	-

For the overall result of the pre-screening, the partial results from the individual criteria were summed up and evaluated in the following way.

4.1.3.1 Valuation Key

All countries with more or equal three points will be considered for further investigations. Countries, which got a zero in one of the three partial key criteria, are automatically kicked out of the screening even they reached three or more points in sum. The reason therefore is that every criterion on its own is a key factor to even be able to conduct a geothermal energy project or that there is even the possibility of geothermal potential that can be re-covered.

[99] Cp. Außenministerium Österreich (Access 30.11.10)

4.1.4 Pre-screening result

The result of the pre-screening is following:

Table 6: Pre-screening result

Countries	Q1	Q2	Q3	Sum
Austria	1	1	2	**4**
Australia	2	2	2	**6**
Egypt	1	1	2	**4**
Faroe Islands	0	0	2	**2**
Iraq	0	0	0	**0**
Ireland	0	0	2	**2**
Kazakhstan	1	1	2	**4**
Libya	0	0	1	**1**
New Zealand	2	2	2	**6**
Norway	0	0	2	**2**
Pakistan	1	1	1	**3**
Romania	1	2	2	**5**
Slovakia	1	2	2	**5**
Tunisia	0	0	1	**1**
United Arab Emirates	0	0	1	**1**
United Kingdom	0	1	2	**3**
Yemen	1	1	0	**2**

The yellow marked rows are the countries, which are considered for further detailed analysis. The countries are:

- Austria
- Australia
- Egypt
- Kazakhstan
- New Zealand
- Pakistan
- Romania
- Slovakia
- United Kingdom

4.2 Geothermal potential evaluation

In the following pages, the method and process of the development of the geothermal potential assessment tool will be explained. The process will mainly follow the eight steps, which are explained in 3.2.1. where also the method is explained, namely SWING.

It will get described how to find the objectives for the MCDA what is the easy part, but also the way of finding the right criteria will be discussed. This step is much more difficult as it is not easy to develop an evaluation system that approves the objectives in a plausible way. As these criteria are complex systems with a lot of dependencies they have to get analysed in an analytical way to establish a structured model which can get split up from the top level down to lowest level without missing any criterion in its broad hierarchy system. In addition, the weighting methods and their values will be discussed.

4.2.1 Establish decision context

As first step, it is important to define a decision context to be sure what even is the goal and target of the whole process. This step should be the fundament for the completely further development of the system. It should involve all structures that surround the decision. Central to it are also the objectives and criteria of the decision making body. Therefore, the decision context for the MCDA for this master thesis is following:

Define the geothermal energy electricity production potential of all OMV E&P countries. The results should give OMV an overview and tool to priorities their geothermal expansion plans. Therefore, all-important key facts have to be considered which influence a big oil and gas E&P company like OMV while conducting an international project.

4.2.2 Identifying of options

The next logical step is to find and identify the options for the MCDA. This step usually takes a long time, as it is hard to find all possibilities of option at once. Most of the time a part of options gets identified during the further steps of the MCDA development process.

In this case, it is easy as the options were already identified by the decision context and clearly stated as all countries from the OMV E&P portfolio. Nevertheless, this big bunch of options was already sorted out to a number, which can be considered as geothermal potential countries. This step was required to filter out a number of options, which can be considered as options with no future to a number that makes sense to analyse. That is why the pre-screening was conducted with the result of sorting out eight countries out of 17 to go on with the analysis of nine geothermal potential countries (see 4.1.4)

4.2.3 Identifying of criteria and assessing of performance level

4.2.3.1 Identify criteria

Criteria are performance measurements by which the options will be judged. The criteria serve as the performance measures for the MCDA, which should be specific and measurable objectives. Therefore, a measurement or a judgement needs to specify how well each option meets the objectives expressed by the criteria. But to develop a complete set of criteria, it has to be kept in mind following question: 'Is it possible in practice to measure or judge how well an option performs on these criteria?[100].

[100] Cp. Wang, J. (2009), p. 2269

While assessing the bunch of options, it also requires thoughts about the consequences of these options or strictly spoken the consequences are the facts, which are assessed, not the options themselves. The consequences differ in many ways, and those ways that matter because they achieve objectives are referred to as criteria, or attributes[101].

The criteria can be identified by a decision making team or as an individual. There are many methods to develop the criteria. One of the easiest ways is to do a brainstorming where all responses should be noted down uncritically. The problem of this method is that it may works fine in a group but for an individual more structured methods are needed.

If options are already given, then a 'bottom-up' way to identify criteria is to ask how the options differ from one another in ways that matter. A 'top-down' approach is to ask about the aim, purpose, mission or overall objectives that are to be achieved. Sometimes overall objectives are given. The guideline for this approach can be for example the use of a PEST-analysis. Thereby the problem is split up in the four dimensions:

- Political/Legal
- Economic
- Social
- Technological

These four groups can be extended to more dimensions, which will affect the options, e.g. ecological or demographic aspects [102]. These are further broken down into criteria, some of which are susceptible to numerical measurement, including monetary valuation, others to rating, and some to qualitative description only.

In addition, the perspectives of interest groups are important to include in the criteria finding process as both decision-maker objectives and interest group viewpoints may be different. There are different ways to assess them. One approach can be directly to involve the affected parties in some or all stages of the development process of MCDA. A second approach is to examine policy statements and secondary information sources from the various interest groups and to analyse these to derive criteria to reflect their concerns[103].

As already described above, it can be a good idea to split the criteria in groups to separate the criteria in distinguishable components of the overall objective for the decision, especially for MCDAs, which contain a relative large number of criteria what means eight or more. There are three reasons for grouping criteria:

- To check if the set of criteria selected is appropriate to the problem
- To ease the process of calculating criteria weights in large MCDA applications
- To facilitate the emergence of higher level views of the issues

The structure should simply reflect a clear, logical and shared point of view about how the criteria that are more or less relevant to the MCDA can be combined together into coherent groups where each of the criteria addresses a single component of the overall problem. Most of the time the criteria are reflecting individual measurable performance indicators on the one hand and on the other hand, the groups of criteria reflect sub-objectives to the single main objective that underlies the MCDA[104].

[101] Cp. Wang, J. (2009), p. 2269
[102] Cp Stahl, H. (2011), p.44
[103] Cp. Department for Communities and Local Government (2009), p. 33
[104] Cp. Center of International forestry research (1999), p. 19ff

The result should show a hierarchy, criteria should be combined in higher levels to new groups, which again can be summarized in dimensions and so on. The advantage is that the groups can be evaluated against each other and thereby the results can be analysed in a more detailed way.

To approve the final choice of criteria they need to be assessed against a range of qualities:

- Completeness

  The completeness should reflect if all important and necessary criteria are included in the MCDA to compare the overall performance of the options.

- Redundancy

  The redundancy should reflect if there are no criteria included in the MCDA, which are unnecessary.

- Operationality

  The operationality should reflect if all options can be judged against each criterion. It makes no sense to pay attention to criteria where no scale of measurement, like weight and distance can be found.

- Mutual independence of preferences

  The mutual independence of preferences should reflect if it is possible to assign preference scores for the options on one criterion without knowing what the options preference scores on any other criteria are. If this is the case, the criteria are mutual independent from each other. This condition has to be met if the sum of weighted averages is to be used to combine preference scores across criteria and this is usually the case for all MCDAs.

- Size

  The size issue should check if the structure is not larger than it needs to be as an excessive number of criteria leads to extra analytical effort in assessing input data and can make therefore the analysis more difficult.[105]

4.2.3.2 Assess performance level

The measures used in MCDAs are often qualitative descriptions, natural units or sometimes a crude numerical scale.

The first step while developing performance levels is to set up consistent numerical scales for the assessment of criteria, to ensure that the sense of direction is the same in all cases, so that normally better levels of performance lead to higher value scores and low performance to low values.

Therefore, it is convenient to define value scores, which vary between 0-100 or 0-10 on an interval scale. The big advantage of an interval scale is that differences in scores have consistency within each criterion. The next step is to define the levels of performance. Hence, any two-reference points on the scale have to be defined, usually the extreme scores of 0 and 10 are used. There are two possibilities to scale or define the performance:

- Global scaling
- Local scaling

The global scaling assigns a score of zero to represent the worst level of performance that is likely to encounter in a decision problem and 10 to represent the best level. The other

[105] Cp. Department for Communities and Local Government (2009), p. 35ff

option, the local scaling assigns zero to the performance level, which performs at least well in the current considered set of options and 10 to the best performance. The advantage of the global scaling is that it more easily accommodates new options at a later stage if these record performances that lie outside those of the original set. Nevertheless, it also has the disadvantages that it requires extra, not necessarily helpful judgements in defining the extremes of the scale.

In this master thesis, scales from 0-10 will be used with the global scaling method as this assessment tool should be able to assess new options at a later stage too, because the E&P portfolio changes over the time, therefore scales are needed which can account also for other countries with maybe more extreme values.

When the ends of the scales are established for each criterion, scores may be established for the options in three ways:

- Value function:

  A measure of achievement is translated on the criterion concerned into a value score on the 0 to 10 scale. Usually a linear dependency is created between performance and the criterion, but there are also cases where it is may be desirable to use a non-linear function. For example, it is well known that human reaction to changes in noise levels measured on a decibel scale is non-linear.

- Direct rating

  This is used when a commonly agreed scale of measurement for the criterion in question does not exist, or where there is neither the time nor the resources to undertake the measurement. Direct rating uses the judgement of an expert simply to associate a number in the 0 to 10 range with the value of each option on that criterion.

- Indirect issue approach

  Options get pair wise assessed relative to each other[106].

In this master thesis, only value functions will be used to define the performance scales.

4.2.3.3 Criteria derive procedures

This point follows the explained methods from above. It will be explained in detail how the range of criteria were derived and assessed.

Therefore, as a first step, the decision context has to get analysed and a method has to be defined to split up the problem and to build out of the complex construct a well arranged system which can again get analysed in further steps with the aim to find all necessary criteria. The complex problem which has to get analysed in an analytical way and should find a first structuring method, is defined by following statements: 'Define the geothermal electric energy production potential of a country' on the one hand and on the other hand it has to be kept in mind: 'The results should give OMV an overview and tool to priorities their geothermal expansion plans'. The context states different issues:

1. Each framework condition of a **country** has to be analysed. Therefore, all countrywide key factors have to be considered and country specific key figures should get used. Furthermore, every country is based on laws and mainly driven

[106] Cp. Department for Communities and Local Government (2009), p. 41ff

by the country specific political system. These two facts can overthrow easily a project.

2. The results of the tool are used as decision tool for a **company**, what means that the tool has to consider that all results have to take into account that all future operations and plans are profitable as only such projects are even interesting for companies. Hence, only criteria should be defined which influence the feasibility of a project for a company.
3. To define a potential of a country, the whole country has to be considered. That means that **every region**, which has a geothermal potential, has to be covered and analysed to determine out of the sum of the regions the potential of the whole country.
4. Only the **electric energy production potential** should be evaluated. Therefore only a geothermal energy potential is not enough, it has to be differentiated between geothermal energy potential and the geothermal electric energy production potential what needs higher reservoir temperatures (>80°C). But on the other hand the remaining energy what is mainly heat in a geothermal electricity energy production system can be a very important point to make profit, as this waste heat can get sold and therefore also bring money and at the same time make a project profitable.

Based on the issues the whole criteria derive process was started. It was decided to start the structuring process from top-down. The first structuring point was recognized from the point one and three from above. The problem is that laws and political systems are valid for a whole country, but the most country have more than one potential region, which are all get analysed on their own. Hence, not all criteria are valid for a whole country but rather for a region only. Because of this finding, it was decided to differentiated in a first step between national and regional wide key figure or criteria, thereby all regions in a country get analysed and considered as every region makes a contribution to the overall geothermal potential of a country.

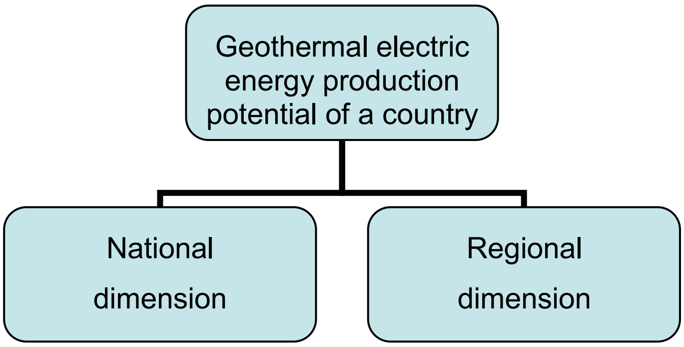

Figure 32: First step of criteria derive procedure

To find the next level of structure, it was decided to use a PEST-analysis as guideline. For the result please see 4.2.3.1.

The political and legal group is definitive a part of the national dimension. Like already discussed above, the main part of laws is usually valid for the whole country and the political systems normally influence the whole country.

The economic is the next category, but this time it is not that easy to define the classification of the dimension. Economic aspects are influenced national wide but also only regional basis. Therefore, it was decided to introduce economic aspects in both dimensions to be able to record regional economic criteria and the country wide or national economic facts.

The social category is hard to define in a more or less technical setting of task. Social concern will be part of criteria but a pure social request was hard to define which influences the overall context. Therefore, no social category will be needed and hence, the category will get rejected for further investigations.

The last category, the technological category mainly depends for a geothermal potential analysis on geological properties as these properties drive a project and thus, the technology, which is needed to conduct a successful geothermal project. That is the reason why the technological category will be renamed to "geological category". The geology depends mainly on the region and is therefore classified as regional dimension. Nevertheless, it has to be differentiated between which kinds of production systems fits to the reservoir properties, e.g. is an aquifer in place and can the fluid be produced or is only the heat stored in the formation and a fluid has to be pumped down to produce the heat. These issues are driven by different key criteria, thus, the geological characteristics have to be analysed separated by their possible production system criteria. The result is that the geological characteristics have to be split up again in to production system specific characteristics and geological or reservoir specific characteristics which are valid for the whole region. It will get differentiated between HDR production systems and hydrothermal production systems (see 2.3). It has to be chosen out of these two possibilities which system can be used for every region.

From a company side of view there can also show up countrywide technical issues, hence the technological category has to be considered also in the national dimension.

By further investigations it was realised that there is also a mix of different criteria of all four categorizes from above for the regional aspect that is why it was decided to group these aspects in area characteristics.

After defining the criteria of the individual characteristics from the national dimension it was realised that one criterion is so important for the overall evaluation that the weighting of this criterion has to play a bigger role, therefore it was decided, to upgrade this criterion in a higher level to be able to give it a higher significance in the evaluation process of the assessment tool. The criterion is:

- Resources characteristics

The next lower level of the structuring system should already reflect the criteria-level, to keep the system easy and well-arranged and not to over complicate the structuring system with unnecessary levels. Therefore, the five characteristics will be analysed on their own and all criteria will be described for each group. The way of finding the criteria, the range of each criterion and the performance score definition will be discussed.

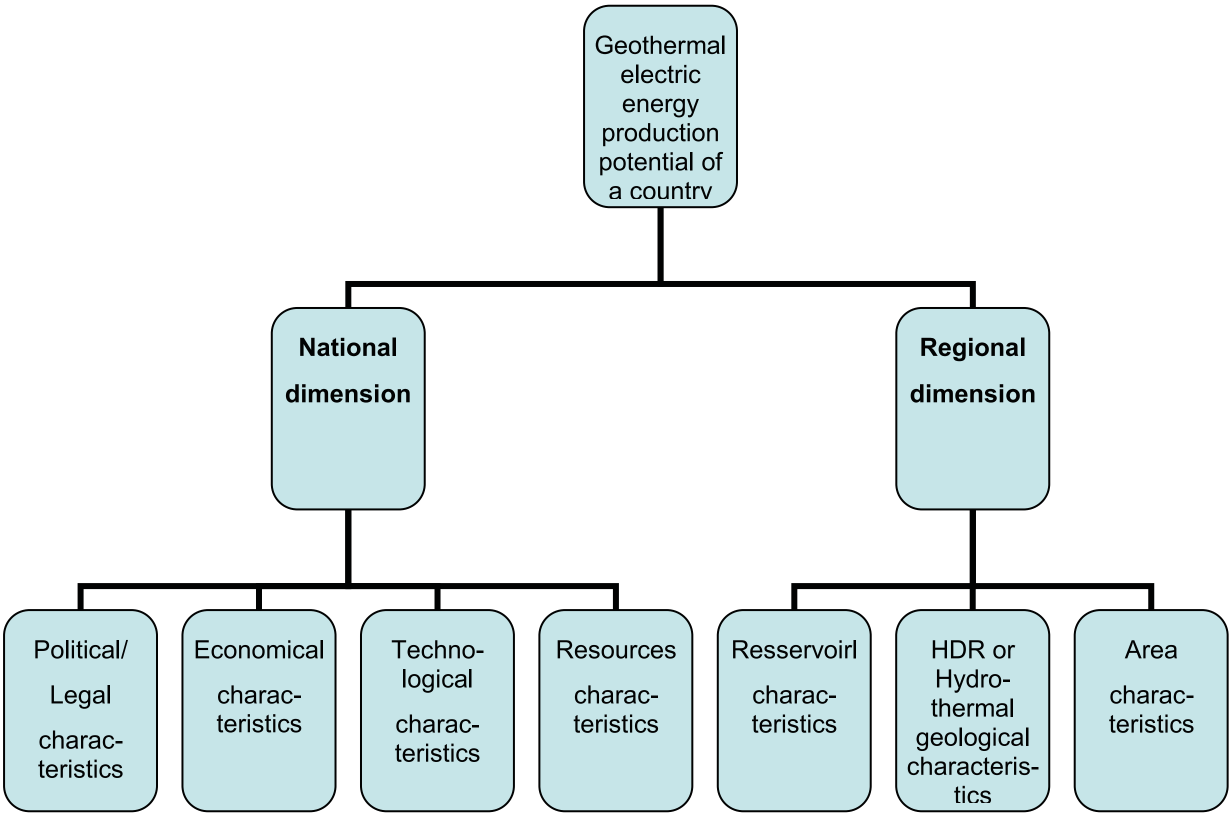

Figure 33: Second step of criteria derive procedure

4.2.3.4 Criteria and their performance scales

Political/Legal Characteristics

The first characteristics, which were analysed, were the political and legal characteristics group. There are two characteristics summarised to one group:

- Political characteristics
- Legal characteristics

Therefore, in first instance the political characteristics were analysed. It was done a brainstorming about which political motivated criteria can influence a company to carry out a geothermal project in a country and in second instance, the process was repeated.

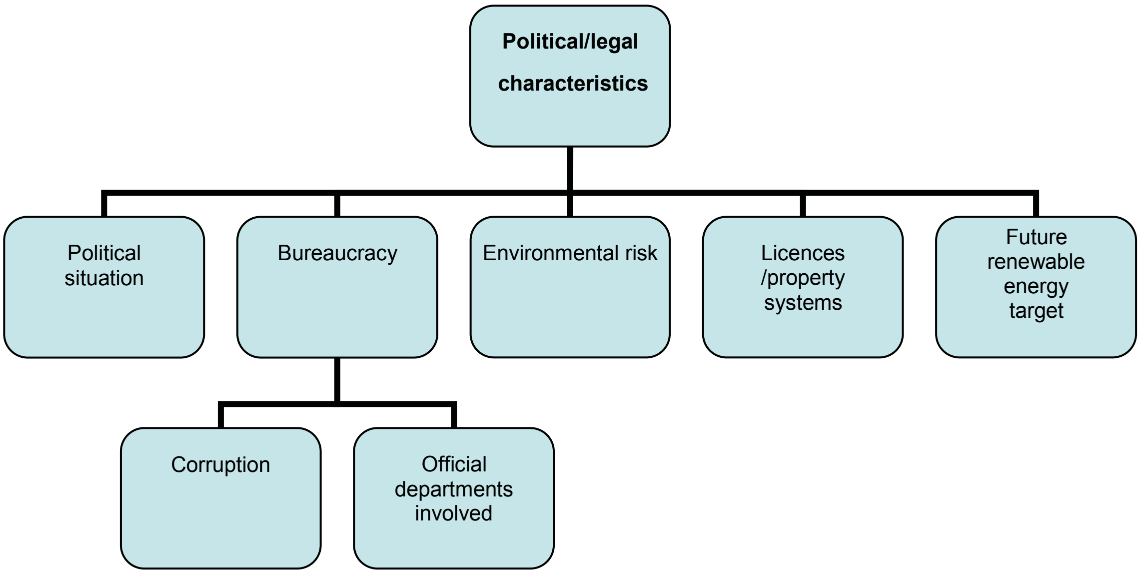

Figure 34: Overview of the criteria of the political/legal characteristics

Following criteria describe the political/legal characteristics:

Political situation criterion

As the political system on its own has no influence on the geothermal potential of a country, the political situation or stability can have a big influence as it can overthrow a project. If there is no access to possible geothermal potential areas, then these areas cannot be counted as potential areas as they are not developable in a commercial way. This assumption should reflect the definition of reserves from the petroleum industry. In this industry, reserves only count as reserves when they are producible in a commercial way. The thought for this criterion was the same. A country or region cannot get counted as potential country or region if this area is not accessible because of a political unstable situation in the region. But not only a total instability in a region can have a hazardous impact on a project or the potential of the region, also every jeopardizing of safety because of terrorism for example, can influence the risk of success of project. Therefore, the criterion has to take also these facts into account. With the aid of the Austrian foreign ministry, a scale to evaluate the political situation performance of a country was established.

Qualitative performance indicators were used as criteria. The worst level of performance was defined as war in the whole country, because if this situation prevails, there is no chance to conduct a geothermal energy project and therefore the geothermal potential has to be considered as zero. For the best level of performance, country has to be safe with no security worries and it should be no terrorism target. The rest of the scale was worked out by linear grading. Based on this scale all countries got evaluated on their political situation in their country.

Table 7: Political situation performance scale

political situation criterion
10= no security worries/ no terrorism target
9= no security worries/ possible terrorism target
8= security worries because of crime rate/ no terrorism target
7= security worries because of aggressive atmosphere/ no terrorism target
6= no security worries/ was terrorism target in the last year and still high terror risk
5= security worries because of aggressive atmosphere/ was terrorism target in the last year and still high terror risk
4= daily risk of terror acts
3= parts of the country are not under governments control
2= in parts of the country is war
1= in the whole country is war

Bureaucracy

The bureaucracy can be considered as in-between of legal and political influences. Both characteristics play a role to define the bureaucracy of a country. The reason for considering the bureaucracy is that it has a huge impact on the attractiveness for a company to invest in a country or even to carry out projects there. Is the bureaucracy high and intransparent, the effort and the risk to fail with project is high. Therefore, it is a direct risk and effort indicator for a country. In a lot of countries it is required to show presence years before a project can get even started, in such countries it takes its time to socialise with the governments and the key persons of a country to be successful. If this work was not considered upfront, the chances to start a business in the country from the scratch from up now is more or less zero. Nevertheless, also like discussed above, the intransparency of the system can make out of the process a bumpy road. As there was no criterion founded which describes both problems, it was decided to split the bureaucracy in two sub-criteria, to be able to analyse the bureaucracy in a proper and efficient way.

The performance indicators are defined in a different way this time. To yield the criterion, the two sub criterion gets multiplied and result is the performance indicator for the bureaucracy criterion. To be able to multiply the two sub-criteria, it was assumed that ever department can be corrupt and therefore a weighting for the tow sub-criteria will not reflect the right result. Hence, one sub-criterion ranges between 1 to 0 and the other one between 10 to 0 that in the end the result also is in the range of 10 to 0.

The first sub-criteria should describe the extra effort to even be able to run a project.

Corruption

The corruption in country reflects the extra effort to carry out projects in the best way. In corrupt country a lot of extra effort what can be money or time, is required. As performance scale, the published corruption index of 2010 from the Transparency International Organisation[107] can be used. This index evaluates based on different indicators the corruption of a country.

