New Approaches for Estimating Land Cover Changes in Relation to Geothermal Power Plants:

The Case of Hengill area, Iceland

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30 ECTS thesis submitted in partial fulfillment of a
Magister Scientiarum degree in Life and Environmental Sciences

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Abstract

Geothermal emission contains polluting trace elements that have been reported to damage vegetation in the vicinity of geothermal power plants. In this study a new method, NEEDS (New Energy Externalities Development for Sustainability), is used to assess potential changes in land quality in relation to geothermal power plants. The method is further evaluated for local conditions in Iceland with Hengill geothermal area as a case study. The NEEDS methodology predicts land quality changes by using species richness indices correlated with CORINE[1] data. The objective of this study is to assess changes in land quality within the study site between 2000 and 2006 and also to evaluate the applicability of the method for local conditions in Iceland. PDF (Potentially Disappeared Fraction) value is calculated to obtain relative species richness and to evaluate changes in land quality. The results indicate the relative total decline of the species richness to be 11% with the time span from 2000-2006 within the approximately 510 hectares area of the study site. Comparison of the study area and the reference areas show that the probability of such a large change is close to zero. Hence, the results of the NEEDS calculations indicate that the construction of the Hellisheiði power plant has had a substantial impact on the relative species richness of the area and thereby decreased the area's land quality.

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[1] Coordination of Information on the Environment

Útdráttur

Sýnt hefur verið fram á að snefilefni sem finnast í útblæstri jarðvarmavirkjanna geta valdið skemmdum á gróðri í nágrenni virkjana. Í þessu verkefni er nýrri aðferð, NEEDS (New Energy Externalities Development for Sustainability) beitt til að meta mögulegar breytingar á landgæðum vegna orkuvinnslu jarðvarma. Jafnframt er lagt mat á aðferðina fyrir íslenskar aðstæður með því að skoða jarðhitasvæðið Hengil. NEEDS aðferðafræðin er byggð á aðferð sem spáir fyrir um breytingar á gæðum lands með því að tengja landfræðileg gögn CORINE[2] saman við gögn um tegundaauðgi. Markmið þessarar rannsóknar er annars vegar að meta breytingar á landgæðum Hengilsvæðisins á tímabilinu 2000 og 2006, og hins vegar að meta notkunargildi NEEDS aðferðarinnar fyrir staðbundnar aðstæður hér á landi. PDF gildi (Potentially Disappeared Fraction) er reiknað til að fá hlutfallslega tegundaauðgi og til að skoða breytingar á landgæðum. Niðurstöður rannsóknarinnar benda til hnignunar á tegundaauðgi milli áranna 2000 og 2006 upp á 11% á um 510 hektörum á rannsóknarsvæðinu. Samanburður rannsóknarsvæðisins og viðmiðunarsvæða sem stuðst er við sýnir að líkur á svo mikilli breytingu á náttúrulegan hátt eru nær engar. Niðurstöður útreikninga NEEDS benda þannig til að bygging Hellisheiðarvirkjunar hafi haft talsverð áhrif á hlutfallslega tegundaauðgi á svæðinu og þannig til minnkunar á landgæðum svæðisins.

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[2] Coordination of Information on the Environment

Preface

This thesis is the final fulfillment (30 ECTS) of the requirements for M.Sc. degree in Environmental Science and Natural Resources. The thesis is a part of a larger project called *Externalities* which attempts evaluating external costs deriving from geothermal power plants.

The duration of the *Externalities* project was 2 years and was funded by The Icelandic Center for Research (RANNIS). Project manager of the Externalities project was Fanney Frisbæk (Innovation Center Iceland) and María Hildur Maack (Icelandic New Energy) was instrumental.

This study was designed only to provide information on land quality changes in context with geothermal power plants. The Externalities project might have limited the study in some aspects to that particular scope.

Table of Contents

Abstract .... **iii**
Útdráttur .... **v**
Preface .... **vii**
List of Figures .... **xi**
List of Tables .... **xii**
Glossary .... **xiii**
Acknowledgements .... **xv**

1 Introduction **1**
1.1 Geothermal energy and external effects 1
1.2 Objectives 6

2 Background **7**
2.1 External effects of geothermal power plants 7
2.1.1 Chemicals in geothermal steam 7
2.1.2 Primary effects on vegetation 8
2.1.3 Secondary effects on vegetation 10
2.2 Assessment methods in Iceland 11
2.2.1 Environmental Impact Assessment 11
2.2.2 CORINE categorization approach 12

3 Study site **17**
3.1 Physical settings 17
3.1.1 Geothermal areas in Iceland 17
3.1.2 The study site: Hengill area 18
3.2 Vegetation 20

4 Methodology **25**
4.1 NEEDS methodology to evaluate land quality changes 25
4.1.1 Structure 25
4.1.2 Land cover changes as a result from land use changes 26
4.2 Data 28
4.2.1 CORINE Land Cover 28
4.2.2 Species richness 29
4.3 Validation 29

5 Results **31**
5.1 CORINE-analysis of the Hengill area 31
5.2 Quantification of land cover changes 34
5.3 Validation for Icelandic circumstances 37

6 Discussion and Conclusions 41

References 45

Appendix A: CLC nomenclature 51

Appendix B: CLC-categories and their species richness for Central Europe. 53

Appendix C: Derivation of Equation 4 56

List of Figures

Figure 1: Emission of CO2 (in grams per kilowatthours) from different energy source... .... ……….…2

Figure 2: Effluent pipeline from Hellisheiði power plant, seen from the highway.... ………3

Figure 3: Links between this study, the Externalities projet and the NEEDS project ..5

Figure 4: An example of a dose response curve, where a particular dose or toxic stress results in a particular response………... ………9

Figure 5: Distribution of CO2 emissions by source in Iceland in 2008............................. 10

Figure 6: Simplistic view of the major EIA steps .... ……………….11

Figure 7: Categories structure of the CORINE method..................................... ………….13

Figure 8: The connection between Large scale and small scale research......................... .15

Figure 9: Distribution of high- and low temperature geothermal fields in Iceland. The study site is located in the southwest of the country................................. 18

Figure 10: Geographical map of Hengill area displaying the two geothermal power plants in the area, i.e. Hellisheiði and Nesjavellir 20

Figure 11: Dead moss in the neigbourhood of Reykjanes power plant in about 300 m distance from the source.. 21

Figure 12: Results from moss chemical measurements (mg/kg, dryweight) at different locations in southern Iceland, with Bláfjöll as a reference site. Three sampling spots were selected around Hellisheiði power plant (HE-neyðarlosun, HE-17 and HE-stöðvarhús). Two sampling spot were selected for Nesjavellir power plant and one for Svartsengi (a geothermal power plant