[107] Cp. Transparency International

For the scale, quantitative performance indicators were used. The results of the corruption index reflect the performance of the sub-criterion. As worst level of performance was the total corrupt system defined, as for such systems a lot of extra effort is needed. While as best level was defined as no corruption in the system. The conversion from the qualitative classification to a quantitative classification was already done by the corruption index. The dependency on performance indicators and the quantities criteria is linear. Based on this scale all countries were evaluated.

Table 8: Conversion of the quantitative classification of the corruption index to the qualitative classification system for the corruption and the performance scale

corruption index	corruption
1= 9.2-10	1= not corrupt system
0.9= 8.3-9.1	0.9= very low corrupt system
0.8= 7.4-8.2	0.8= low corrupt system
0.7= 6.5-7.3	0.7= medium low corrupt system
0.6= 5.6-6.4	0.6= medium corrupt system
0.5= 4.7-5.5	0.5= medium high corrupt system
0.4= 3.8-4.6	0.4= high corrupt system
0.3= 2.9-3.7	0.3= major corrupt system
0.2= 2-2.8	0.2= extreme corrupt system
0.1= <2	0.1= total corrupt system

Official department involved

The second sub-criteria should describe the intransparency and complexity of the effort to get and conduct a geothermal project in country. Therefore, the number of official departments, which are involved to get a permit to carry out a project and to produce the energy, reflects the complexity of a project. As more departments involved as more complex gets the project and as more intransparent is it.

For the scale, quantitative performance indicators were used. The performance was measured on the total number of official departments that are involved to perform a geothermal project from the exploration to the production successful. As worst level of performance was an involvement of more than nine official departments defined and the best level of performance is when only one department has to be contacted. The numbers for the performance measurement were defined by using Austria as reference as there are five departments involved, what was used as average. It is assumed that there are countries where more departments are involved but also countries where fewer departments are involved. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all countries were evaluated.

Table 9: Official departments involved performance scale

Official departments involved
10= 1
9= 2
8= 3
7= 4
6= 5
5= 6
4= 7
3= 8
2= 9
1= >9

Environmental risk

The environmental risk is also a mix of political and legal characteristics, but it counts mainly as legal issue. By thinking about which legal issues can have the biggest influence on a geothermal project, the environmental laws came up. As this point is for the most western companies but also countries, especially after the BP accident in the Gulf of Mexico, a very important point. This criterion should reflect the effort, which is required to follow the environmental standards and guidelines of a country.

It was assumed that higher environmental standards or more environmental laws in a country will increase also the effort of performing a successful geothermal project in this country. It does not make sense to count the number of environmental laws, as the content of the laws determines the environmental standard and not the number of laws. Further, it is hard to read all laws and to specify the performance of them. Hence, another performance standard was required. This standard was found in the environmental performance index defined by the University of Yale[108]. This index defines with the aid of different criteria the environmental standard of countries. Therefore, it was decided to use it as measurement of the environmental risk. Is the environmental standard high in a country, a lot of extra effort is needed to conduct a geothermal project, it is required to fulfil way more official requirements as in countries with a lower environmental standard.

For the scale quantitative performance indicators were used. The results of the environmental performance index reflect the performance of the criterion. As worst level of performance was huge effort defined, as the high effort and also environmental standard can overthrow the whole project and therefore jeopardize the success of the project for a company. The best level was defined as nearly no effort as there is always a rest effort or minimum environmental standard in a country. The conversion from the qualitative classification to a quantitative classification was already done by the environmental performance index. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all countries were evaluated.

[108] Cp. Homepage Yale (access 03.02.11)

Table 10: Conversion of the quantitative classification of the environmental performance index to the qualitative classification system for the environmental risk and the performance scale

Environmental Performance Index	Environmental risk
10= <47	10= nearly no effort
9= 47- 52.9	9= very low effort
8= 53-58.9	8= low effort
7= 59-64.9	7= moderate low effort
6= 65-70.9	6= moderate effort
5= 71-76.9	5= moderate high effort
4= 77-82.9	4= high effort
3= 83-88.9	3= major effort
2= 89-94.9	2= extreme effort
1= 95-100	1= huge effort

Licence/property system

One of the key criteria even to carry out a geothermal energy project is to have access to a piece of country. If this aspect is not given, the possibility to conduct a geothermal project equals zero. Therefore, the availability of an area in the designated region as licence, leasing or ownership is essential. The licence/property system criterion should describe this issue in the way that the still available area where it is allowed to conduct a geothermal project, gets determined as fraction of the overall area where it is allowed to conduct a geothermal project.

It has to be differentiated between licence systems and property/leasing systems as the area determination has to be done in a different way. While it is quite easy for the licence systems due the fact that the licence areas are predefined and thus, only the availability of the offered permits has to be checked to determine the licence system criterion. The determination process for the property/leasing system is more complex. For this analysis, it got assumed that all the area in a region is available for geothermal projects and only special areas, like nature protected areas are count as not available. In addition, the area within a radius of 10km of already existing geothermal wells was considered as area which is not available, because of the interaction between the wells.

For the scale, quantitative performance indicators were used. As worst level of performance was 0-9% of available area defined and the best level was defined as 90-99% availability of area in a country. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all countries were evaluated.

Table 11: Licence property system performance scale

Licence/property system
10= 90-99%
9= 80-89%
8= 70-79%
7= 60-69%
6= 50-59%
5= 40-49%
4= 30-39%
3= 20-29%
2= 10-19%
1= 0-9%

Future renewable energy target

Dependent on the defined renewable electricity energy targets of a country, are they set really high or low, the country has to support the plans more or less enthusiastic to reach the goal and show the population to be serious about their aims. Therefore, the renewable electricity energy target as quote of the total electricity consumption mix is an indicator for how much a country is interested to support and promote renewable energy projects. Thereby, the difference between the initial quote and the future target reflects the necessary effort to reach the goal. If the quote difference between now and a defined future date is small, the efforts to support and subsidies such project will be small, but if the quote difference is high, the country has to endeavour itself to reach the goals. Hence, a country with a high quote difference has better to be interested that many renewable electricity energy projects will be conducted on their ground and should better support them to attract investors and companies, to reach the target. Furthermore, it reflects the interest of getting more independent of fossil fuels and the interest in decreasing the CO_2 emission to support the worldwide greenhouse emission reduction targets.

It has to be paid attention to the fact that the future electricity energy consumption mix will increase over time, but this effect will be neglected, as it was decided that the difference in the quote only, without accounting for the higher consumption mix in the future, reflects already more than enough the priority and support of renewable energy projects of a country. Furthermore it is hard to find values for the energy consumption growth rate for countries and thus, it eases also the criterion finding process. For the future reference date, the year 2020 was used, because it is a long enough period to change things and the most countries published their targets for the year 2020.

For the scale, quantitative performance indicators were used. The performance was measured on the difference between the initial quote and the quote of the year 2020 of the consumption of renewable energy on the total energy mix. As worst level of performance was 5% difference defined, as values lower than 5% have only a small impact on the overall energy mix and hence, reflects that the country cares not that much about the increase of renewable energies. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all countries were evaluated.

Table 12: Future renewable energy target performance scale

Future renewable energy target
10= >13%
9= 12-12.9%
8= 11-11.9%
7= 10-10.9%
6= 9-9.9%
5= 8-8.9%
4= 7-7.9%
3= 6-6.9%
2= 5-5.9%
1= <5%

Technical characteristics

As most technical aspects are depending more on the regional factors, it is hard to find national wide technical characteristics. However, after a systematic analysis, following criteria, which influence the geothermal potential on a national wide basis, could be identified:

OMV personal infrastructure

No project is to achieve if there is not a key personal available. Therefore, this fact was considered as one of the key criteria to even be able to conduct a project. If there is no work force, which has the knowledge and the experience to carry out a geothermal project, the chance of successful results is very low. Therefore, it was decided that a minimum of key personal has to be in the country to run and control the projects. If the number of labour is high, the chance of a successful project is high too and vice versa. Another aspect is that a staff expansion costs extra money too.

For the scale, quantitative performance indicators were used. As worst level of performance was <10 key personal defined and the best level was defined as >89 key personal in the country. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all countries were evaluated.

Table 13: OMV personal infrastructure performance scale

OMV personal infrastructure
10= >89
9= 89-80
8= 79-70
7= 69-60
6= 59-50
5= 49-40
4= 39-30
3= 29-20
2= 19-10
1= <10

Resources

On a national level, the countrywide resources are interesting to analyse. A possibility to present the resources is to use the country's total geothermal potential.

Total geothermal potential

The total geothermal potential of a country is one of the key indicators for the geothermal electric energy production potential of a country. It gives an overview about the resources in a country and depends more or less on the geological circumstances. Is the overall geothermal potential in a country high the possibility to produce electricity out of it is high too and vice versa.

For the scale, quantitative performance indicators were used. As worst level of performance was <1,000PJ defined and the best level was defined as >12,000PJ total geothermal potential of the whole country. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all countries were evaluated.

Table 14: Total geothermal potential performance scale

Total geothermal potential
10= >12,000PJ
9= 11,999 – 11,000PJ
8= 10,999 – 10,000PJ
7= 9,999 – 9,000PJ
6= 8,999-7,000PJ
5= 7,999 – 6,000PJ
4= 5,999 – 4,000PJ
3= 3,999 – 2,000PJ
2= 1,999 – 1,000PJ
1= <1,000PJ

Economic characteristics

Economic aspects are the key criteria in a commercial project. They define if a project is economical and hence, if it is possible to make profit out of it. As this assessment tool should help a company to identify the geothermal electric energy potential of a country, it has priority to analyse the potential also on their economics. A project depends strongly on these criteria and can be overthrown by it. The economic criteria mainly reflect the criteria, which are responsible and influence the profitability and revenues of a project.

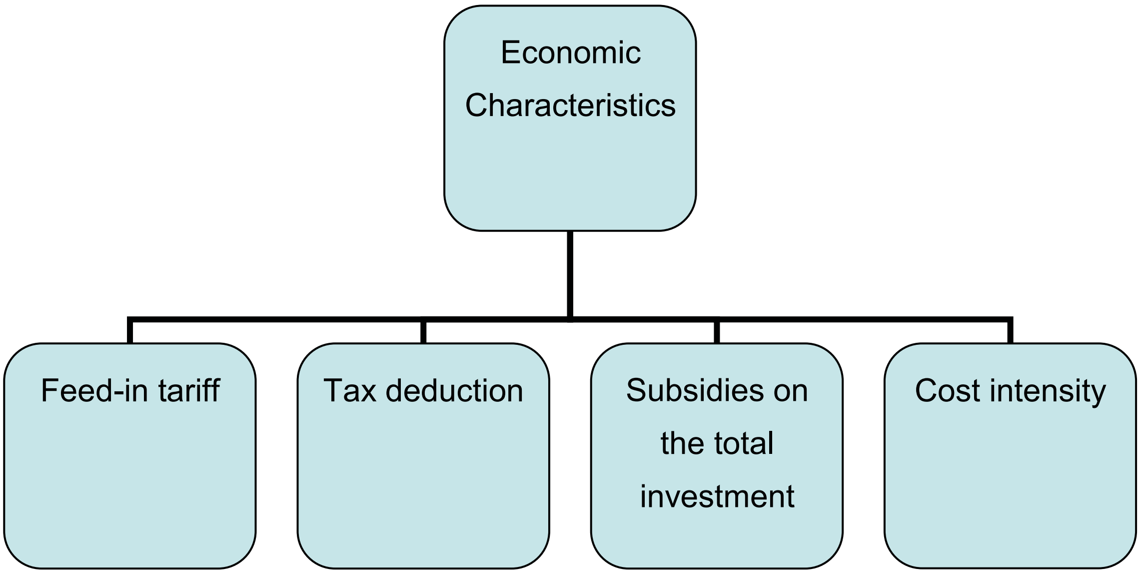

Figure 35: Overview of the criteria of the economic characteristics

Following criteria describe the economic characteristics:

Feed-in tariff

The revenues out of geothermal electric energy production projects are mainly made from the sold energy in form of electricity. In addition, a small fraction of revenues is achieved by selling the waste heat after the electric production process. The heat can be feed in the district heating grid, but like stated above it plays only a secondary role. Therefore, the selling price of the electricity plays a decisive role in a geothermal project.

The sales prices are mainly depending on the feed-in tariffs in a country. They can also be influenced by the renewable energy targets of a country, like already discussed above in Future renewable energy target, with the aid of subsidies on the feed-in tariff. The selling prices are negotiated more or less at the beginning of project, in the power purchase agreement what is a legal contract between the energy producer and the purchaser of the energy[109]. Therefore, the subsidies on the feed-in tariff are a good indicator for the achievable sales prices of the energy. If the subsidies are high, the energy producer will make more money and vice versa. There is always a negotiation range in which the price can be and thus, a risk that the prices are lower as expected.

For the scale, quantitative performance indicators were used. The performance was measured on the feed-in tariffs for geothermal energy. As worst level of performance was >3€ct/kWh defined and the best level with >26€ct/kWh. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all countries were evaluated.

[109] Cp GEOFAR (2009), p.20

Table 15: Feed-in tariff performance scale

Feed-in tariff [€ct/kWh]
10= >26
9= 26-24
8= 20-23
7= 18-20
6= 17-15
5= 14-12
4= 11-9
3= 8-6
2= 5-3
1= >3

Tax deduction

The actual earnings, which a company can make out of the revenues from a project, are also depending on the fractions of taxes that have to be paid from a company to the country. Earnings are defined in most basic definition in the following way:

Revenues
-Costs
EBIT
-Interests
-Taxes
Earnings

The amount of the taxes can vary in a big range and are different from country to country. Hence, the influences on the earnings are also ranging. Therefore tax deductions can make a country very attractive for an investing company, as such deductions again can make project profitable. As higher these tax deductions are, as more attractive can get a country for a company considered and vice versa. To count this attractiveness factor, it was decided to analyse the tax deductions as fraction on the total revenues, which are made from the selling of the electric energy.

For the scale, quantitative performance indicators were used. The performance was measured on the feed-in tariffs for geothermal energy. As worst level of performance was 0% defined and the best level with >39.9% tax deduction on the electric energy revenues. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all countries were evaluated.

Table 16: Tax deduction performance scale

Tax deduction
10=39.9% on electric energy revenues
9=35-39.9%
8= 30-34.9%
7= 25-29.9%
6= 20-24.9
5= 15-19.9%
4= 10-14.9%
3= 5-9.9%
2= 0.1-4.9%
1= 0%

Subsidies of the total investment

Subsidies play an important role in renewable energy projects, because these promotions have a big impact on the overall conductivity of project, these promotions can make the difference if a project is profitable or not. Like the criterion above, it is an attractiveness indicator for companies to invest in a country. The only difference to the tax deduction is that the costs of the project are lowered and not the taxation fraction (see Tax deduction above). Are the subsidies high, the economical attractiveness for a company is high too and vice versa. Nowadays, such subsidies can be a huge fraction of the total needed investment to carry out the project and that is why it plays an important role in geothermal projects.

For the scale, quantitative performance indicators were used. The performance was measured on the subsidies of the total investment for geothermal energy project. As worst level of performance was 0% defined and the best level with >79.9% subsidies on the total needed investment to accomplish a geothermal projects. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all countries were evaluated.

Table 17: Subsidies of total investment performance scale

Subsidies of total investment
10= >79% of total investment
9= 70–79.9%
8= 60-69.9%
7= 50-59.9%
6= 40-49.9%
5= 30-39.9%
4= 20-29.9%
3= 10-19.9%
2=0.1-9.9%
1= 0%

Cost intensity

The value of money is in every country different, one dollar in the one country equals not one dollar in another country, it has more or less value. To account for this effect, a criterion was in demand. Therefore, the cost intensity will be introduced. It should reflect the drilling costs to a predefined reference depth and hence, make the cost intensity or value of money comparable with other countries. It is important to define a reference depth as the cost vs. depth function is not linear (see Figure 9). Thus, as reference depth, 3,000m were defined which is more or less an average depth for geothermal wells. The data for the average drilling costs can be found in databases and were provided in this case by the OMV.

For the scale, quantitative performance indicators were used. As worst level of performance was >3,099€/m defined and the best level was defined as <1,500€/m at a reference depth of 3,000m. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all countries were evaluated.

Table 18: Cost intensity performance scale

cost intensity [€/m]
10= <1,500
9= 1,699-1,500
8= 1,899-1,700
7= 2,099-1,900
6= 2,299-2,100
5= 2,499-2,300
4= 2,699-2,500
3= 2,899-2,700
2= 3,099-2,900
1= >3,099

General Reservoir Characteristics

The reservoir characteristics should count for criteria, which are independent from the production system. Here, only criteria should be defined that describe geological criteria that are valid for the whole region.

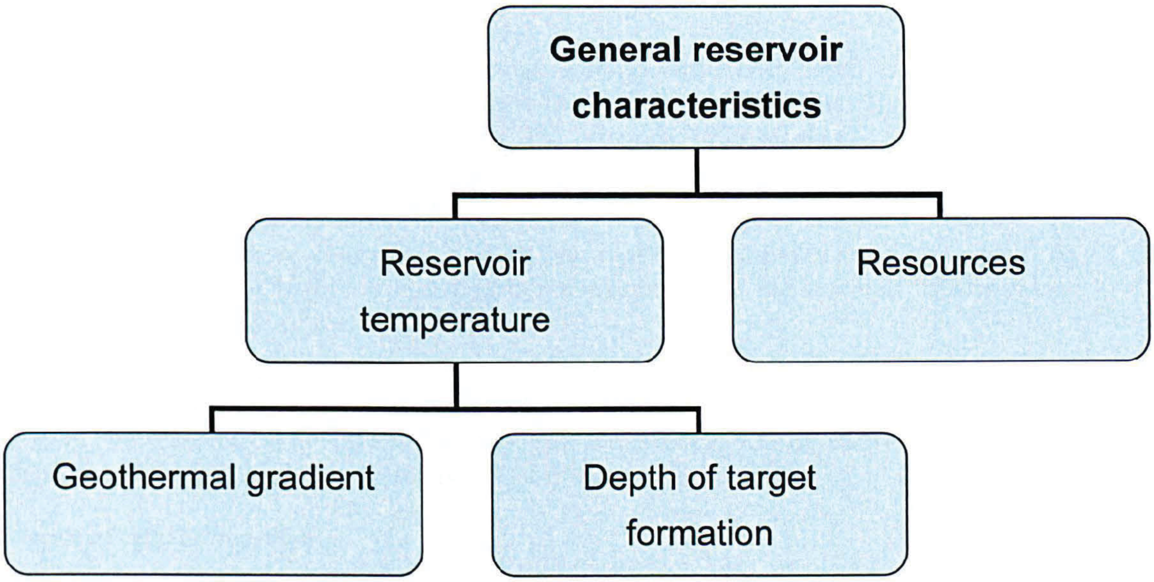

Figure 36: Overview general reservoir characteristics

Following criteria describe the general reservoir characteristics:

Reservoir temperature

The reservoir temperature is one of the key criteria for a geothermal project. It shows which amount of energy is stored in the formation or down hole fluid and hence, it is an indicator for the amount of energy which can get recovered. It is more or less one of the main drivers for a geothermal energy project, as the stored energy in form of heat is also the energy that can be recovered and therefore run a geothermal energy plant. As higher the temperatures in the reservoir as more energy can be recovered. Nevertheless, the reservoir temperature is build up by two sub-criteria. Both criteria are evaluated and multiplied with each other. The result gives the reservoir temperature, which is evaluated by a performance scale. Based on this scale all reservoirs were evaluated.

Table 19: Reservoir temperature performance scale

Reservoir temperature [°C]
10 = >240
9= 221-240
8= 201-220
7= 181-200
6= 161-180
5= 141-160
4= 121-140
3=101-120
2= 81-100
1= <80

Geothermal gradient

The geothermal gradient is the rate of change of temperature with depth, in the earth. The internal temperature of the earth increases with depth from the surface. In the earth crust, the average geothermal gradient is about 2.5°C for every 100m of depth. Some areas have much higher heat flows because of deep fault zones, rifting, magmatic intrusions, or active tectonic forces (also see 2.1 and Figure 2).

The geothermal gradient determines and mainly drives the temperature of a reservoir. As higher the gradient as higher are the possible temperatures in the reservoir by also taking into account the depth of it and vice versa.

In this case, no performance scale will be defined, as only for the reservoir temperature, a scale will be defined and the sub-criteria will be only used to calculate a value for the criterion of the reservoir temperature. The reservoir temperature will be the result of the geothermal gradient multiplied with the depth of the target formation.

Depth of target formation

The depth of the target formation criterion shows how deep the reservoir is located under the surface. This is an important criterion as it has influence on different aspects in a geothermal project. On the one hand, it drives the reservoir temperature, as the temperature is the result of the geothermal gradient multiplied with the depth of the target formation. Therefore, when the target formation is located very deep under the surface, the reservoir temperature will be higher and hence, the stored energy is higher. On the other hand, the depth influences the costs strongly. The cost for a well are increasing with depth and the function of drilling costs vs. depth is not a linear function and normally increases exponential with depth (see Figure 9). Thus, if the reservoir is located deeper under the surface, the drilling costs will increase exponentially and can jeopardize the whole project, as the drilling costs of a project are the main part of the expenditures. The result is that the depth has a positive and negative character for a geothermal project. For both characteristics will be paid attention in the assessment tool.

If it gets paid attention for the positive and the negative aspects, the possible influences on the whole assessment tool should be discussed shortly. It seems that the criterion is double counted on the one hand and on the other hand that it is counted one time positive and negative what means that the influences should normally cancel out each other and have therefore no influence on the overall result. As first point, the double counting issue will be discussed.

It is desirable to present the same basic effect from more than one point of view, so that the overall context of the decision is fully understood by those who are involved. It is important when moving from a multi-perspective form of presentation of options on to the process of choice between options, that the potential for any double counting is recognised and the final performance matrix used for decision making is suitably amended to remove it. This will be the case in the assessment tool, as the performance scale will measure not both. For the reservoir temperature, only the quantitative value of the target formation depth will be used to calculate the temperature, as for the drilling costs influence, a performance scale will be established.

For the negative and positive character and their cancelling out issue, the same reason is valid as for the double counting. Only in one case, a performance scale is established and in the other case only an indirect influence can be seen.

Again, for the assessing of the reservoir temperature no performance scale will be defined, as only for the reservoir temperature a scale will be defined and the sub-criteria "depth of target formation" will be only used to calculate a value for the criterion of the reservoir temperature. The reservoir temperature will be the result of the geothermal gradient multiplied with the depth of the target formation.

In this case a deeper reservoir has a positive character, as the expected temperatures will be higher too and therefore the possible recoverable energy is higher too what means that the project is more attractive and shows a higher geothermal energy potential.

Resources

The geothermal resources of a region are reflecting a fraction of the overall geothermal potential in a country and can therefore be considered as one of the key indicators for the geothermal electric energy production potential of the region. It gives an overview about the resources in a region and depends more or less on the geological circumstances. Are the geothermal resources in a region high the possibility to produce electricity out of it is high too and hence, the geothermal potential of the whole country is higher too as it counts as fraction for the whole country. The assumption is also valid vice versa.

For the scale quantitative performance indicators were used. As worst level of performance was <4GJ/m^2 defined and the best level was defined as >20GJ/m^2 geothermal resources of the region. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all regions got evaluated.

Table 20: Resources performance scale

Resources [GJ/m^2]
10= >20
9= 20 - 18
8= 17,9- 16
7= 15,9- 14
6= 13,9- 12
5= 11,9 - 10
4= 9,9 - 8
3= 7,9 - 6
2= 5,9 - 4
1= <4

HDR- or Hydrothermal geological Characteristics

As every geothermal potential area has to be developed by another production system because of the different kinds of reservoirs and circumstances, it has to be distinguished between HDR reservoirs and hydrothermal reservoirs. Both production systems are driven and influenced by different properties that is why it has to be differentiated between various perspectives. Before the criteria get a scoring, it has to be clarified which kind of production system will be used or with which system it is even possible to develop the geothermal resources in the region. The only criterion to decide which system will be used depends on the fact if the reservoir has an aquifer from which the water can be produced or not. If the reservoir has an aquifer, the hydrothermal characteristics will be used, if there is no aquifer and water has to be pumped down, it is a typical HDR production system (also see 2.3).

Geology of hydrothermal reservoirs

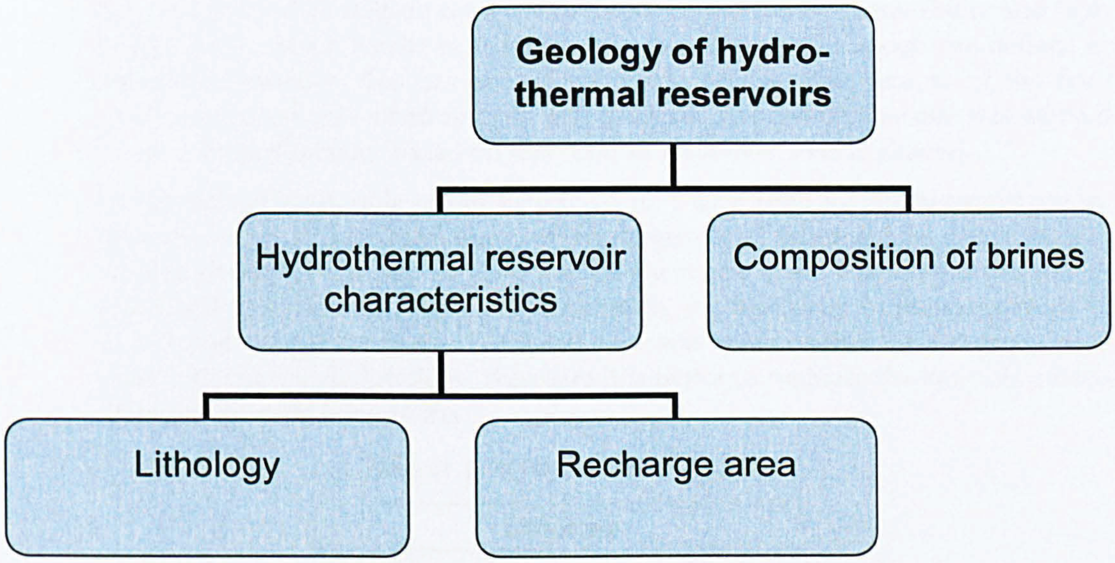

Figure 37: Overview of the geology of hydrothermal reservoir criteria

Following criteria describe the geology of hydrothermal reservoirs:

Hydrothermal reservoir characteristics

The hydrothermal reservoir characteristics should describe the quality and life expectancy of a reservoir regarding the production, which depends on the permeability and the size of the aquifer, and if the aquifer is refilled or not (see Figure 37).

To determine the hydrothermal reservoir characteristics criterion, the two sub-criteria are multiplied with each other and the result of this multiplication gives the key figure for the hydrothermal reservoir characteristics.

Lithology

The lithology of a reservoir has an influence on the permeability and the life span of the reservoir. While dolomite or chalk is normally fractured and therefore the channels through which the geothermal fluid can be produced are relatively big and therewith the capillary forces are small and the permeability is high, these fractures allow a higher geothermal fluid production. Gets sandstone or schist compared to dolomite or chalk, the formations have smaller channels and permeabilities and therefore the production is usually lower.

Another fact is that these small channels from sandstone and schist formations can get plugged way easier than the big channels of the dolomite and chalk formations. Furthermore the sandstone and schist formations weather easier too, so the produce more than enough particles which can jeopardize the channels to get plugged. This fact influences the life span of a reservoir. If the channels get plugged very fast, the production will go down faster too and the life span is very short and vice versa.

Both influences show the same result, it is better to have a dolomitic or limy formation than a sandy or schistic formation. This makes the evaluation easier as the lithologies can be ranked in the same order.

Qualitative performance indicators were used as criteria. The worst level for lithology was defined as schistic reservoir, because of the lowest permeability and high plugging risk, which results in a shorter life span. The best lithology was defined as dolomitic formation that has normally a higher permeability because of the fractured matrix and only small risk of being plugged. The rest of the scale was worked out as a linear function. Based on this scale all reservoirs were evaluated.

In this sub-criterion only values between 1 to 5 were used for the performance indicators, as on the one hand only 5 different groups of lithology play a role in geothermal energy production systems and on the other hand, when the sub-criterion gets multiplied with the recharge area criterion, the results are in the same range (1 to 10) as all the other criteria. Furthermore, it was assumed that the recharge area is valid for every single lithology, therefore it is better to multiply the two sub-criteria as to weight every sub-criteria.

Table 21: Lithology performance scale

Lithology
5 = dolomite
4 = chalk
3 = plutonite
2 = sandstone
1 = schist

Recharge area

The recharge area just determines if the reservoir is open or closed and therefore, if the reservoir gets steadily refilled by fluids from other formations. The fluids are then heated in the target formation and can be used for the energy production and no surface fluid injection is needed to keep the down hole pressure constant to have a constant production over the lifespan. If the reservoir is a closed formation, e.g. by tight sealing, there is no chance of a refilling with fluids from other formations and therefore the reservoir is finite and the down hole pressure will decrease with an on-going production and without any fluid injection from the surface. Hence, an open system will be favourable for a project as it means that the reservoir is more or less infinite and no injector is theoretically needed.

Qualitative performance indicators were used as criteria. In this case it will be differentiated only between two criteria, namely open or closed reservoir. Therefore, the closed reservoir was defined as worst level, because of the finite lifetime of the reservoir. The best level was defined as open reservoir as it is more or less infinite and no injector is needed. Based on this scale all reservoirs were evaluated.

Table 22: Recharge area performance scale

Recharge area
1= closed
2= open

Composite of brines

The composite of brines describes the average total dissolved solids (TDS) in the reservoir fluid. As higher the concentration of dissolved solids is as higher is the chance of debris in the production system. The debris can lower or even plug the whole production system and hence, the geothermal fluid production will be lowered what again lowers the energy production and therefore the earnings of the project, which are needed to finance or refund the investments of whole project, are jeopardized.

It will not be differentiated between what kind of solids are dissolved as every kind of solids can build up debris if the concentration is high enough. Another point, which has to be discussed, is the possibility of the influence of the TDS on corrosion. In addition, this effect will be neglected, as in most countries or regions, the brine composition is even hardly known and in most of the time, there is no detailed information about chemical specifications.

For the scale, quantitative performance indicators were used. The performance was evaluated by the TDS in the reservoir fluid. As worst level of performance was >30g/l defined and the best level with >5.9g/l. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all reservoirs were evaluated.

Table 23: Composite of brines performance scale

Composition of brines [g/l]
10= <5.9
9= 8.9-6
8= 11.9-9
7= 14.9-12
6= 17.9-15
5= 20.9-18
4= 23.9-21
3= 26.9-24
2= 29.9-27
1= >30

Geology of HDR-reservoirs

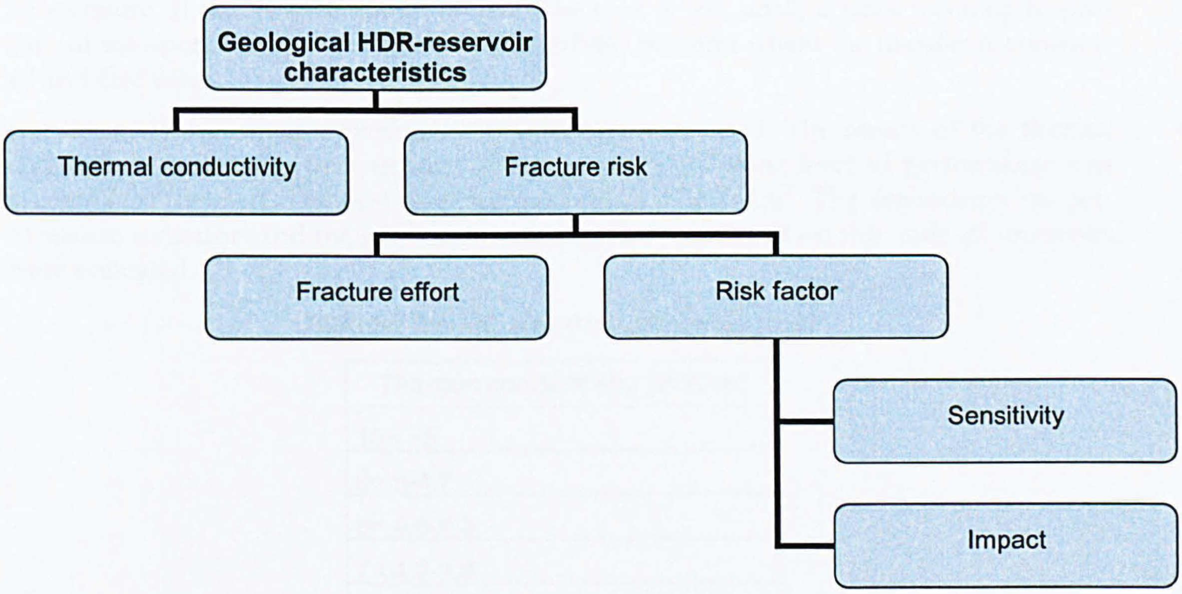

Figure 38: Overview Geological key figures for a HDR-reservoir structure

Following criteria describe the geological of HDR reservoir:

Thermal conductivity

Thermal conductivity is defined as following:

"Fourier's law of heat conduction defines specific heat flow q_i, i.e. heat flow normalized by area, as the product of the thermal conductivity tensor λ_{ij} and the temperature gradient vector $\partial T / \partial x_j$:"[110]

$$q_i = -\lambda_{ij} \frac{\partial T}{\partial x_j}.$$

Equation 3: Thermal conductivity formula[111]

"Thermal conductivity in some rocks is, to a good approximation, isotropic, particularly for volcanic and plutonic rocks. In these cases, heat flow will be predominantly vertical, and it is sufficient to consider only the vertical component. Thermal conductivity of many sedimentary and metamorphic rocks, in contrast, is strongly anisotropic, and lateral heat flow will be significant. Hence information on anisotropy is often required, demanding laboratory measurements in different directions."[112]

The definition should more or less describe the influence of the thermal conductivity on the HDR technique. As the thermal conductivity describes how fast heat can be transported through a material, it has a huge influence on a HDR system. The HDR technique uses fractures in the formation to heat up cold fluid. Therefore, fluid is pumped down on an injection well, through the fractures in which the fluid gets heated up and is produced through a production well (see also 2.3.2). As this process is a steady process and the heat of the rock gets discharged constantly by the contact with the cooler fluid, the surface of

[110] Cp. Clauser et al (2006), p. 23
[111] Cp. Clauser et al (2006), p. 23
[112] Cp. Clauser et al (2006), p. 24

the rock has to be hot enough to provide enough heat to heat up the fluid to the target temperature. If the thermal conductivity of the rock is too small, it takes too long to provide or transport enough heat to the surface of the fractures where the transfer is conducted and vice versa.

For the scale, quantitative performance indicators were used. The results of the thermal conductivity reflect the performance of the criterion. As worst level of performance was <1.9mW/m^2 defined. The best level was defined as >5mW/m^2. The dependency on performance indicators and the quantities of criteria is linear Based on this scale all reservoirs were evaluated.

Table 24: Thermal conductivity performance scale

Thermal conductivity [W/K*m]
10= >5
9= 5-4.7
8= 4.6-4.3
7= 4.2-3.9
6= 3.8-3.5
5= 3.4-3.1
4= 3-2.7
3= 2.6-2.3
2= 2.2-1.9
1= <1.9

Fracture risk

The fracture risk should describe the possible risks, e.g. earthquakes that can appear when the formation gets fracture to create channels through the target formation.

After an earthquake in December 2006 in Basel, Switzerland, which was caused by fracture activities for a HDR geothermal project, the whole project was cancelled as the possibilities of damage for the neighbourhood, was too high. Therefore the surrounding area of such projects can have a big influence on the accomplishing of a project as the incident in Switzerland shows, thereby the neighbours were alerted by an earthquake and enforced a cancelling of the whole project[113]. Therefore, the different risk factors, which can appear because of the fracture process, have to be taken into account, as the results can easily jeopardize or even cancel the project.

The fracture risk criterion consists of two sub-criteria, which are multiplied with each other, and the result presents the fracture risk criterion. Following two sub-criteria describe the fracture risk criterion:

Fracture effort

The fracture effort should describe how much pressure is needed to fracture the target formation. Therefore, the average fracture gradient at the depth of the target formation is used. The fracture gradient gives the pressure, which is needed to fracture a formation and to produce the channels in the reservoir through which the

[113] Source: bazonline Homepage (access 13.04.11)

geothermal fluid is pumped. Usually the fracture gradient increases with depth and the pressure is introduced by hydraulic systems.

With a higher fracture gradient and therefore the need of higher down hole pressures, the risk of causing an earthquake is higher too. Hence, low fracture gradients at target depth are favourable and vice versa[114].

For the scale, quantitative performance indicators were used. The results of the fracture gradient at target depth reflect the fracture effort. As worst level of performance was <0.5kPa defined. The best level was defined as >0.9kPa. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all reservoirs were evaluated.

Table 25: Fracture effort performance scale

Fracture effort [kPa]
1= >0.9
0.9= 0.85-0.899
0.8= 0.8-0.849
0.7= 0.75-0.799
0.6= 0.7-0.749
0.5= 0.65-0.699
0.4= 0.6-0.649
0.3= 0.55-0.599
0.2= 0.5-0.549
0.1= <0.5

Risk factor

The risk factor should describe the dependency of the sensitivity of the population of the geothermal potential region vs. the possible impact of an incident caused by the fracturing process. The multiplication of the two criteria gives the risk factor.

Sensitivity

The sensitivity should show how alerted is the population in the region against possible incidents through the fracturing process. Therefore, it got assumed that a higher developed society with a higher education is more awaked against the impact of such an incident and also the possible impacts on their life. While a lower developed society with nearly no education will more or less accept the impacts, as it is assumed that they are not aware against such incidents. To be able to measure the stage of development of a society an evaluation factor is needed and this factor was found in the human development index (HDI). This index is given for every country on the world and gets evaluated by different criteria which definitely describe the needed factors[115].

For the scale, quantitative performance indicators were used. The results of the HDI reflect the sensitivity of the population for the criterion. As worst

[114] Cp. Gowd et al (1980)

[115] UN DP (2010), p 3

level of performance was total sensitivity defined, as a high sensitivity what means a high HDI jeopardize the success of the project for a company. The best level was defined as no sensitivity what means a very low HDI. The conversion from the qualitative classification to a quantitative classification was already done by the HDI. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all regions got evaluated.

Table 26: Conversion of the quantitative classification of the human development index to the qualitative classification system for the sensitivity and the performance scale

HDI	Sensitivity
1= >0.9	1= no sensitivity
0.9= 0.85-0.899	0.9= very low sensitivity
0.8= 0.8-0.849	0.8= low sensitivity
0.7= 0.75-0.799	0.7= moderate low sensitivity
0.6= 0.7-0.749	0.6= moderate sensitivity
0.5= 0.65-0.699	0.5= moderate high sensitivity
0.4= 0.6-0.649	0.4= high sensitivity
0.3= 0.55-0.599	0.3= major sensitivity
0.2= 0.5-0.549	0.2= extreme sensitivity
0.1= <0.5	0.1= total sensitivity

Impact

The impact should describe the possible damages or outcomes if an incident like in Basel happens. Therefore, it should be a criterion to measure the threats, which can show up because of the fracture process, e.g. earthquakes. As it is very hard to determine these hazards, it was decided to evaluate it by the distance and the size of the next bigger city as this has a huge impact on the outcome. If a city is huge and next to the geothermal project area and the fracturing process produces an earthquake, the city is directly next to the epicentre of the earthquake and therefore the threats of bigger damages in the city are higher too. Furthermore, if the city is bigger too, more damage regarding costs is possible too. Hence, it was decided that this kind of evaluation can be used to determine the impact.

Nevertheless, the evaluation has like in Depth of target formation, a positive and negative aspect. For the impact, it is counted as negative aspect to be directly next to a city, on the other side there is also a positive aspect. If the geothermal project area is next to a bigger city, the possibility of a better infrastructure is given and if a city is really near to the project area, the waste heat can be sold as direct heating for the community. This kind of double counting of a negative and positive aspect and the possible out cancelling was already discussed in Depth of target formation and is also valid for this criterion.

For the scale, quantitative performance indicators were used. The results of the distance to the next bigger city reflect the impact as criterion. As worst level of performance was total impact defined, as a high impact what means a low distance to the next bigger city jeopardize the success of the project for a company. The best level was defined as no impact what means no bigger city is near the project. The conversion from the qualitative classification to a quantitative classification is shown in Table 27. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all regions were evaluated.

Table 27: Conversion of the quantitative classification of the impact to the qualitative classification system and the performance scale

urban vicinity	impact
10= next city 500km --> 30,000 population	10= no impact
9= next city 400km --> 30,000 population	9= very low impact
8= next city 300km --> 30,000 population	8= low impact
7= next city 200km --> 30,000 population	7= moderate low impact
6= next city 100km --> 30.000 population	6= moderate impact
5= city with 30,000-50,000 population in the area	5= moderate high impact
4= city with 50,001-100,000 population in the area	4= high impact
3= city with 100,001-500,000 population in the area	3= major impact
2= city with 500,001-1,000,000 population in the area	2= extreme impact
1= city >1,000,000 population in the area	1= total impact

Area characteristics

The area characteristics should describe all criteria, which can influence the geothermal project in the region regarding attractiveness of the region to the project, threats of the regions to the project and opportunities of the region to the project. For all this influences has to be paid attention, to determine the overall attractiveness of the region for geothermal project. If for example the threats are much higher than advantages, nobody will accomplish a geothermal project in the region. Therefore, the following criteria should help to evaluate the attractiveness of the area:

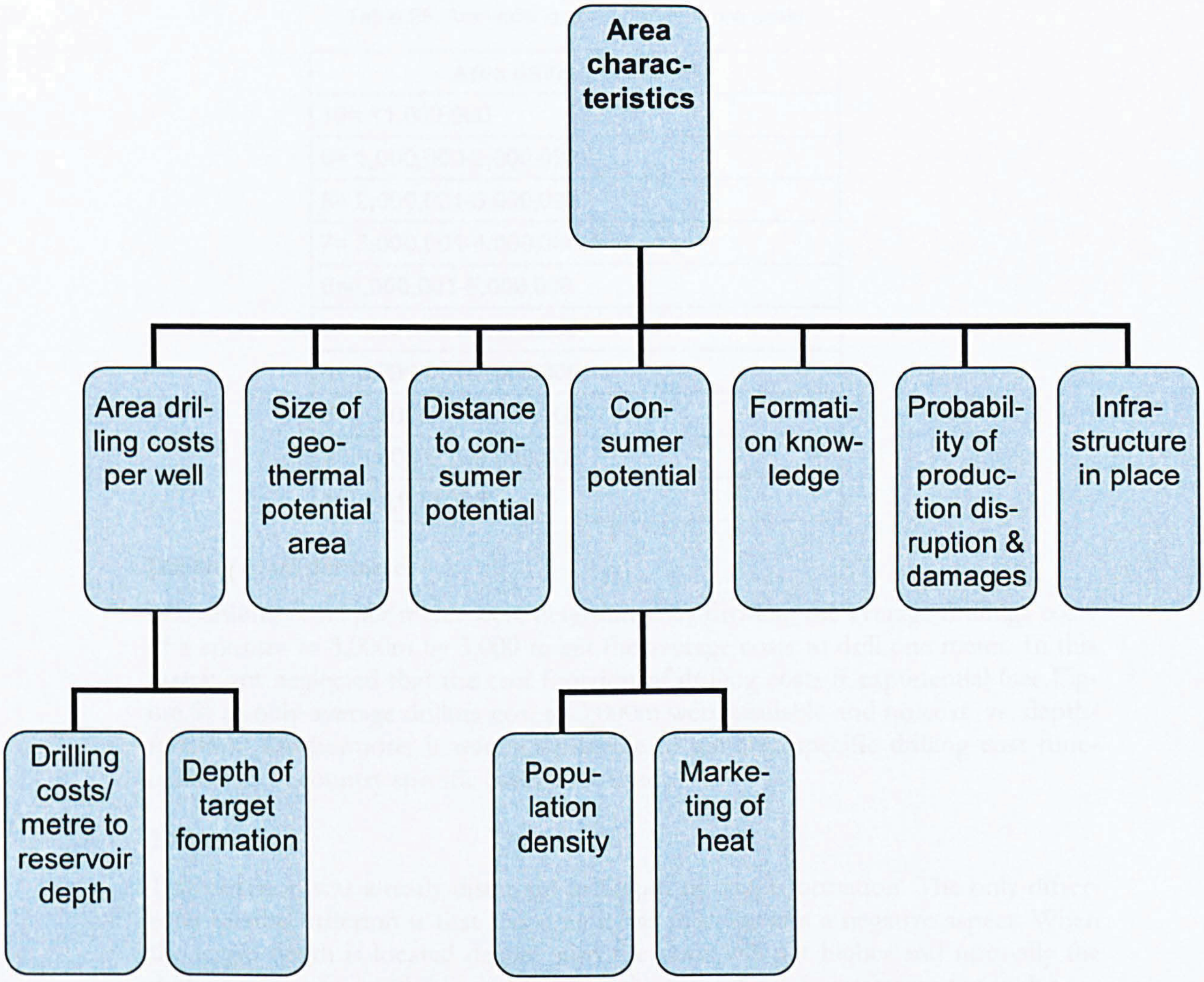

Figure 39: Overview of the area characteristics structure

Following criteria describe the area characteristics:

Area drilling costs per well

The area drilling costs should describe the rough drilling costs to drill a geothermal well to the target formation. This criterion consists of two sub-criteria, namely drilling costs per meter criterion and the target depth criterion. These two sub-criteria get multiplied what gives as result the area drilling cost criterion. Only the area drilling costs will get evaluated by a performance scale.

For the scale, quantitative performance indicators were used. As worst level of performance was >9,000,000€ defined. The best level was defined as <1,000,000€. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all regions were evaluated.

Table 28: Area drilling costs performance scale

Area drilling costs [€]
10= <1,000,000
9= 1,000,000-2,000,000
8= 2,000,001-3,000,000
7= 3,000,001-4,000,000
6=4,000,001-5,000,000
5= 5,000,001-6,000,000
4= 6,000,001-7,000,000
3= 7,000,001-8,000,000
2= 8,000,001-9,000,000
1= >9,000,000

Drilling costs per meter

The drilling costs per meter were determined by dividing the average drillings costs of a country to 3,000m by 3,000 to get the average costs to drill one meter. In this case it got neglected that the cost function of drilling costs is exponential (see Figure 9) as only average drilling cost to 3,000m were available and no cost vs. depth-function. Furthermore, it was not possible to get area specific drilling cost functions, hence, country specific costs were used.

Target depth

This criterion was already discussed in Depth of target formation. The only difference for this criterion is that this time it has more or less a negative aspect. When the target depth is located deeper, also the costs will get higher and normally the drilling costs of a geothermal project are the biggest risk investments for such projects. Therefore, a deeper target depth jeopardizes the whole project easier than a lower depth.

For all further explanations and details, please see 'Depth of target formation'.

Size of geothermal potential area

The size of the geothermal potential area should describe, as the name of the criterion already says, the size of the area where a geothermal potential exists and only such potential where it is possible to produce electric energy out of the stored heat energy in this area. To explain it in another way, the criterion should describe the horizontal expansion of the potential target formation by projecting this area onto the surface and measure it by its size.

Is this size of the potential area large, the possibility to drill more wells and hence, produce more energy is higher too. In addition, the infrastructure for one well can be expanded and used by more production facilities what saves money as the infrastructure in place can be used by more than one system. Is the area smaller, it is not possible to construct too many production facilities as there has to be a certain offset between the production wells, which is required as otherwise too much heat is produced from a small area, which cannot be provided from the surrounding formation fast enough, and the energy output will decrease.

For the scale, quantitative performance indicators were used. As worst level of performance was >1,000km^2 defined. The best level was defined as <10,000km^2. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all regions were evaluated.

Table 29: Size of geothermal potential area performance scale

Size of geothermal potential area [km^2]
10= >10,000
9= 9,999-8,000
8= 7,999-7,000
7= 6,999-6,000
6= 5,999-5000
5= 4,999-4,000
4=3,999-3,000
3=2,999-2,000
2=1,999-1,000
1= >1,000

Distance to the consumer potential

This criterion was already discussed in Impact'. The definition of the criterion is the same, the only difference is that for this evaluation only the positive aspect will be used.

It is an advantage if a big city is next to the geothermal project area as on the one hand usually a proper infrastructure is already in place to build the systems, maintenance it and to transport the produced energy. On the other hand, the waste heat, which accumulates while producing electric energy out of the heat, can be sold as distribution heat to the nearby community. Therefore, the project can make some extra money next to the sold electricity. For further details, please see 'Impact'.

For the scale, quantitative performance indicators were used. The worst level of performance was defined as the next city with a population less than 30,000 inhabitants is more than 500km away from the potential area. The best level was defined as a city with a population more than 1,000,000 inhabitants in the potential area. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all regions were evaluated.

Table 30: Distance to the consumer potential performance scale

Distance to the consumer potential
10= city >1,000,000 population in the area
9= city with 500,001-1,000,000 population in the area
8= city with 100,001-500,000 population in the area
7= city with 50,001-100,000 population in the area
6= city with 30,001-50,000 population in the area
5= next city 100km --> 30,000 population
4= next city 200km --> 30,000 population
3= next city 300km --> 30,000 population
2= next city 400km --> 30,000 population
1= next city 500km --> 30,000 population

Consumer potential

The consumer potential should describe next to the criterion "distance to consumer potential", the possible demand in the area to sell the electricity and the waste heat. The criterion consists of two sub-criteria, namely the population density criterion and the marketing of heat criterion. To evaluate the consumer potential criterion, the two sub-criteria get evaluated and multiplied with each other. The result gives the performance of the consumer potential criterion.

Population density

The population density describes how many people live in average in one square kilometre of a specific area. It should show how big the demand is in specific region. Is the population density high, the demand will be high too as more people need more energy than less people do. Therefore, the sales volume of the energy will be higher too and vice versa.

For the scale, quantitative performance indicators were used. The worst level of performance was defined as zero inhabitants/km^2. The best level was defined as 5,000-10,000inhabitants/km^2. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all regions got evaluated.

Table 31: Population density performance scale

Population density [population/km^2]
1=5,000-10,000
0.9=5,000-1,000
0.8=1,000-666
0.7=666-333
0.8=333-100
0.5=26-100
0.4= 11-25
0.3= 1-10
0.2= 0.1-1
0.1= 0

Marketing of heat

The marketing of heat should describe how big the demand of waste heat is. The demand will be theoretical higher in cold climatic zones as it is more often cold than compared to hotter climatic zones. Therefore, the waste heat demand, which can be feed in a heat distribution system for a near community to be used as heating system, can be sold to this community and thus, some extra money can be made. These extra revenues can be a big part especially in cold climatic zones as the communities have a way higher heat demand than in hot climatic zones.

Hence, to evaluate the marketing of heat criterion, the climatic zones get used. Like described above it were assumed that the need of heat and therefore the demand of heat is higher in colder climatic zones than in hotter zones and vice versa.

Qualitative performance indicators were used as criteria. The worst level for the marketing of heat was defined as total sale what equates the climatic zone of an ice shield. The best marketing of heat was defined as no sale what equates the climatic zone of the desert. The rest of the scale was worked out as a linear function. Based on this scale all regions were evaluated.

Table 32: Conversion of the qualitative classification of the climatic zones to the qualitative classification system for marketing of heat and the performance scale

Climatic zones	Marketing of heat
10= ice sheet	10= total sale
9= tundra	9= extreme sale
8= subarctic	8= major sale
7= continental humid	7= high sale
6= mediterranean	6= moderate high sale
5= subtropical	5= moderate sale
4= tropical - wet	4= moderate low sale
3= tropical - wet - dry	3= low sale
2= steppe	2= very low sale
1= desert	1= no sale

Knowledge of the formation

The knowledge of the formation criterion should describe more or less how much reliable information about the formation is available. This information includes for example seismic, logs and cores. As more data is available about a region and the formation as lower is the risk of wrong interpretations what again includes higher chance of a successful project. If in a region more than enough wells are already drilled, it can be assumed that for this region seismic, logs and cores are available and also a proper geological map. With all this knowledge, the chance of a successful drilled phase is increased and as the drilling counts as most expansive part, the success of the whole project is increased too.

To evaluate the knowledge of the formation criterion, the number of drilled wells in the area will be used as these wells reflect more or less the available and reliable information about a formation in a region. If in a region already more wells were drilled, it can be assumed that, a lot of data and information about the geology in this region will be available and vice versa. Hence, to evaluate the knowledge of the formation, the number of wells per square kilometre in a region will be counted and evaluated.

For the scale, quantitative performance indicators were used. The results of the drilled wells per square kilometre reflect the knowledge of the formation criterion. As worst level of performance was no knowledge or total new field defined, as for a new field only very poor information is available what means that the risk of jeopardizing the project is very high. The best level was defined as a total known field what means more than 0.05 drilled wells per square kilometre are drilled and therefore many data is available. The conversion from the qualitative classification to a quantitative classification is shown in Table 33. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all regions were evaluated.

Table 33: Conversion of the quantitative classification of the impact to the qualitative classification system and the knowledge of the formation performance scale

Wells drilled in the area [drilled wells/km2]	Knowledge of the formation
10= >0.05	10= total known field
9= 0.049 - 0.025	9= very good (a little bit of the area is uncertain)
8= 0.024 - 0.01	8= good (parts of area is uncertain)
7= 0.0099-0.008	7= medium high (wells all over the field distributed, geophysical parameter from nearly all wells)
6= 0.0079-0.006	6= medium (wells all over the field distributed)
5= 0.0059-0.004	5= medium low (wells all over the field distributed, low geophysical information)
4= 0.0039-0.002	4= moderate (wells on half of the area)
3= 0.0019-0.1	3= low (few wells, pretty new field, seismic + logs)
2= <0.001	2= very low (few wells, pretty new field, only seismic)
1= 0	1= no knowledge or total new field

Probability of production disruptions & damages

The probability of production disruption & damages criterion should describe the risk of incidents or accidents because of natural disasters. These disasters include earthquakes, floods and cyclones. In every region around the world the risk is different and also the kind of natural disaster which can appear depends on the location of the region, e.g. is it next to the sea or a big river than the risk of flooding is higher or is the region located on a high risk earthquake zone than the risk of earthquakes is higher. All these disasters can lead to production disruptions or even damages on the production facilities.

To evaluate the probability of production disruption & damages, world maps were used which have marked the different risk regions of every natural disaster. Therefore, the chance of a production disruption or damage is higher in high-risk zones of one of the three natural disasters and vice versa.

For the scale, qualitative performance indicators were used. The results of the disaster risk reflect the probability of production disruption & damages criterion. As worst level of performance was total loss of production & total demolition defined, as a very high risk of a natural disaster means that the risk of production disruption and damages is very high. The best level was defined as no downtime and no damages what means in this region is nearly no risk of any natural disaster. The conversion from the qualitative classification of the disaster risk to a qualitative classification of production disruption & damages criterion is shown in Table 34. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all regions were evaluated.

Table 34: Conversion of the qualitative classification of the disaster risk to the qualitative classification system for the chance of production disruption & damages and performance scale

Disaster risk	Probability of production disruption & damages
10= no earthquakes/ floods /cyclones	10= no downtime & no damage
9= very low earthquakes/ floods /cyclones risk	9= little chance of downtime & little damages
8=low earthquakes/ floods /cyclones risk	8=low chance of losses of production & low damage
7=medium low earthquakes/ floods /cyclones risk	7=medium low chance of losses of production & medium low damage
6= medium earthquakes/ floods /cyclones risk	6= medium chance of losses of production & medium damage
5= medium high earthquakes/ floods /cyclones risk	5= medium high chance of losses of production & medium big damage
4= high earthquakes/ floods /cyclones risk	4= high chance of losses of production & high damage
3= very high earthquakes/ floods /cyclones risk	3= major chance of losses of production & major damage
2= major earthquakes/ floods /cyclones risk	2= extreme chance of losses of production & extreme damage
1= extreme earthquakes/ floods /cyclones risk	1= total loss of production & total demolition

Infrastructure in place

The infrastructure in place criterion describes how good developed a region is. This criterion pays attention to how much investments have to be done for the infrastructure to be even able to perform a successful geothermal energy production project. For example, if the region is located in the middle of a desert, there are no roads, no electric grid, and absolutely no buildings, everything has to be constructed what means a higher investment is needed to even be able to start the project by building an accurate infrastructure.

For the scale, qualitative performance indicators were used. The results of the infrastructure reflect the infrastructure in place criterion. As worst level of performance was no infrastructure defined, as no infrastructure needs the highest investment and therefore jeopardizes the whole project. The best level was defined as total geothermal infrastructure in the area. The conversion from the qualitative classification of the infrastructure to a qualitative classification of infrastructure in place is shown in Table 35. The dependency on performance indicators and the quantities of criteria is linear. Based on this scale all regions were evaluated.

Table 35: Conversion of the qualitative classification of the infrastructure to the qualitative classification system for infrastructure in place and performance scale

Infrastructure	infrastructure in place
10= more than one geothermal plant in the area	10= total geothermal infrastructure in the area
9= one geothermal plant in the area or geothermal heat infrastructure	9= necessary geothermal infrastructure in the area
8= strong industry area (plants in the area)	8=energy infrastructure in the area
7= medium industry area (one plant)	7= most parts of the energy infrastructure in the area
6= low industry area	6= parts of the energy infrastructure in the area
5= gas & oil infrastructure in the area	5= few parts of the energy infrastructure in the area
4= any other infrastructure (hotels, cities,...)	4= other/civil infrastructure (hotels, cities,...)
3=small villages	3=parts of civil infrastructure
2= streets or grid	2= basic infrastructure
1= no infrastructure	1= no infrastructure

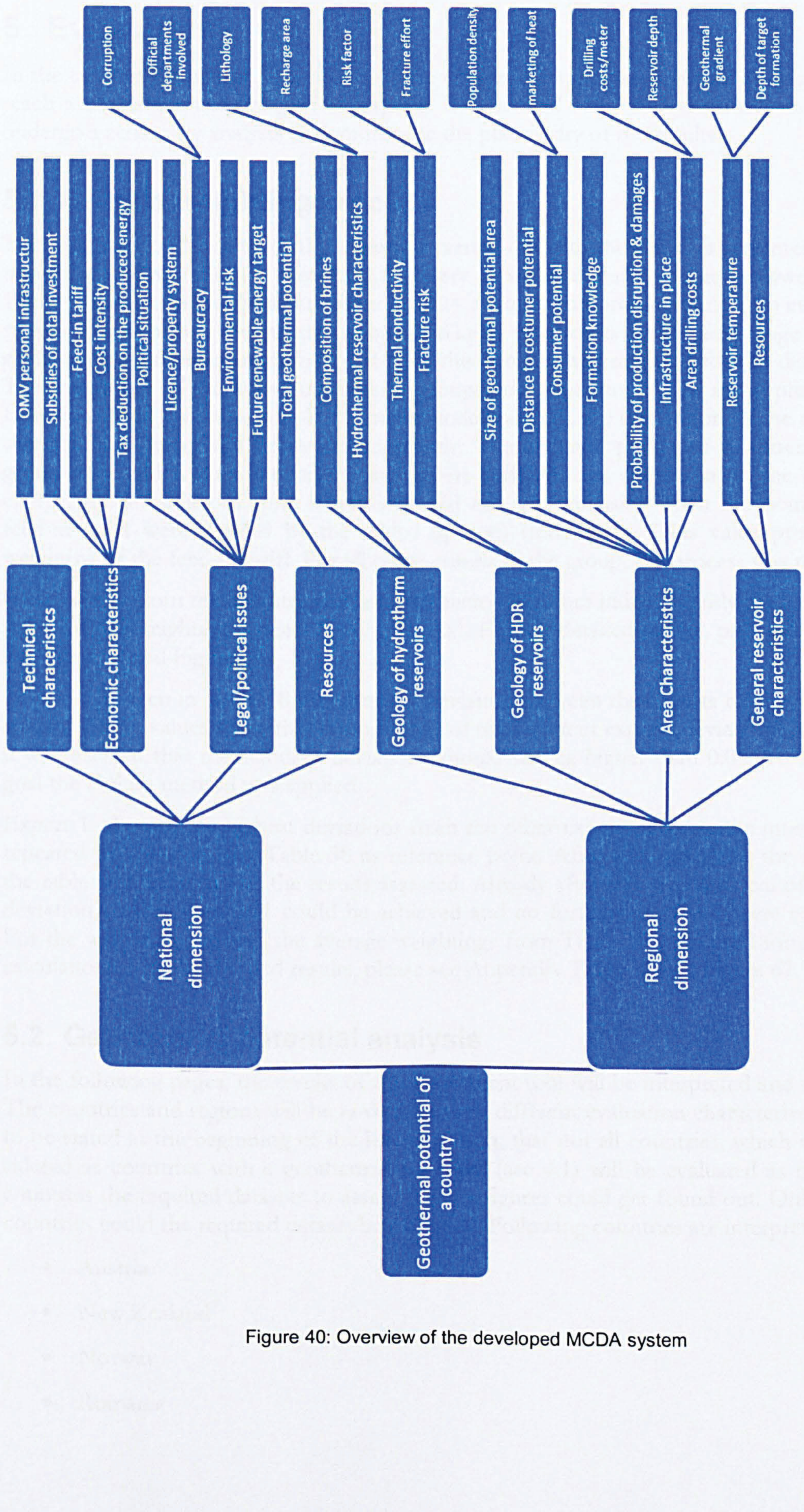

Figure 40: Overview of the developed MCDA system

5 Evaluation

In the chapter Evaluation, the results of the expert interviews are analysed and assessed to reach a consistent weighting of all experts. In a second step, the assessment tool has to undergo a sensitivity analysis to demonstrate the plausibility of the results.

5.1 Criteria weighting process

The weighting of the individual criteria was carried out with the aid of expert interviews by using the SWING method (see 3.2.2.1). Every expert could assign points between 0 and 100 (0= absolute not important criterion, 100= absolute important criterion) to every criterion in its group. In a second step, they could again give points in the same range for every group in the dimensions and in a last step, this process was repeated for the dimensions. The weightings of the individual criteria, groups and dimensions were accomplished with Equation 2. To give an example for better understanding, the calculation of the economic characteristic group will be described shortly: The assigned points of all criteria in this group were added up what means the feed-in tariff, the tax deduction on the produced energy, the subsidies of total investment and the cost intensity. Then the points of the feed-in tariff were divided by the added up sum from above. This value presents the weighting of the feed-in tariff. For all other criteria in the group, the process was repeated.

Four experts from the industry and research sector filled out independently the list of questions for the weighting process (see Appendix). For the detailed results, please see Appendix Table 38 and Figure 66.

As it can be seen in Table 38 the standard deviation between the experts reaches values up to 0.08. These values show that the opinions of the different experts deviate too much and it was decided that the standard deviations should not be higher than 0.01. To reach this goal the Delphi method was applied.

Expert 1. showed the highest deviations from the other experts. Hence, the interview was repeated by showing him Table 38 as reference point. After accomplishing the interview, the table was updated and the results assessed. Already after this step the goal of standard deviation smaller than 0.01 could be achieved and no further interviews were conducted. For the weighting process, the average weightings from Table 39 were used for all further calculations. For the detailed results, please see Appendix Table 39 and Figure 67.

5.2 Geothermal potential analysis

In the following pages, the results of the assessment tool will be interpreted and evaluated. The countries and regions will be ranked by their different evaluation characteristics. It has to be stated at the beginning of the interpretation, that not all countries, which were considered as countries with a geothermal potential (see 4.1) will be evaluated as not for all countries the required datasets to assess the key figures could get found out. Only for five countries could the required dataset be provided. Following countries are interpreted:

- Austria
- New Zealand
- Norway
- Romania

- Slovakia

It has to be mentioned that New Zealand and Norway have a very important role, as these two countries are used as benchmarks. New Zealand can be considered as a country with a very high potential and Norway as country with a very low potential. Therefore, these countries are more or less used as benchmark for the upper limit (New Zealand) and lower limit (Norway). For OMV Austria, Romania and Slovakia were the countries, which had highest priority to get interpreted and ranked. So all effort was put in these countries to identify their key figures. The key figure tables with all necessary data and the calculation of the assessment tool for all five countries can be found in the Appendix.

5.2.1 National dimension evaluation

In a first step, the overall result of the national dimension of all countries will be discussed, to be able to analyse the result in more detail in further steps. Following result showed the national dimension for the five countries:

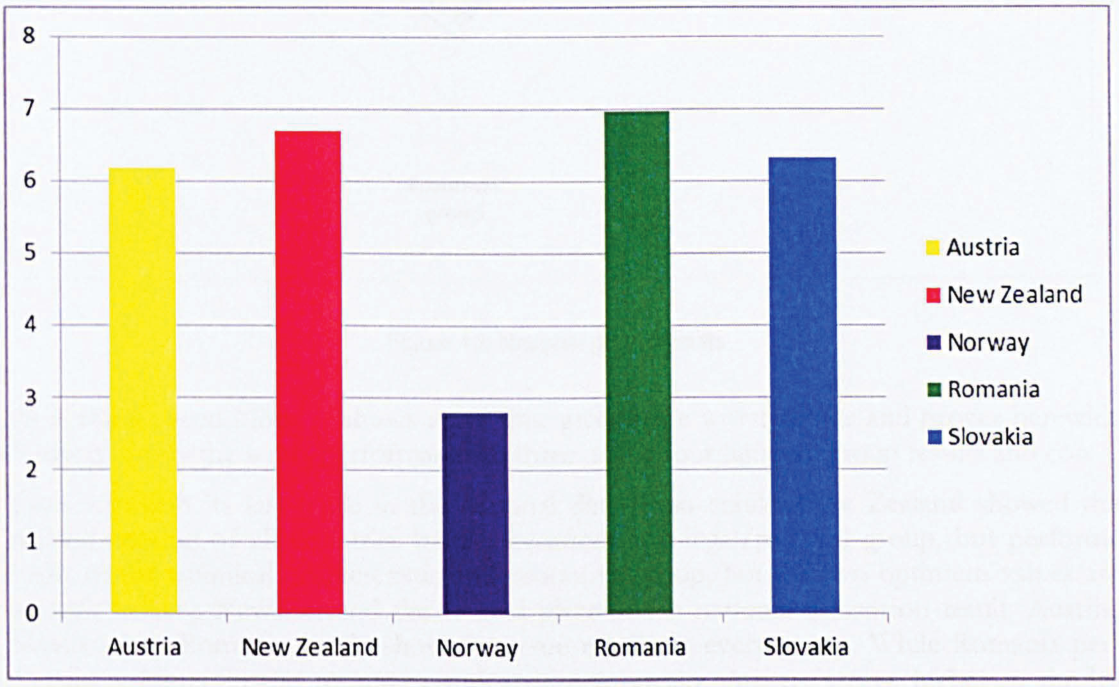

Figure 41: National dimension result

Romania shows in a direct comparison with all the other four countries the best result in the national dimension. This result shows that Romania is the most attractive country to carry out a geothermal energy project by considering all circumstances on the national level. New Zealand is the second most attractive country followed by Slovakia and Austria. Norway shows the worst performance of all countries, with not even half of the points compared with rank four and is therefore the most unattractive country from national stand point of view.

To interpret the national dimension result in more detail, an analysis of the national groups was accomplished. Therefore, all four groups, technical characteristics, legal/political group, economic group and resources of all five countries, were compared (see Figure 42). It has to be mentioned that in the national dimension result the weighting coefficients are taken into account and therefore, the group results can only be used as a trend interpretation for the national dimension result.

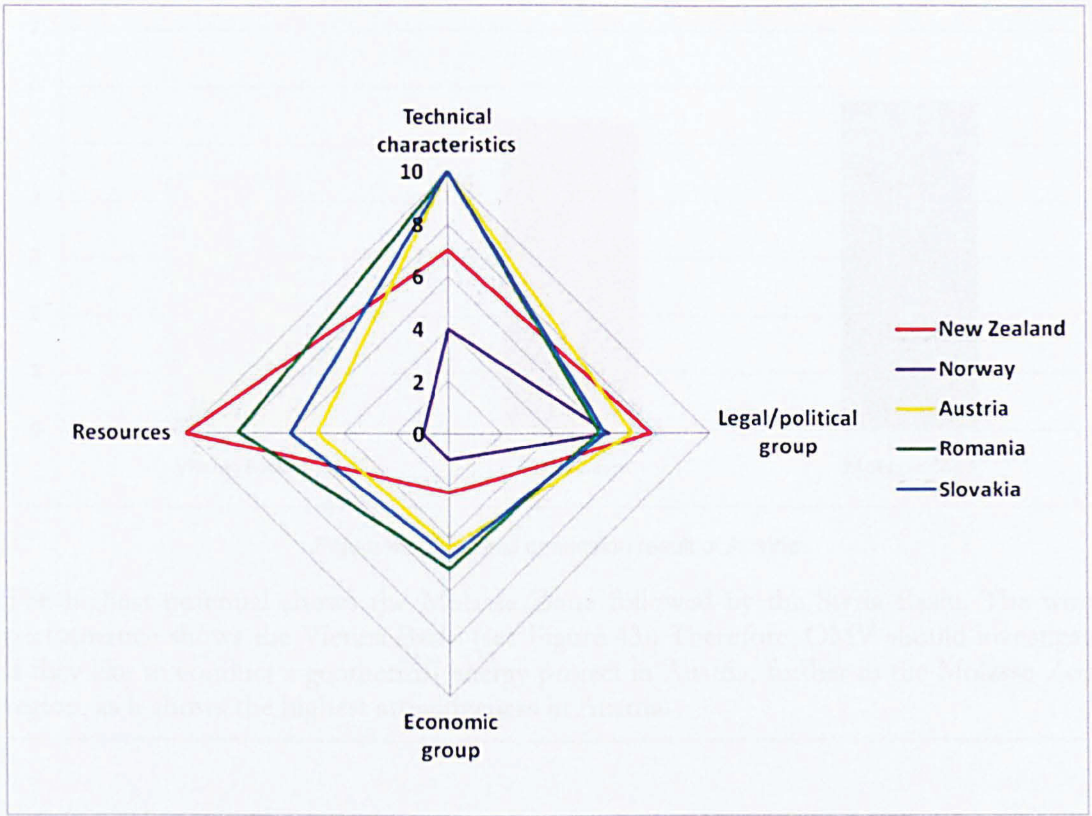

Figure 42: National group results

As it can be seen Norway shows in all four groups the worst results and proves herewith Norway shows the worst performance in three of the four national group results and con

firms herewith its last place in the national dimension result. New Zealand showed the highest scoring of all countries in the resources and legal/political group, but performs badly in the technical characteristic and economic group, but the two optimum values are enough to save New Zealand the second place in the national dimension result. Austria, Slovakia and Romania nearly show the same results in every group. While Romania performance better in the resources and economic group, Austria scores higher in the legal/political group, but like stated above, the weighting influences the national dimension result.

5.2.2 Regional dimension evaluation

The regions of every country, with more than one region will be interpreted in detail.

5.2.2.1 Austria

In a first step, the overall result of the regional dimension of Austria of all regions will be discussed, to be able to analyse the result in more detail in further steps. Following result showed the regional dimension for the three regions:

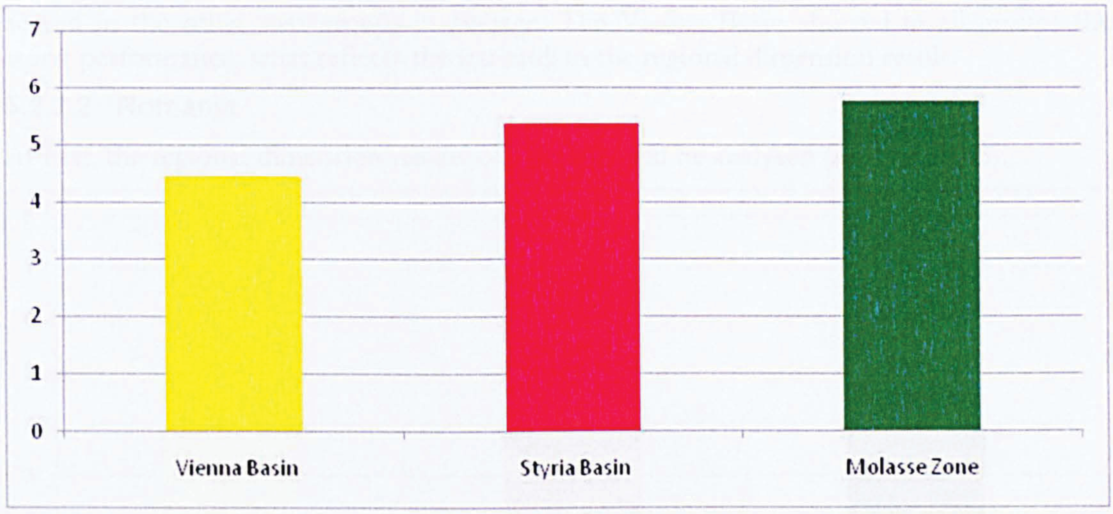

Figure 43: Regional dimension result of Austria

The highest potential shows the Molasse Zone followed by the Styria Basin. The worst performance shows the Vienna Basin (see Figure 43). Therefore, OMV should investigate, if they like to conduct a geothermal energy project in Austria, further in the Molasse Zone region, as it shows the highest attractiveness in Austria.

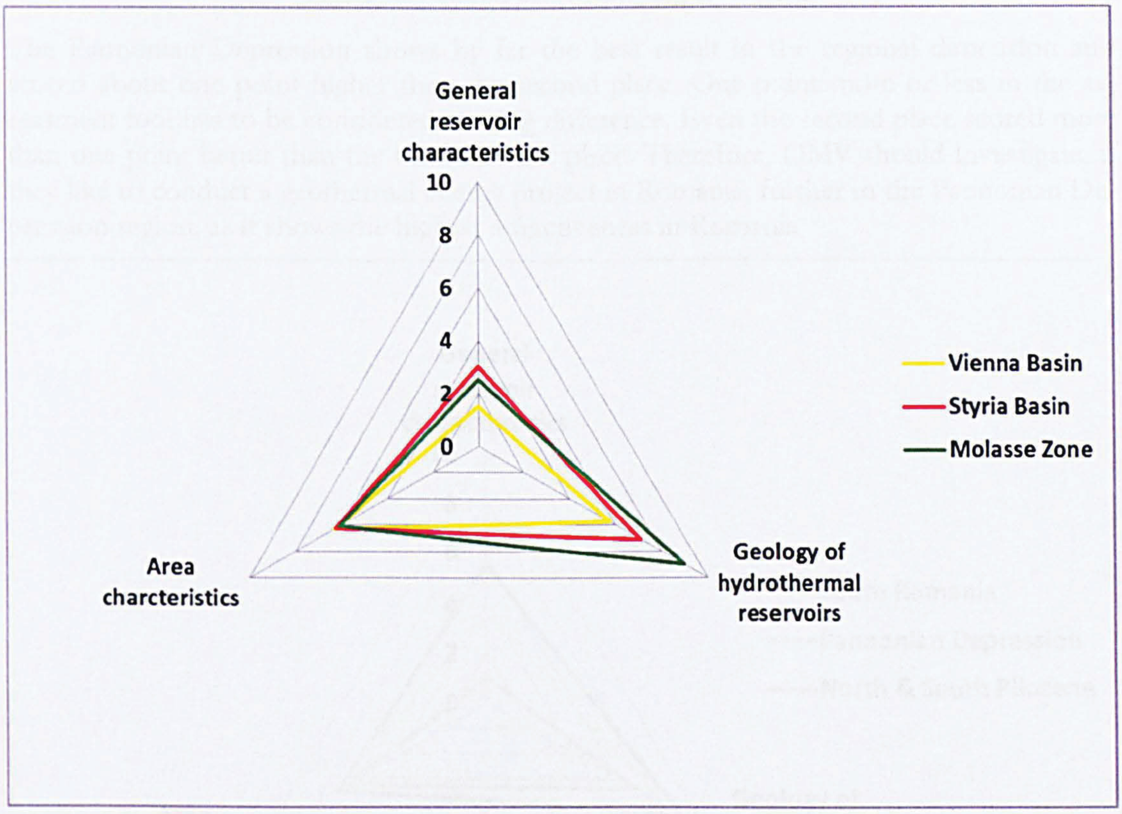

Figure 44: Regional group result of Austria

The regional group results of Austria confirm the regional dimension result. While the Molasse Zone scores in the area characteristics and the general reservoir characteristics in average, it shows the best results by far in the group of geology of hydrothermal reservoirs. The Styria Basin showed in the general reservoir characteristics the best performance and scored in the other two groups in average. The Vienna Basin showed in all groups the worst performance, what reflects the last rank in the regional dimension result.

5.2.2.2 Romania

At first, the regional dimension results of Romania will be analysed (see Figure 45).

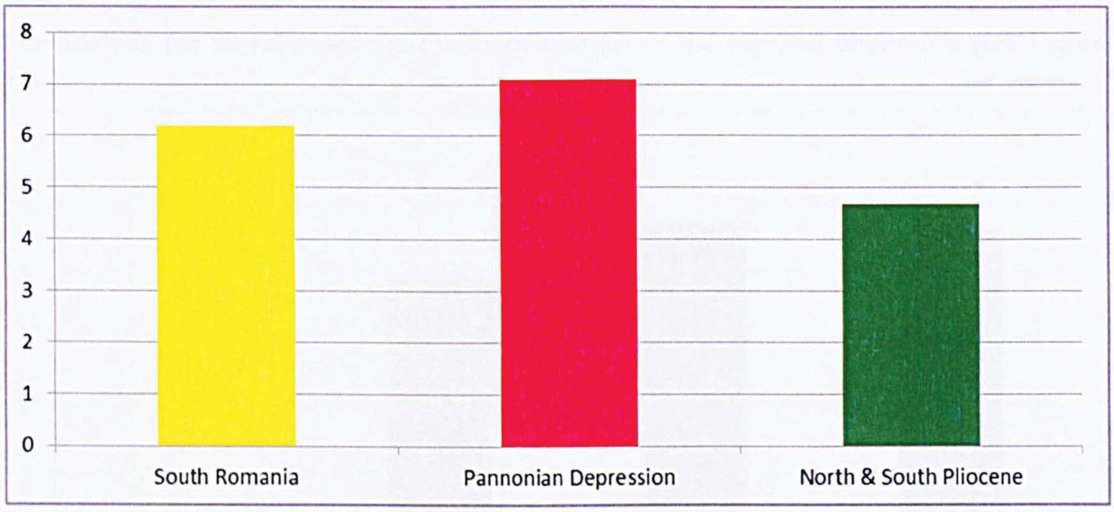

Figure 45: Regional dimension result of Romania

The Pannonian Depression shows by far the best result in the regional dimension and scored about one point higher than the second place. One point more or less in the assessment tool has to be considered as a big difference. Even the second place scored more than one point better than the third and last place. Therefore, OMV should investigate, if they like to conduct a geothermal energy project in Romania, further in the Pannonian Depression region, as it shows the highest attractiveness in Romania

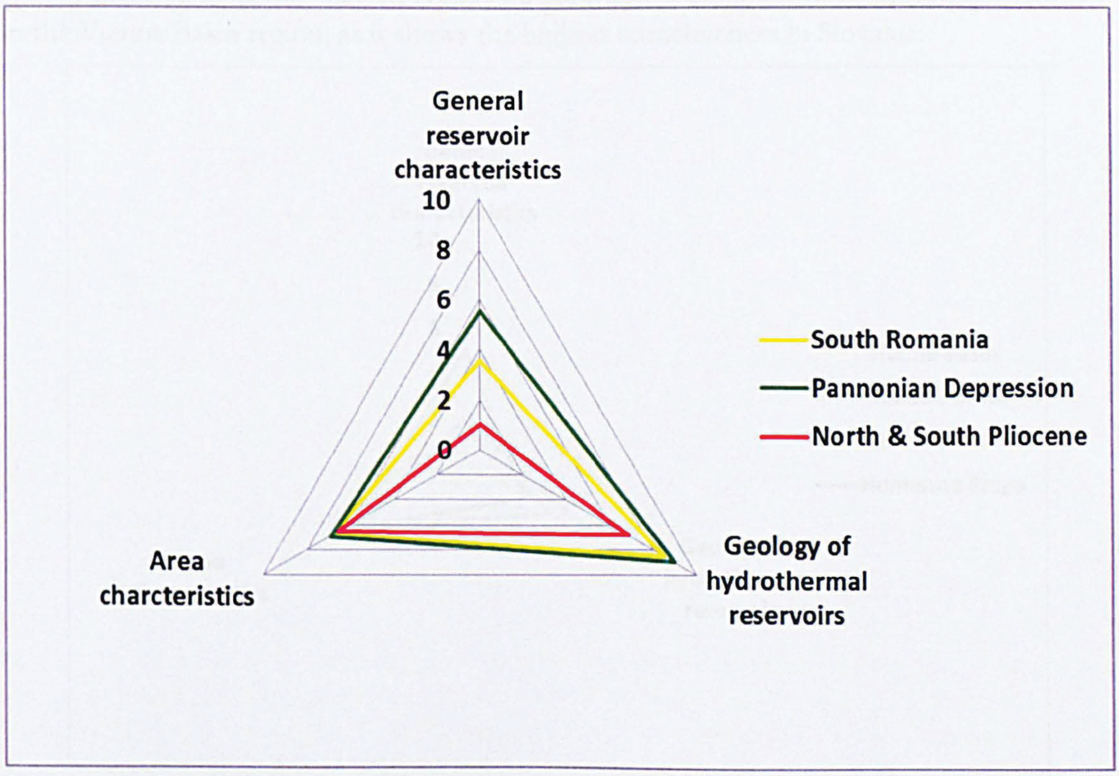

Figure 46: Regional group result of Romania

The Pannonian Depression performs in all groups as best, compared to the other regions. South Romania scored in all groups in average and North & South Pilocene showed in every group the worst result. Therefore, reflect the group results exactly the regional dimension results.

5.2.2.3 Slovakia

The analysis for Slovakia will start with an analysis of the regional dimension (see Figure 47).

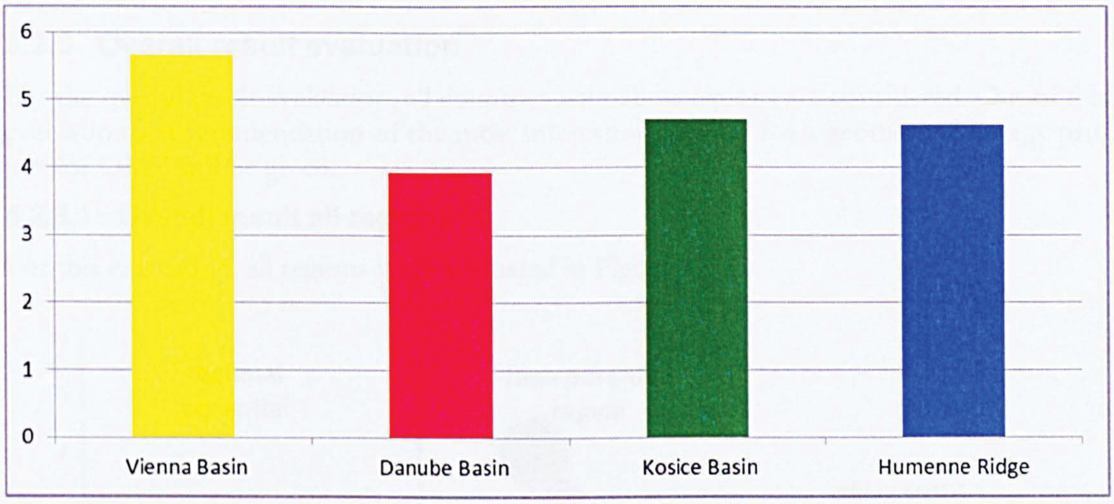

Figure 47: Regional dimension result of Slovakia

The Vienna Basin showed the best performance of all regions in Slovakia. The Kosice Basin reaches the second place with narrow margin on the third place, which reached the Hummenne Ridge. The worst performance shows the Danube Basin. Therefore, OMV should investigate, if they like to conduct a geothermal energy project in Slovakia, further in the Vienna Basin region, as it shows the highest attractiveness in Slovakia.

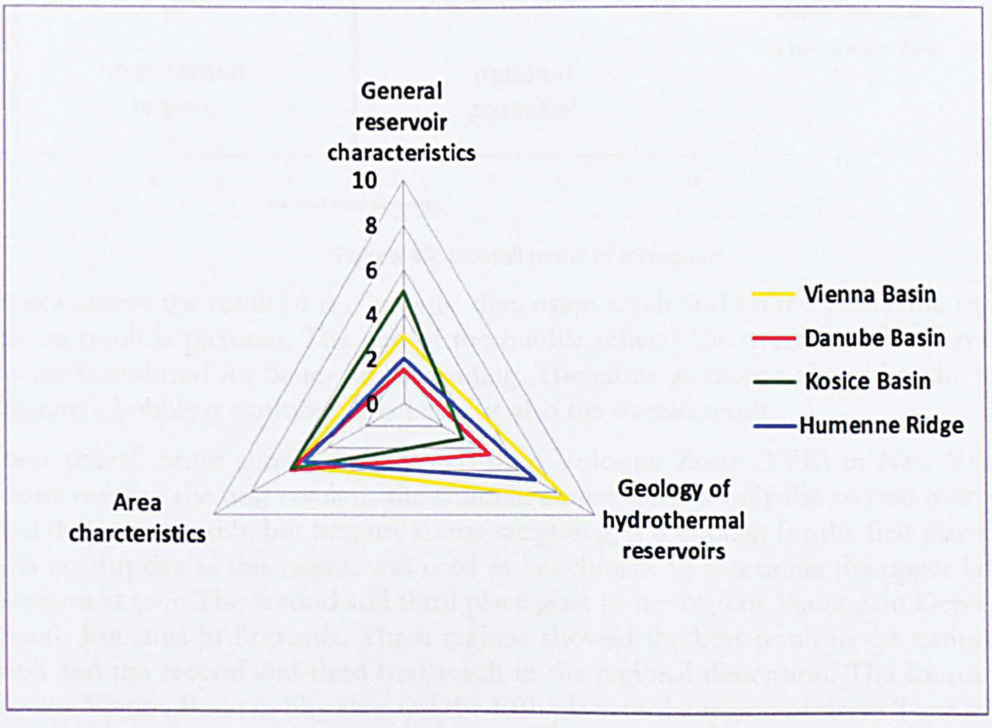

Figure 48: Regional group result of Slovakia

The Vienna Basin scored in all three groups with the highest scoring, what confirms the dimension result. The Kosice Basin shows interesting group results compared to its second place in the dimension result. While it shows an average result in the area characteristics group, it shows on the one hand the best performance of all regions in the general reservoir characteristics group and on the other hand the worst in the group of geology of hydrothermal reservoirs. The Humenne Ridge region scored more or less average in all groups and the Danube Basin showed nearly in every group the worst performance, only in the area characteristics the Danube Basin showed the highest scoring..

5.2.3 Overall result evaluation

For the overall result evaluation, all countries with all its regions are considered. Out of this evaluation a recommendation of the most interesting country for a geothermal energy project for OMV will be given.

5.2.3.1 Overall result all regions

For this evaluation, all regions were evaluated in Figure 49.

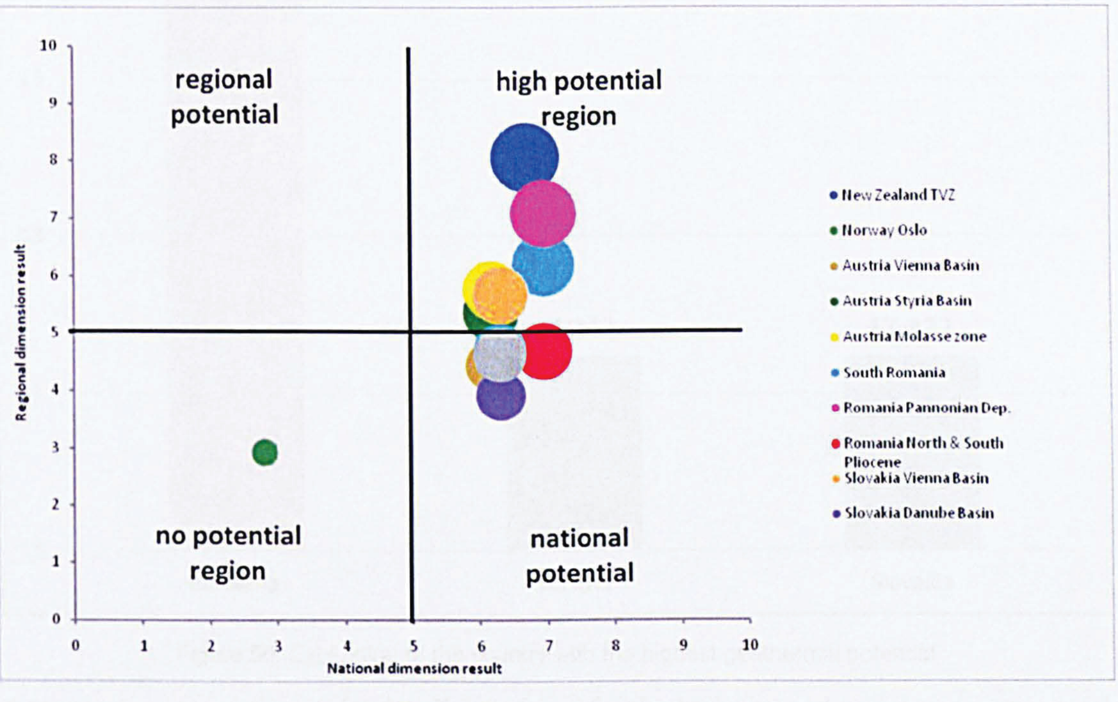

Figure 49: Overall result of all regions

The x-axis shows the result of the national dimension result and on the y-axis, the regional dimension result is pictured. The size of the bubble reflects the overall result. Also quadrants were introduced for better understanding. Therefore, as more right and at the top of the diagram a bubble is positioned, as better is also the overall result.

The best overall result shows the region Taupo Volcanic Zone (TVZ) in New Zealand. This zone reached the best result in the regional dimension but only the second best in the national dimension result, but because of the weighting, it is enough for the first place. This result is no surprise as this region was used as benchmark to determine the upper limit of the assessment tool. The second and third place goes to the regions Pannonian Depression and South Romania in Romania. These regions showed the best result in the national dimension and the second and third best result in the regional dimension. The fourth place goes to the Vienna Basin in Slovakia and the fifth place to the region Molasse Zone in Austria. For all further regions, the ranks are stated in Table 36.

Table 36: Overall result of all regions

Country/ Region	Rank	Overall result	National	Regional
New Zealand/ TVZ	1	7.29	6.69	8.06
Romania/ Pannonian Dep.	2	7.02	6.96	7.08
Romania/ South Romania	3	6.63	6.96	6.19
Slovakia/ Vienna Basin	4	6.03	6.31	5.67
Austria/ Molasse zone	5	5.99	6.18	5.75
Romania North & South Pliocene	6	5.98	6.96	4.70
Austria/ Styria Basin	7	5.82	6.18	5.36
Slovakia/ Kosice Basin	8	5.62	6.31	4.71
Slovkia/ Humenne Ridge	9	5.59	6.31	4.64
Austria/ Vienna Basin	10	5.42	6.18	4.44
Slovakia/ Danube Basin	11	5.28	6.31	3.92
Norway/ Oslo	12	2.86	2.82	2.92

Based on these results and due to the fact that OMV is mostly interested in the countries Austria, Romania and Slovakia, the evaluation for the recommendation to the OMV is done by adding up the best three regions of a country.

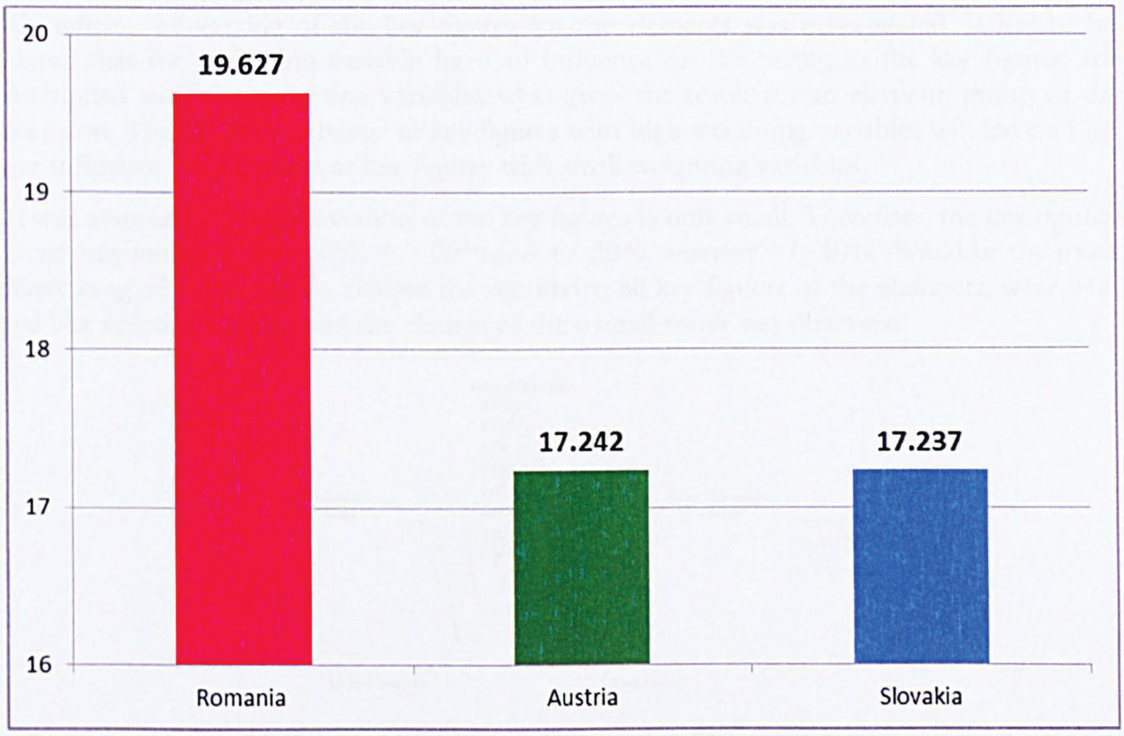

Figure 50: Evaluation of the country with the highest geothermal potential

As it can be seen in Figure 50, has Romania by far the highest geothermal energy potential by considering the best three regions in the country. Austria and Slovakia show nearly the same result, whereat Austria shows a slightly better result. Therefore, the recommendation is to investigate further in Romania if a geothermal energy project is planned and there, in the region Pannonian Depression. In further steps, Austria and Slovakia should be analyzed. It has also to be stated or kept in mind, because of the close run between Austria and Slovakia, that Slovakia has more potential regions than Austria. Therefore, has Slovakia a small advantage against Austria and maybe should be considered for the second place in the ranking, even the performance is slightly lower than the Austrian performance.

5.3 Sensitivity analysis

The sensitivity analysis should show the impact of changes in various variables on the total result and therefore, reflect how sensitive the system is on variation of the datasets (see 3.3.2).

5.3.1 Key figure sensitivity

While the weighting variables were determined by expert interviews and calculated on the base of their evaluation, the key figures were determined by assessing quantitative or qualitative characteristics with the aid of performance scales. These performance scales were developed by using the characteristics of the key figure and out of the average, the highest/best and lowest/worst characteristics, a performance scale was established. Thereby the accuracy of the characteristics has a huge influence on the scales and on their evaluation.

Therefore, the varying of the key figures for the elements was investigated. It has to be stated that the weighting variable have an influence on the result, as the key figures are multiplied with the weighting variables what gives the result for an element, group or dimension. That is why, a change in key figures with high weighting variables will have a bigger influence on the result as key figures with small weighting variables.

It was assumed that the deviation of the key figures is only small. Therefore, the key figures were only varied by +/- 10%, +/- 20% and +/-30%, whereat +/- 10% should be the most likely rang of variation. To analyse the sensitivity, all key figures of the elements, were varied like described above and the change of the overall result was observed.

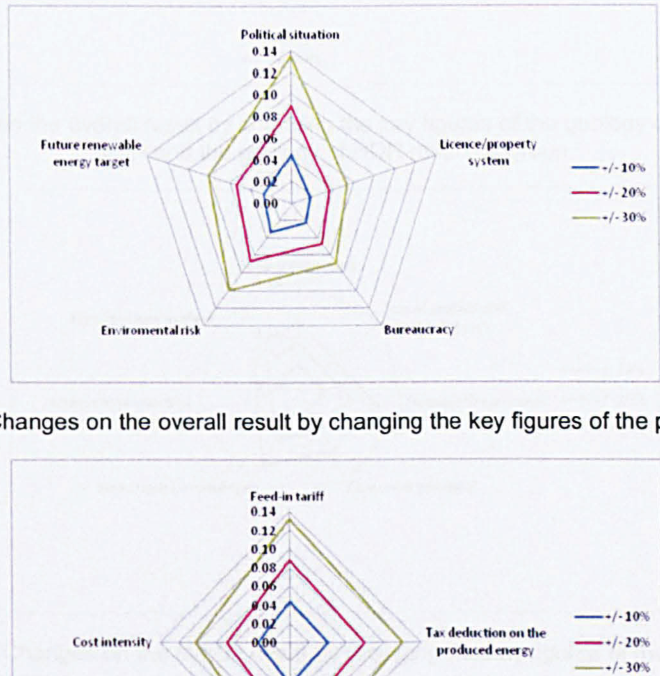

Figure 51: Changes on the overall result by changing the key figures of the political group

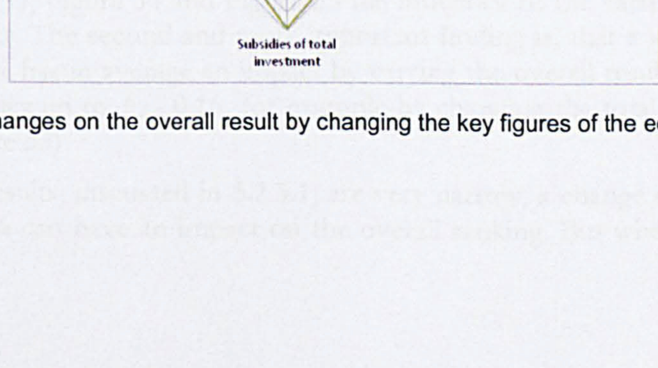

Figure 52: Changes on the overall result by changing the key figures of the economic group

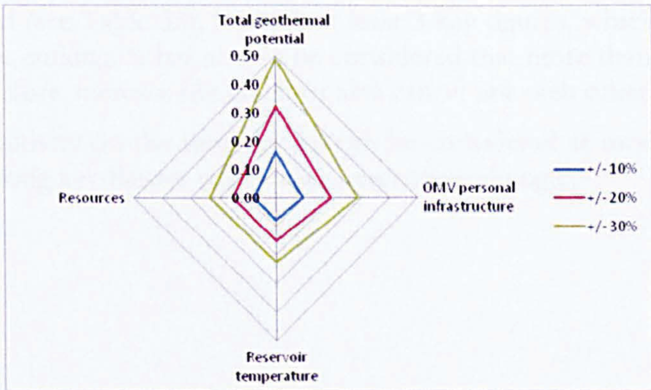

Figure 53: Changes on the overall result by changing the key figures of the technical characteristics-, resources- and general reservoir characteristics group

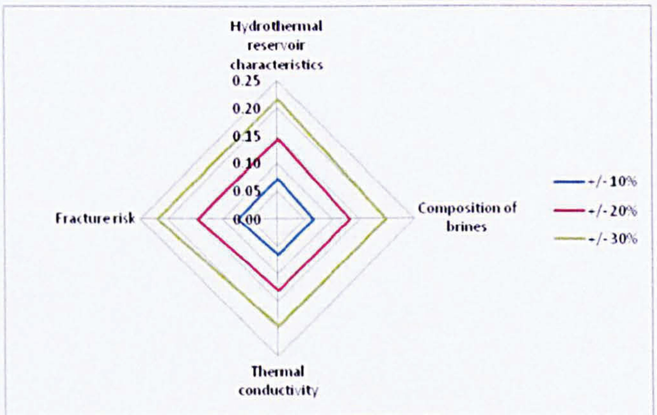

Figure 54: Changes on the overall result by changing the key figures of the geology of hydrothermal reservoir- and the geology of HDR reservoir group

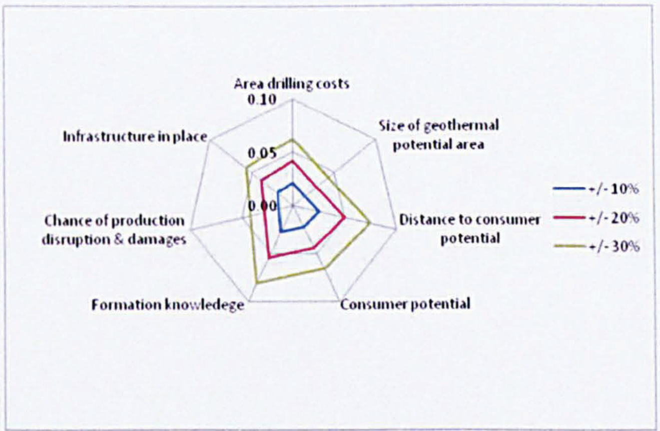

Figure 55: Changes on the overall result by changing the key figures of the area group

As it can be seen in **Fehler! Verweisquelle konnte nicht gefunden werden.**Figure 51, Figure 52, Figure 53, Figure 54 and Figure 55 the influence of the variation of the key figures behaves linear. The second and more important finding is, that a variation of the elements by +/- 10% has in average an impact by varying the overall result by +/- 0.02-0.04, but can reach values up to +/- 0.16, for example by changing the total geothermal energy element (see Figure 53).

As some of the results, discussed in 5.2.3.1, are very narrow, a change of one element key figure by +/- 10% can have an impact on the overall ranking. But when only the best regions get compared (see Table 36), it needs at least 3 key figures, which are wrong by +/- 30%, to change the ranking. It has also to be considered that more than one key figure can be wrong and therefore, increase the effect or also cancel out each other.

Therefore, the sensitivity on the total system can be considered as moderate, as it needs a high number of wrong key figures with a high percentage change.

6 Conclusion

The aim of this master thesis was to develop an assessment tool to define the geothermal energy potential of the OMV E&P countries and to find out with the aid of this tool which countries have the highest potential. Based on this study, a recommendation should be given in which countries OMV should put in further effort.

In the theoretical part of the thesis, an overview about the geothermal energy basics, the geothermal project key processes and all frameworks for the development of an assessment tool was given and discussed. Based on these findings, the multiple criteria decision analyses method was chosen to be used as framework for establishing a geothermal energy assessment tool in the main part of the master thesis. For the weighting method, the SWING method was elected. The methods meet exactly the requirements of the needed properties to develop a functional assessment tool to evaluate the geothermal potential of a country. The tool involves different criteria that have different importance and therefore have to be weighted, with the target to evaluate different alternatives. It is a very easy and uncomplicated system. Moreover, a short overview about the political circumstances, the involvement of the OMV in the countries and the geology of the OMV E&P countries are given.

As the OMV E&P country portfolio consists of 17 countries with a mix of geothermal potentials, from countries with no potential up to countries with very high geothermal potentials, it was decided to do a pre-screening. The reason therefore was, to reduce the number of countries to an amount that can be considered as commercial geothermal potential countries and to receive a number, where a detailed analysis is even possible.

To carry out the pre-screening, three meaningful and significant criteria were defined and related performance scales for the criteria were established. All 17 countries were evaluated by these three criteria. Based on the results, nine countries out of the 17 were considered as countries with a realistic and economic geothermal potential. Following nine countries were chosen for further investigations: Austria, Australia, Egypt, Kazakhstan, New Zealand, Pakistan, Romania, Slovakia and United Kingdom.

After the successful pre-screening process and the definition of the potential countries, the criteria for the assessment tool were defined. Therefore, a decision context was established and analysed. To split up the problem and to build a well arranged system out of the complex construct, the multiple criteria decision analyses system was determined as best fitting system. It was decided to start the structuring process with a top-down approach, by distinguishing between a national and a regional dimension. To define the next lower level of the system, the group-level was introduced by using a political-economic-social-technological-analysis as guideline. The groups were then again divided by an element-level. To be able to assess these elements, performance scales were defined by using a country with nearly no potential and one country with a very high geothermal energy potential as benchmark.

The final assessment tool consists therefore of three levels. The highest level is called dimension, with the national and regional dimension. The dimension level was split up in groups that are again divided by elements. The national dimension consists of four groups, namely technical characteristics, economic characteristics, legal/political issues and resources. These four groups were again divided in 13 elements. The regional dimension is based on three groups, the general reservoir characteristics, the area characteristics and depending of what kind of reservoir is in the individual regions, either geology of hydrothermal reservoirs or geology of HDR reservoirs. The three groups were divided in 11 sub-elements.

To verify and weight the individual dimensions, groups and elements, expert interviews were carried out. As the results of the individual experts for the weighting showed a too high variance in the results, the Delphi method was applied. Within one round of applying the Delphi method, the variance could be lowered to a desired variance level.

The verified multiple criteria decision analysis tool was filled with the desired key figures. Hereby it was recognized that it is not possible to come up with all key figures for all regions of the nine pre-screened countries. Therefore, it was decided in agreement with OMV that only the most important and interesting countries for OMV will be analyzed. Furthermore, one country with nearly no geothermal energy potential and one with a very high potential were used as benchmarks. Based on this decision following countries were evaluated: Austria, Romania and Slovakia. The benchmark countries are Norway as low performance country and New Zealand as high performance country.

For the evaluation of the assessment tool results, only the results of Austria, Romania and Slovakia were discussed. In a first step, the national dimension result were analyzed to evaluate, which country shows the best circumstances on a national level to carry out a geothermal energy project. The highest attractiveness showed Romania, followed by Slovakia and Austria. In a second step, the regional dimensions of all individual countries were analyzed, to determine the regions in a country that have the highest potential. The highest attractiveness in Austria showed the Molasse Zone followed by the Styria Basin and the Vienna Basin. In Romania following results were achieved, the Pannonian Depression performed best followed by South Romania and North & South Pilocene. For Slovakia the results were following, the Vienna Basin made the first place followed by the Kosice Basin, the Humenne Ridge and the Danube Basin. In a last step, the overall results of all countries and their regions were evaluated. Thereby, showed the Pannonian Depression the best performance, followed by South Romania, both regions are located in Romania. The third place made the Vienna Basin in Slovakia. On the fourth rank, comes the first Austrian region, the Molasse Zone (see Figure 49).

OMV is mostly interested on a recommendation for a country with the highest geothermal energy potential to be able to investigate further in the potential country in the future. Therefore, the country with the highest potential has to be determined. The best three regions of a country were added up and the result analyzed. The analysis showed a clear result, what proved that Romania has by far the highest potential. Austria and Slovakia showed nearly the same result whereat Austria showed a slightly better result. Therefore, the ranking is, Romania followed by Austria and Slovakia, but it has also to be mentioned that Slovakia has more potential regions as Austria. Because of this fact and only the narrow margin, also Slovakia can be considered for the second place in the ranking.

In a last step, the sensitivity of the results was analyzed. The influence of changes in the key figures of the elements was tested by changing the key figures up to +/- 30%. Thereby it was recognized, that a change of +/- 10% can have an impact on the rankings of the overall result. But to change the ranking of the regions it needs at least 3 key figures, which are wrong by +/- 30%. Hence, the assessment tool can be considered as moderate for any changes in the assessment tool.

Overall, an easy and understandable assessment tool to determine the geothermal energy potential of different countries was developed, what was proved on its functionality. The results of the tool show reasonable values.

As further recommendation to the OMV for the future approaches, following statements should be reviewed:

- The missing key figures for the rest of the nine potential countries should be determined and evaluated with the aid of the assessment tool, to be able to define a ranking for all E&P countries of the OMV.
- In case the OMV likes to start soon with a geothermal energy project, it should definitely investigate further in Romanian, as this country can be considered as the country with by far the highest potential in the evaluated three countries.

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Appendix

List of Questions: Weighting

Weighting for an assessment tool to evaluate the geothermal potential of countries

This list of questions should weight the criteria for the performance measurement system to evaluate the geothermal potential of countries.

The performance measurement system consists of two dimensions, a national and a regional one. These dimensions are split up again in groups, which again consist of different elements and sub elements. For better understanding, please see the end.

For every element and sub element key figure were found with the aid of valuation keys. After this process, every element should now get a weighting, which depends on the importance and impact of each element on the group result. The element key figure is multiplied with its weighting and these results are added up for the group result. The groups are again get weighted and added up to the dimension result which get again weighted and should give added up the overall evaluation result.

On the next few pages all elements, groups and dimensions are described shortly. **So please decide how important or how big is the impact of each criterion in your opinion for the overlying group or dimension result. Evaluate with a number between 0 and 100, whereby 0 means the weighted criterion has no importance and should have no impact on the overlying criterion and 100 means the criterion is the most important criterion and should have the biggest influence on the overlying criterion.**

Please give weightings for every element, group and dimension in all conscience.

Element weighting

Political/legal group elements

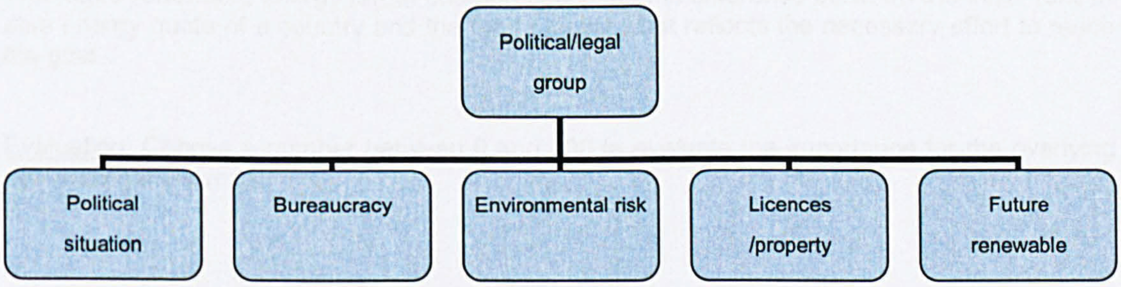

Figure 56: Overview political/legal group

Political situation:

The political situation criterion describes the stability/safety of a country, regarding is a (civil) war in the country or what is the possibility that the country is a terrorism target.

<u>Evaluation:</u> Choose a number between 0 and 100 to evaluate the importance for the overlying political/legal group:

Bureaucracy:

The bureaucracy criterion describes the effort with official departments in a country to even be able to carry out a geothermal project.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying political/legal group:

Environmental risk:

The environmental risk criterion reflects the effort, which is required to follow the environmental standards and guidelines of a country

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying political/legal group:

Licence/property systems:

The licence/property system criterion describes the still available area where it is allowed to conduct a geothermal project as fraction of the overall area.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying political/legal group:

Future renewable energy target:

The future renewable energy target criterion describes the difference between the initial renewable energy quote of a country and the future target what reflects the necessary effort to reach the goal.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying political/legal group:

Economic group elements

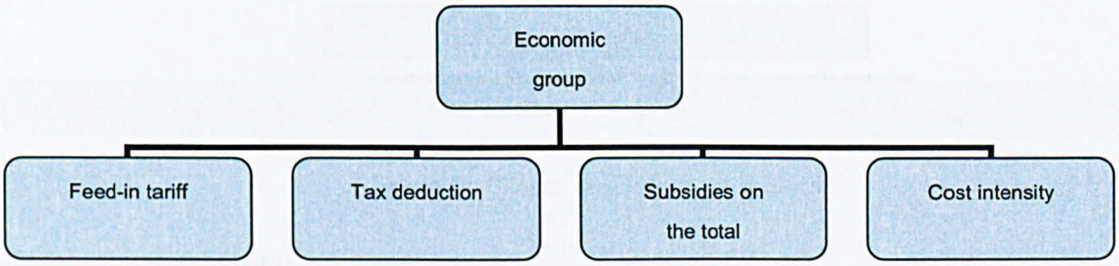

Figure 57: Overview economic group

Feed-in tariff:

The feed-in tariff criterion evaluates the sales prices for the produced geothermal energy, what has a big influence on the profitability of a geothermal project.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying economic group:

☐

Tax deduction:

The tax deduction criterion describes the tax deduction as fraction on the total revenues, which are made from the selling of the electric energy, and is therefore an indicator how attractive a country is for geothermal project.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying economic group:

☐

Subsidies on the total investment

The subsidies on the total investment criterion describe the subsidies as fraction on the total investment and are like above an indicator how attractive a country is for geothermal project.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying economic group:

☐

Cost intensity:

The cost intensity criterion reflects the drilling costs to a predefined reference depth and hence, makes the cost intensity or value of money comparable with other countries.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying economic group:

☐

General reservoir characteristic group elements

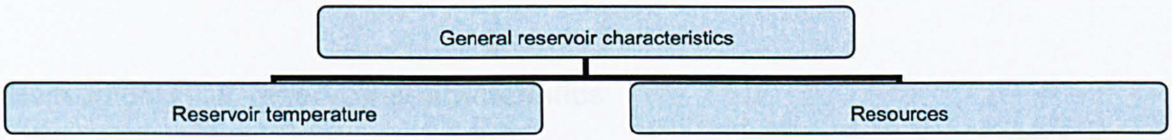

Figure 58: General reservoir characteristics

Reservoir temperature:

The reservoir temperature criterion evaluates the average reservoir temperature of a region by multiplying the temperature gradient and the reservoir depth.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying general reservoir characteristics group:

Resources:

The resources criterion evaluates the geothermal energy resources in a region.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying general reservoir characteristics group:

Geology of hydrothermal reservoirs group elements

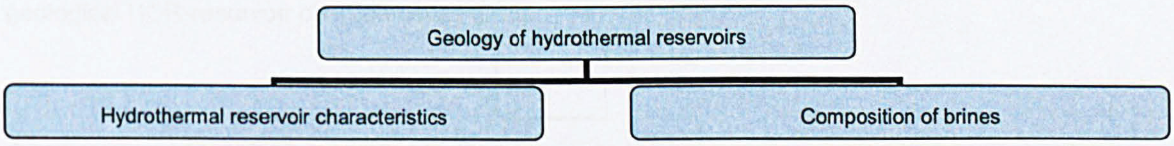

Figure 59: Overview geology of hydrothermal reservoirs

Hydrothermal reservoir characteristics:

The hydrothermal reservoir characteristics criterion describes the quality and life expectancy of a reservoir regarding the production, which depends on the permeability and the size of the aquifer, and if the aquifer gets refilled or not.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying geology of hydrothermal reservoirs group:

Composition of brines:

The composite of brines criterion describes the average total dissolved solids in the reservoir fluid and is therefore an indicator for the possibility of debris.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying geology of hydrothermal reservoirs group:

Geological HDR-reservoir characteristics

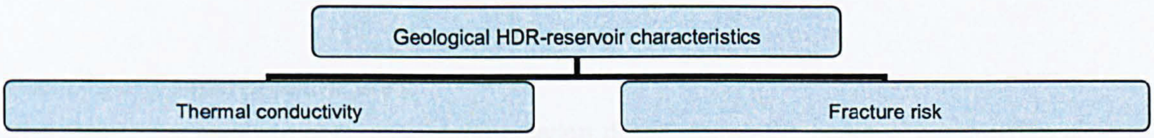

Figure 60: Overview geological HDR-reservoir characteristics

Thermal conductivity:

The thermal conductivity criterion describes how fast heat can be transported through a material and therefore how much fluid can get pumped through the formation what also gives the possible energy production.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying geological HDR-reservoir characteristics group:

Fracture risk:

The fracture risk criterion describes the possible risks, e.g. earthquakes that can appear when the formation gets fracture to create channels through the target formation.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying geological HDR-reservoir characteristics group:

Area characteristics group elements:

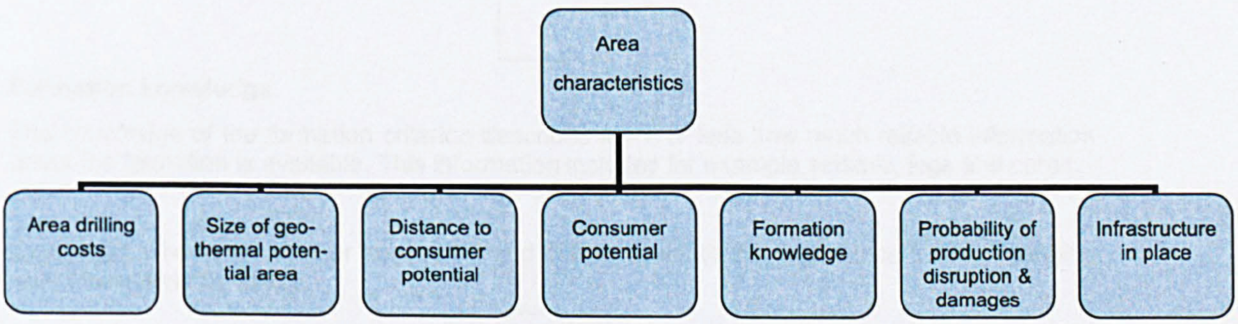

Figure 61: Overview area charcteristics

Area drilling costs

The area drilling costs criterion describes the rough drilling costs to drill a geothermal well to the target formation in a region.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying area characteristics group:

Size of geothermal potential area:

The size of the geothermal potential area criterion describes, as the name of the criterion already says, the size of the area where a geothermal potential exists and only such potential where it is possible to produce electric energy out of the stored heat energy in this area.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying area characteristics group:

Distance to consumer potential

The distance to consumer potential criterion evaluates how far away the next bigger consumer is potential to sell the energy to.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying area characteristics group:

Consumer potential:

The consumer potential criterion evaluates the possible demand in the area to sell the electricity and the waste heat to.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying area characteristics group:

Formation knowledge

The knowledge of the formation criterion describes more or less how much reliable information about the formation is available. This information includes for example seismic, logs and cores.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying area characteristics group:

Probability of production disruption & damages

The probability of production disruption & damages criterion describes the risk of incidents or accidents because of natural disasters.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying area characteristics group:

Infrastructure in place

The infrastructure in place criterion describes how good developed a region is. This criterion pays attention to how much investments have to be done for the infrastructure to be even able to perform a successful geothermal energy production project.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying area characteristics group:

Group weighting

National dimension:

Please weight now the overlying groups of the elements:

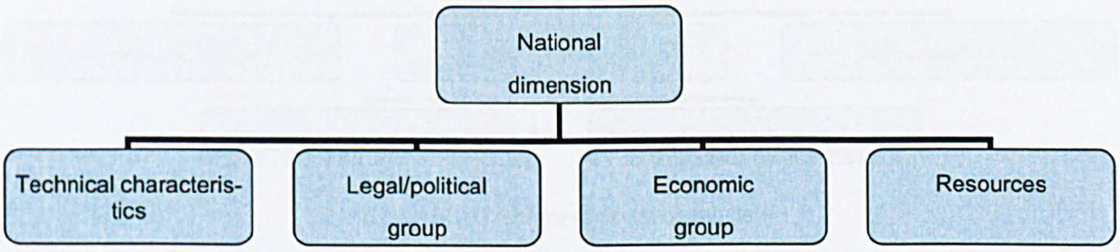

Figure 62: Overview national dimension

Technical characteristics

The technical group evaluates the personal infrastructure of the OMV in the country. No project is to achieve if there is not a key personal available.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying national dimension:

Legal/political group:

Please see the legal/political group elements on page 1. for a better understanding.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying national dimension:

Economic group:

Please see the economic group elements on page 2. for a better understanding.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying national dimension:

Resources:

The total geothermal potential of a country is one of the key indicators for the geothermal electric energy production potential of a country. It gives an overview about the resources in a country and depends more or less on the geological circumstances.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying national dimension:

Regional dimension:

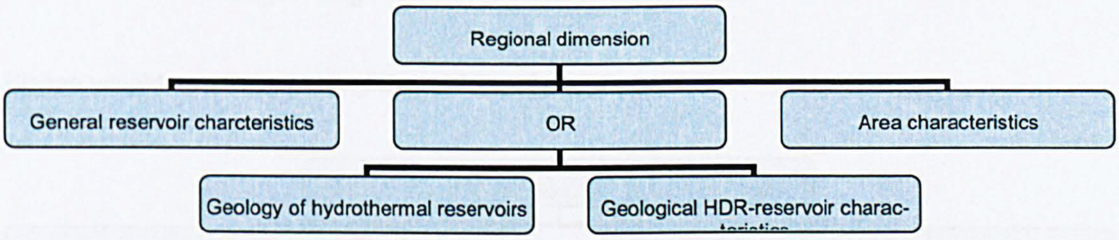

Figure 63: Overview regional dimension

For the region dimension groups it has to be mentioned that either the geology of hydrothermal group or the geological HDR-reservoir characteristics group will be used for the evaluation. It depends on which kind of reservoir it is in the region. So please weight both.

General reservoir characteristics:

Please see the general reservoir characteristics group elements on page 3. for a better understanding.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying regional dimension:

Geology of hydrothermal reservoirs:

Please see the geology of hydrothermal reservoir group elements on page 3. for a better understanding.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying regional dimension:

Geological HDR-reservoir characteristics

Please see the geological HDR-reservoir characteristics group elements on page 3. for a better understanding.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying regional dimension:

Area characteristics

Please see the area characteristics group elements on page 4. for a better understanding.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying regional dimension:

Dimension weighting

Please weight now the overlying dimensions of the groups.

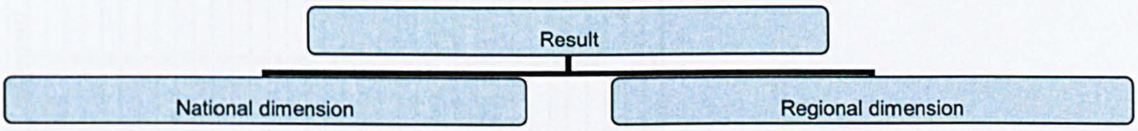

Figure 64: Overview result

National dimension:

Please see the national dimension groups on page 5. for a better understanding.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying overall result:

Regional dimension:

Please see the regional dimension groups on page 6. for a better understanding.

Evaluation: Choose a number between 0 and 100 to evaluate the importance for the overlying overall result:

Thank you very much for your help.

First round results expert interviews

Elements	Weighting Expert 1	Calculation Expert 1	Weighting Expert 2	Calculation Expert 2	Weighting Expert 3	Calculation Expert 3	Weighting Expert 4	Calculation Expert 4	Average Weighting	Average on Calculation	Standard deviation Calculation
Political situation	30	0,11	90	0,31	90	0,31	100	0,33	77,5	0,27	0,11
licence/property system	80	0,29	10	0,03	60	0,21	50	0,17	50,0	0,17	0,11
Bureaucracy	0	0,00	70	0,24	40	0,14	50	0,17	40,0	0,14	0,10
Enviromental risk	80	0,29	80	0,28	50	0,17	50	0,17	65,0	0,23	0,06
Future renewable energy target	90	0,32	40	0,14	50	0,17	50	0,17	57,5	0,20	0,08
Feed-in tariff	90	0,25	70	0,28	80	0,28	70	0,27	77,5	0,27	0,01
Tax deduction on the produced energy	80	0,22	70	0,28	80	0,28	50	0,19	70,0	0,24	0,04
Subsidies of total investment	100	0,28	70	0,28	90	0,31	70	0,27	82,5	0,28	0,02
Cost intensity	90	0,25	40	0,16	40	0,14	70	0,27	60,0	0,20	0,06
Reservoir temperature	90	0,47	90	0,50	100	0,50	100	0,50	95,0	0,49	0,01
Resources	100	0,53	90	0,50	100	0,50	100	0,50	97,5	0,51	0,01
Hydrothermal reservoir characteristics	60	0,75	60	0,50	90	0,56	70	0,50	70,0	0,58	0,12
Composition of brines	20	0,25	60	0,50	70	0,44	70	0,50	55,0	0,42	0,12
Thermal conductivity	80	0,67	60	0,43	90	0,53	70	0,42	75,0	0,51	0,11
Fracture risk	40	0,33	80	0,57	80	0,47	95	0,58	73,8	0,49	0,11
Area drilling costs	80	0,18	75	0,13	70	0,17	50	0,10	68,8	0,15	0,04
Size of geothermal potential area	30	0,07	80	0,14	20	0,05	70	0,15	50,0	0,10	0,05
Distance to consumer potential	90	0,20	90	0,16	70	0,17	80	0,17	82,5	0,18	0,02
Consumer potential	30	0,07	100	0,18	70	0,17	80	0,17	70,0	0,15	0,05
Formation knowledege	80	0,18	80	0,14	100	0,24	100	0,21	90,0	0,19	0,04
Chance of production disruption & damages	60	0,14	50	0,09	30	0,07	50	0,10	47,5	0,10	0,03
Infrastructure in place	70	0,16	90	0,16	50	0,12	50	0,10	65,0	0,14	0,03
Groups											
Technical characteristics	70	0,58	80	0,25	20	0,09	30	0,10	50,0	0,26	0,23
Legal/political group	10	0,08	90	0,28	60	0,27	80	0,28	60,0	0,23	0,10
Economic group	10	0,08	80	0,25	70	0,32	80	0,28	60,0	0,23	0,10
Resources	30	0,25	70	0,22	70	0,32	100	0,34	67,5	0,28	0,06
General reservoir characteristics	**80**	**0,35**	**85**	**0,33**	**70**	**0,33**	**100**	**0,39**	**83,8**	**0,35**	**0,03**
Geology of hydrothermal reservoirs	**80**	**0,35**	**75**	**0,29**	**60**	**0,29**	**90**	**0,35**	**76,3**	**0,32**	**0,04**
Geological HDR-reservoir characteristics	80	0,35	85	0,33	60	0,29	80	0,31	76,3	0,32	0,03
Area charcteristics	70	0,30	90	0,35	80	0,38	75	0,29	78,8	0,33	0,04
Dimension											
Regional	70	0,70	90	0,53	60	0,6	100	0,56	80,0	0,60	0,08
National	30	0,30	80	0,47	40	0,4	80	0,44	57,5	0,40	0,08

Table 37: First round expert interview results

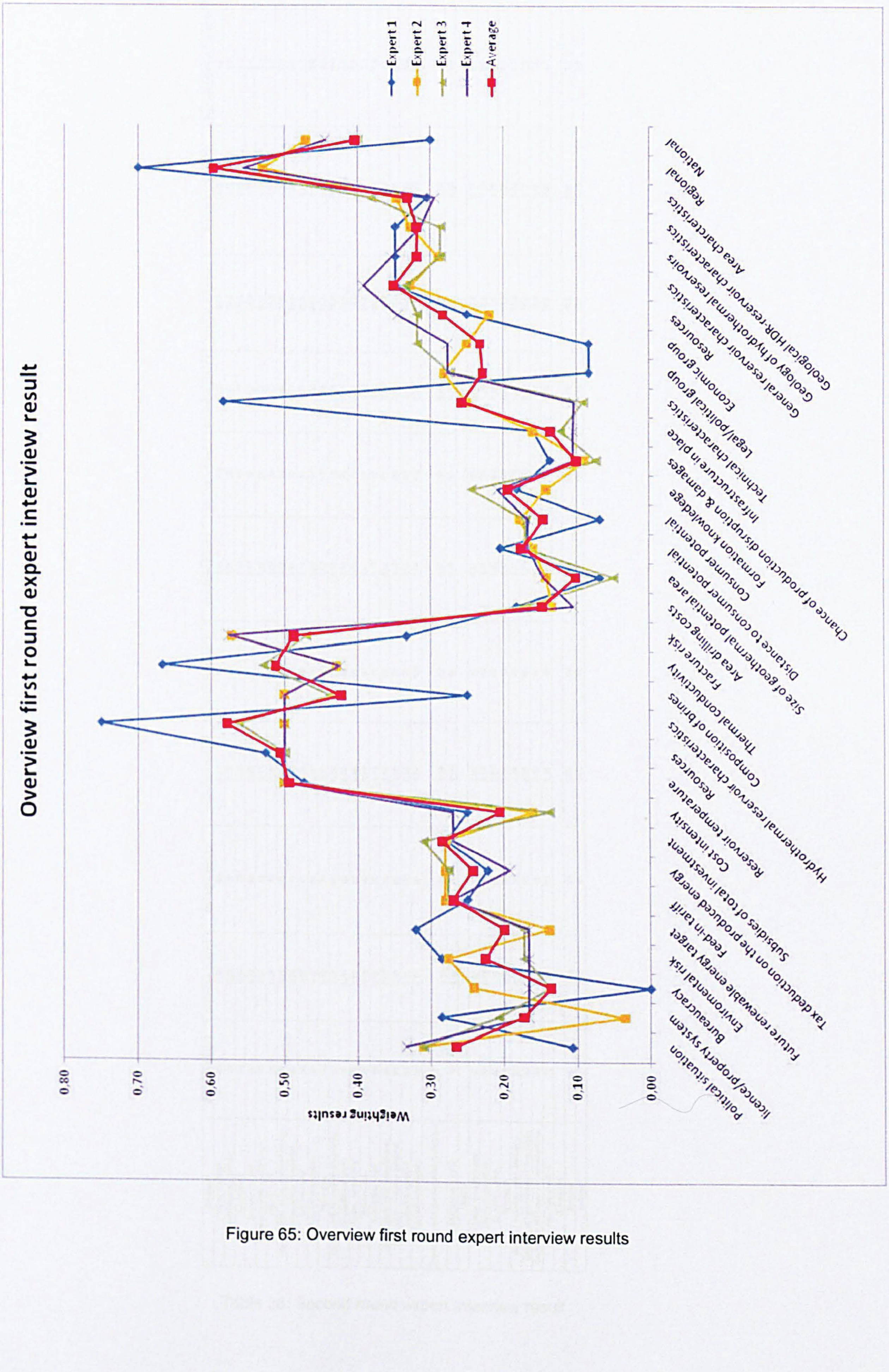

Figure 65: Overview first round expert interview results

Table 38: Second round expert interview result

Elements	Weighting Expert 1	Calculation Expert 1	Weighting Expert 2	Calculation Expert 2	Weighting Expert 3	Calculation Expert 3	Weighting Expert 4	Calculation Expert 4	Average Weighting	Average on Calculation	Standard deviation Calculation
Political situation	80	0,30	90	0,31	90	0,31	100	0,33	**90,0**	0,31	0,0
licence/property system	20	0,07	10	0,03	60	0,21	50	0,17	**35,0**	0,12	0,1
Bureaucracy	20	0,07	70	0,24	40	0,14	50	0,17	**45,0**	0,16	0,1
Enviromental risk	80	0,30	80	0,28	50	0,17	50	0,17	**65,0**	0,23	0,1
Future renewable energy target	70	0,26	40	0,14	50	0,17	50	0,17	**52,5**	0,18	0,1
Feed-in tariff	90	0,26	70	0,28	80	0,28	70	0,27	**77,5**	0,27	0,0
Tax deduction on the produced energy	80	0,23	70	0,28	80	0,28	50	0,19	**70,0**	0,24	0,0
Subsidies of total investment	90	0,26	70	0,28	90	0,31	70	0,27	**80,0**	0,28	0,0
Cost intensity	90	0,26	40	0,16	40	0,14	70	0,27	**60,0**	0,21	0,1
Reservoir temperature	90	0,47	90	0,50	100	0,50	100	0,50	**95,0**	0,49	0,0
Resources	100	0,53	90	0,50	100	0,50	100	0,50	**97,5**	0,51	0,0
Hydrothermal reservoir characteristics	60	0,55	60	0,50	90	0,56	70	0,50	**70,0**	0,53	0,0
Composition of brines	50	0,45	60	0,50	70	0,44	70	0,50	**62,5**	0,47	0,0
Thermal conductivity	70	0,50	60	0,43	90	0,53	70	0,42	**72,5**	0,47	0,1
Fracture risk	70	0,50	80	0,57	80	0,47	95	0,58	**81,3**	0,53	0,1
Area drilling costs	80	0,17	75	0,13	70	0,17	50	0,10	**68,8**	0,15	0,0
Size of geothermal potential area	30	0,07	80	0,14	20	0,05	70	0,15	**50,0**	0,10	0,1
Distance to consumer potential	90	0,20	90	0,16	70	0,17	80	0,17	**82,5**	0,17	0,0
Consumer potential	50	0,11	100	0,18	70	0,17	80	0,17	**75,0**	0,16	0,0
Formation knowledege	80	0,17	80	0,14	100	0,24	100	0,21	**90,0**	0,19	0,0
Chance of production disruption & damages	60	0,13	50	0,09	30	0,07	50	0,10	**47,5**	0,10	0,0
Infrastructure in place	70	0,15	90	0,16	50	0,12	50	0,10	**65,0**	0,13	0,0
Groups											
Technical characteristics	60	0,23	80	0,25	20	0,09	30	0,10	**47,5**	0,17	0,1
Legal/political group	50	0,19	90	0,28	60	0,27	80	0,28	**70,0**	0,26	0,0
Economic group	80	0,31	80	0,25	70	0,32	80	0,28	**77,5**	0,29	0,0
Resources	70	0,27	70	0,22	70	0,32	100	0,34	**77,5**	0,29	0,1
General reservoir characteristics	**80**	**0,35**	**85**	**0,33**	**70**	**0,33**	**100**	**0,39**	**83,8**	0,35	0,0
Geology of hydrothermal reservoirs	**80**	**0,35**	**75**	**0,29**	**60**	**0,29**	**90**	**0,35**	**76,3**	0,32	0,0
Geological HDR-reservoir characteristics	80	**0,30**	85	0,33	60	0,29	80	0,31	**76,3**	0,31	0,0
Area charcteristics	70	**0,30**	90	0,35	80	0,38	75	0,29	**78,8**	0,33	0,0
Dimension											
Regional	70	0,58	90	0,53	60	0,6	100	0,56	**80,0**	0,57	0,0
National	50	0,42	80	0,47	40	0,4	80	0,44	**62,5**	0,43	0,0

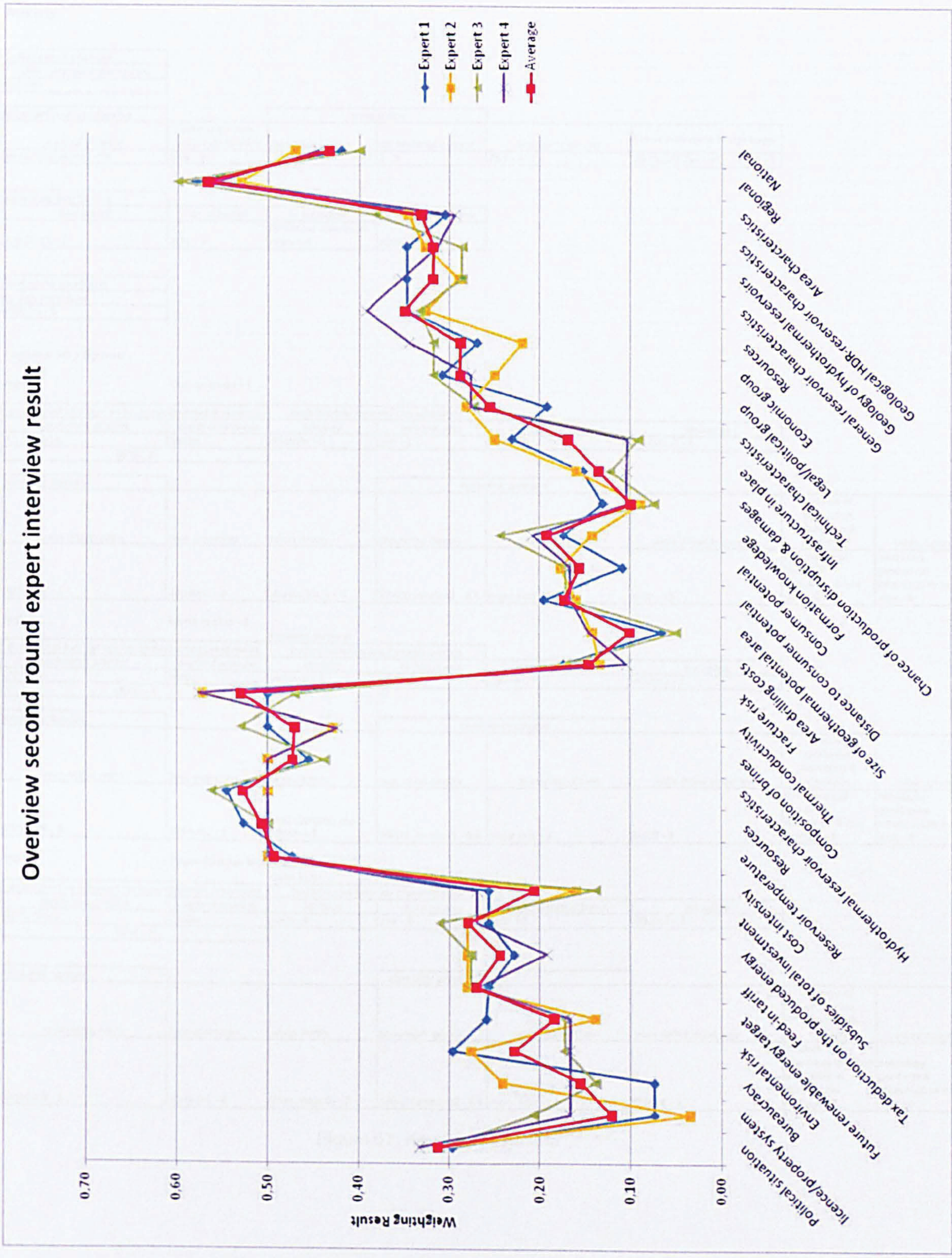

Figure 66: Overview second round expert interview results

Austria

Technical key figures
OMV personal infrastructure
680 - **10**

legal/political key figures		bureaucracy			
political situation	area of availabe licences/properties	Corruption factore	departments involved	Environmental risk	Future renewable energy target
no security worries - **10**	85% - **8**	7.9 - **0.8**	2 - **9**	78.1 - **4**	25,3%(2007)--> 34% (2020) - **5**

economic key figures			
feed-in tariff	tax reduction	subsidies	drilling costs/metre
7,5ct/kWh - **3**	10% - **4**	30%of the Investment costs - **4**	2000€ - **7**

Resources key figure
country resources
5900 PJ - **5**

regional key figures

region **Vienna Basin - 1**

geological key figures for hydrothermal reservoirs		hydrothermal reservoir characteristics			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
3,2 °C/100m	3000m	dolomite - **5**	yes - **2**	50 g/l - **1**	0.5GJ/m2 - **1**
96°C - **2**					

area key figures			consumer potenzial				
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages	infrastructure
6000000€ - **4**	2250km2 - **3**	Vienna 20km - **5**	25-100 pers/km2 - **0.5**	major sale - **8**	0.08 - **10**	low chance of losses of production & low damage - **8**	necessary geothermal infrastructure in the area - **9**

region **Styria region - 2**

geological key figures for hydrothermal reservoirs		fractured carbonat hydrothermal reservoir characteristics			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
5°C/100m	2600m	carbonat - **4**	yes - **2**	2g/l - **6**	4GJ/m2 - **2**
130°C - **4**					

area key figures			consumer potenzial				
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages	infrastructure
5200000€ - **5**	1250km2 - **3**	Graz (300,000 pop.) - >50km - **5**	25-100 pers/km2 - **0.5**	major sale - **8**	0,026 - **9**	low chance of losses of production & low damage - **8**	necessary geothermal infrastructure in the area - **9**

region **Upper Austrian Molasse Basin - 3**

geological key figures for hydrothermal reservoirs		malm karst hydrothermal reservoir characteristics			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
4.5°C/100m	2200m	karst - **4**	yes - **2**	1g/l - **10**	6GJ/m2 - **3**
99°C - **2**					

area key figures			consumer potenzial				
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages	infrastructure
4400000€ - **6**	5000km2 - **6**	Wels (60,000) - **7**	100-250pers/km2 - **0.6**	major sale - **8**	0,0024 - **4**	medium low chance of losses of production & medium low damage - **7**	necessary geothermal infrastructure in the area - **9**

Figure 67: Key figures Austria

New Zealand

Technical key figures
OMV personal infrastructure
60 - 7

legal/political key figures		bureaucracy			
political situation	area of availabe licences/properties	Corruption factore	departments involved	Environmental effort	Future renewable energy target
no security worries - 10	5% - 1	9.3 - 1	1 - 10	73.4 - 5	73%(2009) - 90%(2025) - 10

economic key figures			
feed-in tariff	tax reduction	subsidies	drilling costs/metre
no - 1	no - 1	no - 1	2000€ - 7

Resources key figure
country resources
15000PJ - 10

regional key figures

region Taupo volcanic zone - 1

geological key figures for hydrothermal reservoirs		hydrothermal reservoir characteristics			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
7°C/100m	2000m	plutonites - 3	yes - 2	3g/l - 10	22GJ/m2 - 10
240°C - 10					

area key figures			consumer potenzial				
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages	infrastructure
4000000€ - 7	1250km2 - 2	Rotorua (60,000) - 7	25-100pers/km2 - 0.5	moderate sale - 5	0.07 - 10	total loss of production & total demolition - 1	total geothermal infrastructure in the area - 10

Figure 68: Key figures New Zealand

Norway

Technical key figures
OMV personal infrastructure
30 - 4

legal/political key figures		bureaucracy			
political situation	area of availabe licences/properties	Corruption factore	departments involved	Environmental effort	Future renewable energy target
no security worries - 10	95% - 10	9.1 - 9	6 - 5	81.1 - 4	99%(2009) - 99%(2020) - 1

economic key figures			
feed-in tariff	tax reduction	subsidies	drilling costs/metre
no - 1	no - 1	25% - 4	3500€ - 1

Resources key figure
country resources
100TJ - 1

regional key figures

region Oslo

geological key figures for HDR-reservoirs			fracture risk		
geothermal gradient	depth of target formation	thermal conductivity	sensitivity	impact	resources
2°C/100m	5000m	3W/K*m - 4	0.87 - 0.9	Oslo city with 500,001-1,000,000 population in the area - 2	0.2GJ/m2 - 1
100°C - 2					

area key figures			consumer potenzial				
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages	infrastructure
17500000€ - 1	0km2 - 1	city with 500,001-1,000,000 population in the area Oslo - 9	11 - 25pers/km2 - 0.4	extreme sale - 9	0.00001 - 1	little chance of downtime & little damages - 9	energy infrastructure in the area - 8

Figure 69: Key figures Norway

Romania

Technical key figures
OMV personal infrastructure
18000 - 10

legal/political key figures		bureaucracy			
political situation	area of availabe licences/properties	Corruption factore	departments involved	Environmental effort	Future renewable energy target
security worries because of crime rate - 8	82 - 9	3.7 - 0.3	5 - 6	67.8 - 6	17,1%(2007) →24%(2020) - 3

economic key figures			
feed-in tariff	tax reduction	subsidies	drilling costs/metre
3 greencertificates per MWh/ 1greencertificate = 55€ = 16,5ct/kWh - 6	no - 1	max. 50,000,000 investment - subsidy 20,000,000 =40% - 6	1800€ - 8

Resources key figure
country resources
10000PJ - 8

regional key figures

region **South Romania - 1**

geological key figures for hydrothermal reservoirs		hydrothermal reservoir characteristics (Carbonat/ fragmented/ jointed)			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
5.3°C/100m	1200m	carbonate - 4	yes - 2	7.5 g/l - 9	12.5GJ/m2 - 6
64°C - 1					

area key figures			consumer potenzial			
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages
2160000€ - 8	31,000km2 - 10	Bucarest - 10	25-100per/km2 - 0.4	high sale - 7	0,00139 - 3	medium low chance of losses of production & medium low damage - 7

region **Pannonian Depression - 2**

geological key figures for hydrothermal reservoirs		hydrothermal reservoir characteristics (carbonat fragmented/ jointed)			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
5°C/100m	2600m	carbonate - 4	yes - 2	2g/l - 10	15 GJ/m2 - 7
130°C - 4					

area key figures			consumer potenzial			
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages
4680000€ - 6	1100km2 - 3	Oradea (200,000) - 8	100 - 250per/km2 - 0.6	high sale - 7	0,03 - 9	low chance of losses of production & low damage - 8

region **North & South Pliocene - 3**

geological key figures for hydrothermal reservoirs		hydrothermal reservoir characteristics (sandstone, consolidated)			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
6.6°C/100m	1000m	sandstone - 2	yes - 2	4g/l - 10	1GJ/m2 - 1
66°C - 1					

area key figures			consumer potenzial			
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages
1800000€ - 9	2100km2 - 3	25km - satu mare(115,000) - 5	25-100per/km2 - 0.4	high sale - 7	0,0395 - 9	medium low chance of losses of production & medium low damage - 7

Figure 70: Key figures Romania

Slovakia

technical key figures
OMV personal infrastructure
165 - 10

legal/political key figures		bureaucracy			
political situation	area of availabe licences/properties	Corruption factore	departments involved	Environmental effort	Future renewable energy target
possible terrorist target - 9	87% - 9	4.3 - 0.4	4 - 4	74.5 - 5	6,7%(2007)→14% (2020) - 4

economic key figures			
feed-in tariff	tax reduction	subsidies	drilling costs/metre
11.1ct€/kWh - 4	no - 1	50% - 7	2000€ - 7

Resources key figure
country resources
8000PJ - 6

regional key figures

region **Vienna Basin - 1**

geological key figures for hydrothermal reservoirs		hydrothermal reservoir characteristics (dolomites, limestone /fragmented/ Jointed)			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
4°C/100m	2000m	dolomite - 5	yes - 2	14g/l - 7	10 GJ/m2 - 5
80°C - 1					

area key figures			consumer potenzial				
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages	infrastructure
4000000€ - 7	800km2 - 1	Bratislava (450,000) - 30km - 5	25-100per/km2 - 0.4	high sale - 7	0.04 - 9	medium low chance of losses of production & medium low damage - 7	parts of the energy infrastructure in the area - 6

region **Danube Basin - 2**

geological key figures for hydrothermal reservoirs		hydrothermal reservoir characteristics (sandstone)			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
4°C/100m	1000m	sandstone - 2	yes - 2	20g/l - 5	5GJ/m2 - 2
40°C - 1					

area key figures			consumer potenzial				
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages	infrastructure
2000000€ - 9	2700km2 - 3	Bratislava (450,000) - 20km - 5	25-100per/km2 - 0.4	high sale - 7	0.0126 - 8	medium low chance of losses of production & medium low damage - 7	parts of the energy infrastructure in the area - 6

region **Kosice Basin - 3**

geological key figures for hydrothermal reservoirs		hydrothermal reservoir characteristics (dolomite, limestone /fragmented/ Jointed)			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
4.7°C/100m	2800m	dolomite - 5	no - 1	30g/l - 1	12GJ/m2 - 6
132°C - 4					

area key figures			consumer potenzial				
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages	infrastructure
5600000€ - 5	860km2 - 1	Kosice (240,000) - 8	25-100per/km2 - 0.4	high sale - 7	0,0223 - 8	low chance of losses of production & low damage - 8	most parts of the energy infrastructure in the area - 7

region **Humenne Ridge - 4**

geological key figures for hydrothermal reservoirs		hydrothermal reservoir characteristics (dolomites, limestone /fragmented/Jointed)			
geothermal gradient	depth of reservoir	lithology	recharge area	composition of brines	resources
4°C/100m	2250m	dolomite - 5	no - 1	8g/l - 9	7,5GJ/m2 - 3
80°C - 1					

area key figures			consumer potenzial				
area drilling costs	heat anamolies	urban vicinity	population density	marketing of heat	wells drilled in the area	chance of production disruption & damages	infrastructure
4500000€ - 6	1000km2 - 1	Humenné (30,000) - 6	25-100per/km2 - 0.4	high sale - 7	0,006 - 6	medium low chance of losses of production & medium low damage - 7	most parts of the energy infrastructure in the area - 7

Figure 71: Key figures Slovakia

New Zealand			
Elements	**New Zealand TVZ**	**Weighting Average**	**Evaluation Average**
Political situation	10	0.31	3.13
licence/property system	1	0.12	0.12
Bureaucracy	10	0.16	1.55
Enviromental risk	5	0.23	1.14
Future renewable energy target	10	0.18	1.84
Feed-in tariff	1	0.27	0.27
Tax deduction on the produced energy	1	0.24	0.24
Subsidies of total investment	1	0.28	0.28
Cost intensity	7	0.21	1.44
Reservoir temperature	10	0.49	4.93
Resources	10	0.51	5.07
Hydrothermal reservoir characteristics	6	0.53	3.16
Composition of brines	10	0.47	4.73
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	7	0.15	1.02
Size of geothermal potential area	2	0.10	0.20
Distance to consumer potential	7	0.17	1.21
Consumer potential	2.5	0.16	0.39
Formation knowledege	10	0.19	1.92
Chance of production disruption & damages	1	0.10	0.10
Infrastructure in place	10	0.13	1.34
Groups			
Technical characteristics	7	0.17	1.18
Legal/political group	7.78	0.26	1.99
Economic group	2.24	0.29	0.64
Resources	10	0.29	2.88
General reservoir characteristics	10.00	0.35	3.50
Geology of hydrothermal reservoirs	7.89	0.32	2.52
Geological HDR-reservoir characteristics	-	-	-
Area charcteristics	6.18	0.33	2.05
Dimension			
National	6.69	0.57	3.79
Regional	8.06	0.43	3.49
Result		-	**7.29**

Norway			
Elements	**Norway Oslo**	**Weighting Average**	**Evaluation Average**
Political situation	10	0.31	3.13
licence/property system	10	0.12	1.21
Bureaucracy	4.5	0.16	0.70
Enviromental risk	4	0.23	0.91
Future renewable energy target	1	0.18	0.18
Feed-in tariff	1	0.27	0.27
Tax deduction on the produced energy	1	0.24	0.24
Subsidies of total investment	1	0.28	0.28
Cost intensity	1	0.21	0.21
Reservoir temperature	2	0.49	0.99
Resources	1	0.51	0.51
Hydrothermal reservoir characteristics	-	0.53	-
Composition of brines	-	0.47	-
Thermal conductivity	4	0.47	1.88
Fracture risk	1.8	0.53	0.95
Area drilling costs	1	0.15	0.15
Size of geothermal potential area	1	0.10	0.10
Distance to consumer potential	9	0.17	1.56
Consumer potential	3.6	0.16	0.56
Formation knowledege	1	0.19	0.19
Chance of production disruption & damages	9	0.10	0.89
Infrastructure in place	8	0.13	1.08
Groups			
Technical characteristics	4	0.17	0.68
Legal/political group	6.12	0.26	1.56
Economic group	1.00	0.29	0.29
Resources	1	0.29	0.29
General reservoir characteristics	1.49	0.35	0.52
Geology of hydrothermal reservoirs	-	0.32	-
Geological HDR-reservoir characteristics	2.84	0.32	0.90
Area charcteristics	4.52	0.33	1.50
Dimension			
National	2.82	0.57	1.60
Regional	2.92	0.43	1.27
Result		-	**2.863**

Austria			
Elements	Austria Vienna Basin	Weighting Average	Evaluation Average
Political situation	10	0.31	3.13
licence/property system	8	0.12	0.96
Bureaucracy	7.2	0.16	1.12
Enviromental risk	4	0.23	0.91
Future renewable energy target	5	0.18	0.92
Feed-in tariff	3	0.27	0.81
Tax deduction on the produced energy	4	0.24	0.98
Subsidies of total investment	4	0.28	1.12
Cost intensity	7	0.21	1.44
Reservoir temperature	2	0.49	0.99
Resources	1	0.51	0.51
Hydrothermal reservoir characteristics	10	0.53	5.27
Composition of brines	1	0.47	0.47
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	4	0.15	0.58
Size of geothermal potential area	3	0.10	0.30
Distance to consumer potential	5	0.17	0.87
Consumer potential	4	0.16	0.62
Formation knowledege	10	0.19	1.92
Chance of production disruption & damages	8	0.10	0.79
Infrastructure in place	9	0.13	1.21
Groups			
Technical characteristics	10	0.17	1.69
Legal/political group	7.04	0.26	1.80
Economic group	4.35	0.29	1.25
Resources	5	0.29	1.44
General reservoir characteristics	1.49	0.35	0.52
Geology of hydrothermal reservoirs	5.74	0.32	1.83
Geological HDR-reservoir characteristics	-	0.32	-
Area charcteristics	6.29	0.33	2.09
Dimension			
National	6.18	0.57	3.50
Regional	4.44	0.43	1.92
Result		-	**5.424**

Austria			
Elements	Austria Styria Basin	Weighting Average	Evaluation Average
Political situation	10	0.31	3.13
licence/property system	8	0.12	0.96
Bureaucracy	7.2	0.16	1.12
Enviromental risk	4	0.23	0.91
Future renewable energy target	5	0.18	0.92
Feed-in tariff	3	0.27	0.81
Tax deduction on the produced energy	4	0.24	0.98
Subsidies of total investment	4	0.28	1.12
Cost intensity	7	0.21	1.44
Reservoir temperature	4	0.49	1.97
Resources	2	0.51	1.01
Hydrothermal reservoir characteristics	8	0.53	4.22
Composition of brines	6	0.47	2.84
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	5	0.15	0.73
Size of geothermal potential area	3	0.10	0.30
Distance to consumer potential	5	0.17	0.87
Consumer potential	4	0.16	0.62
Formation knowledege	9	0.19	1.73
Chance of production disruption & damages	8	0.10	0.79
Infrastructure in place	9	0.13	1.21
Groups			
Technical characteristics	10	0.17	1.69
Legal/political group	7.04	0.26	1.80
Economic group	4.35	0.29	1.25
Resources	5	0.29	1.44
General reservoir characteristics	2.99	0.35	1.05
Geology of hydrothermal reservoirs	7.05	0.32	2.25
Geological HDR-reservoir characteristics	-	-	-
Area charcteristics	6.25	0.33	2.07
Dimension			
National	6.18	0.57	3.50
Regional	5.36	0.43	2.32
Result		-	**5.82**

Austria			
Elements	**Austria Molasse zone**	**Weighting Average**	**Evaluation Average**
Political situation	10	0.31	3.13
licence/property system	8	0.12	0.96
Bureaucracy	7.2	0.16	1.12
Enviromental risk	4	0.23	0.91
Future renewable energy target	5	0.18	0.92
Feed-in tariff	3	0.27	0.81
Tax deduction on the produced energy	4	0.24	0.98
Subsidies of total investment	4	0.28	1.12
Cost intensity	7	0.21	1.44
Reservoir temperature	2	0.49	0.99
Resources	3	0.51	1.52
Hydrothermal reservoir characteristics	8	0.53	4.22
Composition of brines	10	0.47	4.73
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	6	0.15	0.87
Size of geothermal potential area	6	0.10	0.60
Distance to consumer potential	7	0.17	1.21
Consumer potential	4.8	0.16	0.75
Formation knowledege	4	0.19	0.77
Chance of production disruption & damages	7	0.10	0.69
Infrastructure in place	9	0.13	1.21
Groups			
Technical characteristics	10	0.17	1.69
Legal/political group	7.04	0.26	1.80
Economic group	4.35	0.29	1.25
Resources	5	0.29	1.44
General reservoir characteristics	2.51	0.35	0.88
Geology of hydrothermal reservoirs	8.95	0.32	2.85
Geological HDR-reservoir characteristics	-	-	-
Area charcteristics	6.10	0.33	2.02
Dimension			
National	6.18	0.57	3.50
Regional	5.75	0.43	2.49
Result	6.54	-	**5.99**

Romania			
Elements	**South Romania**	**Weighting Average**	**Evaluation Average**
Political situation	8	0.31	2.50
licence/property system	9	0.12	1.08
Bureaucracy	1.8	0.16	0.28
Enviromental risk	6	0.23	1.37
Future renewable energy target	3	0.18	0.55
Feed-in tariff	6	0.27	1.62
Tax deduction on the produced energy	1	0.24	0.24
Subsidies of total investment	6	0.28	1.68
Cost intensity	8	0.21	1.65
Reservoir temperature	1	0.49	0.49
Resources	6	0.51	3.04
Hydrothermal reservoir characteristics	8	0.53	4.22
Composition of brines	9	0.47	4.26
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	8	0.15	1.16
Size of geothermal potential area	10	0.10	1.00
Distance to consumer potential	10	0.17	1.73
Consumer potential	2.8	0.16	0.44
Formation knowledege	3	0.19	0.58
Chance of production disruption & damages	7	0.10	0.69
Infrastructure in place	9	0.13	1.21
Groups			
Technical characteristics	10	0.17	1.69
Legal/political group	5.78	0.26	1.48
Economic group	5.19	0.29	1.49
Resources	8	0.29	2.30
General reservoir characteristics	3.53	0.35	1.24
Geology of hydrothermal reservoirs	8.47	0.32	2.70
Geological HDR-reservoir characteristics	-	-	-
Area charcteristics	6.81	0.33	2.26
Dimension			
National	6.96	0.57	3.95
Regional	6.19	0.43	2.68
Result		-	**6.63**

Romania			
Elements	**Romania Pannonian Dep.**	**Weighting Average**	**Evaluation Average**
Political situation	8	0.31	2.50
licence/property system	9	0.12	1.08
Bureaucracy	1.8	0.16	0.28
Enviromental risk	6	0.23	1.37
Future renewable energy target	3	0.18	0.55
Feed-in tariff	6	0.27	1.62
Tax deduction on the produced energy	1	0.24	0.24
Subsidies of total investment	6	0.28	1.68
Cost intensity	8	0.21	1.65
Reservoir temperature	4	0.49	1.97
Resources	7	0.51	3.55
Hydrothermal reservoir characteristics	8	0.53	4.22
Composition of brines	10	0.47	4.73
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	6	0.15	0.87
Size of geothermal potential area	3	0.10	0.30
Distance to consumer potential	8	0.17	1.38
Consumer potential	4.2	0.16	0.65
Formation knowledege	9	0.19	1.73
Chance of production disruption & damages	8	0.10	0.79
Infrastructure in place	9	0.13	1.21
Groups			
Technical characteristics	10	0.17	1.69
Legal/political group	5.78	0.26	1.48
Economic group	5.19	0.29	1.49
Resources	8	0.29	2.30
General reservoir characteristics	5.52	0.35	1.93
Geology of hydrothermal reservoirs	8.95	0.32	2.85
Geological HDR-reservoir characteristics	-	-	-
Area charcteristics	6.94	0.33	2.30
Dimension			
National	6.96	0.57	3.95
Regional	7.08	0.43	3.07
Result		-	**7.02**

Romania			
Elements	**Romania North & South Pliocene**	**Weighting Average**	**Evaluation Average**
Political situation	8	0.31	2.50
licence/property system	9	0.12	1.08
Bureaucracy	1.8	0.16	0.28
Enviromental risk	6	0.23	1.37
Future renewable energy target	3	0.18	0.55
Feed-in tariff	6	0.27	1.62
Tax deduction on the produced energy	1	0.24	0.24
Subsidies of total investment	6	0.28	1.68
Cost intensity	8	0.21	1.65
Reservoir temperature	1	0.49	0.49
Resources	1	0.51	0.51
Hydrothermal reservoir characteristics	4	0.53	2.11
Composition of brines	10	0.47	4.73
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	9	0.15	1.31
Size of geothermal potential area	3	0.10	0.30
Distance to consumer potential	5	0.17	0.87
Consumer potential	2.8	0.16	0.44
Formation knowledege	9	0.19	1.73
Chance of production disruption & damages	7	0.10	0.69
Infrastructure in place	9	0.13	1.21
Groups			
Technical characteristics	10	0.17	1.69
Legal/political group	5.78	0.26	1.48
Economic group	5.19	0.29	1.49
Resources	8	0.29	2.30
General reservoir characteristics	1.00	0.35	0.35
Geology of hydrothermal reservoirs	6.84	0.32	2.18
Geological HDR-reservoir characteristics	-	-	-
Area charcteristics	6.54	0.33	2.17
Dimension			
National	6.96	0.57	3.95
Regional	4.70	0.43	2.03
Result		-	**5.98**

Slovakia			
Elements	**Slovakia Vienna Basin**	**Weighting Average**	**Evaluation Average**
Political situation	9	0.31	2.81
licence/property system	9	0.12	1.08
Bureaucracy	1.6	0.16	0.25
Enviromental risk	5	0.23	1.14
Future renewable energy target	4	0.18	0.74
Feed-in tariff	4	0.27	1.08
Tax deduction on the produced energy	1	0.24	0.24
Subsidies of total investment	7	0.28	1.95
Cost intensity	7	0.21	1.44
Reservoir temperature	1	0.49	0.49
Resources	5	0.51	2.53
Hydrothermal reservoir characteristics	10	0.53	5.27
Composition of brines	7	0.47	3.31
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	7	0.15	1.02
Size of geothermal potential area	1	0.10	0.10
Distance to consumer potential	5	0.17	0.87
Consumer potential	2.8	0.16	0.44
Formation knowledege	9	0.19	1.73
Chance of production disruption & damages	7	0.10	0.69
Infrastructure in place	6	0.13	0.81
Groups			
Technical characteristics	10	0.17	1.69
Legal/political group	6.02	0.26	1.54
Economic group	4.72	0.29	1.36
Resources	6	0.29	1.73
General reservoir characteristics	3.03	0.35	1.06
Geology of hydrothermal reservoirs	8.58	0.32	2.74
Geological HDR-reservoir characteristics	-	-	-
Area charcteristics	5.65	0.33	1.87
Dimension			
National	6.31	0.57	3.58
Regional	5.67	0.43	2.45
Result		-	**6.03**

Slovakia			
Elements	**Slovakia Danube Basin**	**Weighting Average**	**Evaluation Average**
Political situation	9	0.31	2.81
licence/property system	9	0.12	1.08
Bureaucracy	1.6	0.16	0.25
Enviromental risk	5	0.23	1.14
Future renewable energy target	4	0.18	0.74
Feed-in tariff	4	0.27	1.08
Tax deduction on the produced energy	1	0.24	0.24
Subsidies of total investment	7	0.28	1.95
Cost intensity	7	0.21	1.44
Reservoir temperature	1	0.49	0.49
Resources	2	0.51	1.01
Hydrothermal reservoir characteristics	4	0.53	2.11
Composition of brines	5	0.47	2.37
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	9	0.15	1.31
Size of geothermal potential area	3	0.10	0.30
Distance to consumer potential	5	0.17	0.87
Consumer potential	2.8	0.16	0.44
Formation knowledege	8	0.19	1.54
Chance of production disruption & damages	7	0.10	0.69
Infrastructure in place	6	0.13	0.81
Groups			
Technical characteristics	10	0.17	1.69
Legal/political group	6.02	0.26	1.54
Economic group	4.72	0.29	1.36
Resources	6	0.29	1.73
General reservoir characteristics	1.51	0.35	0.53
Geology of hydrothermal reservoirs	4.47	0.32	1.43
Geological HDR-reservoir characteristics	-	-	-
Area charcteristics	5.95	0.33	1.97
Dimension			
National	6.31	0.57	3.58
Regional	3.92	0.43	1.70
Result		-	**5.28**

Slovakia			
Elements	Slovakia Kosice Basin	Weighting Average	Evaluation Average
Political situation	9	0.31	2.81
licence/property system	9	0.12	1.08
Bureaucracy	1.6	0.16	0.25
Enviromental risk	5	0.23	1.14
Future renewable energy target	4	0.18	0.74
Feed-in tariff	4	0.27	1.08
Tax deduction on the produced energy	1	0.24	0.24
Subsidies of total investment	7	0.28	1.95
Cost intensity	7	0.21	1.44
Reservoir temperature	4	0.49	1.97
Resources	6	0.51	3.04
Hydrothermal reservoir characteristics	5	0.53	2.63
Composition of brines	1	0.47	0.47
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	5	0.15	0.73
Size of geothermal potential area	1	0.10	0.10
Distance to consumer potential	8	0.17	1.38
Consumer potential	2.8	0.16	0.44
Formation knowledege	8	0.19	1.54
Chance of production disruption & damages	8	0.10	0.79
Infrastructure in place	7	0.13	0.94
Groups			
Technical characteristics	10	0.17	1.69
Legal/political group	6.02	0.26	1.54
Economic group	4.72	0.29	1.36
Resources	6	0.29	1.73
General reservoir characteristics	5.01	0.35	1.75
Geology of hydrothermal reservoirs	3.11	0.32	0.99
Geological HDR-reservoir characteristics	-	-	-
Area charcteristics	5.92	0.33	1.96
Dimension			
National	6.31	0.57	3.58
Regional	4.71	0.43	2.04
Result		-	**5.62**

Slovakia			
Elements	Slovikia Humenne Ridge	Weighting Average	Evaluation Average
Political situation	9	0.31	2.81
licence/property system	9	0.12	1.08
Bureaucracy	1.6	0.16	0.25
Enviromental risk	5	0.23	1.14
Future renewable energy target	4	0.18	0.74
Feed-in tariff	4	0.27	1.08
Tax deduction on the produced energy	1	0.24	0.24
Subsidies of total investment	7	0.28	1.95
Cost intensity	7	0.21	1.44
Reservoir temperature	1	0.49	0.49
Resources	3	0.51	1.52
Hydrothermal reservoir characteristics	5	0.53	2.63
Composition of brines	9	0.47	4.26
Thermal conductivity	-	0.47	-
Fracture risk	-	0.53	-
Area drilling costs	6	0.15	0.87
Size of geothermal potential area	1	0.10	0.10
Distance to consumer potential	6	0.17	1.04
Consumer potential	2.8	0.16	0.44
Formation knowledege	6	0.19	1.15
Chance of production disruption & damages	7	0.10	0.69
Infrastructure in place	7	0.13	0.94
Groups			
Technical characteristics	10	0.17	1.69
Legal/political group	6.02	0.26	1.54
Economic group	4.72	0.29	1.36
Resources	6	0.29	1.73
General reservoir characteristics	2.01	0.35	0.70
Geology of hydrothermal reservoirs	6.89	0.32	2.20
Geological HDR-reservoir characteristics	-	-	-
Area charcteristics	5.23	0.33	1.73
Dimension			
National	6.31	0.57	3.58
Regional	4.64	0.43	2.01
Result		-	**5.59**

Figure 72: Assessment tool results for Austria, New Zealand, Norway, Romania and Slovakia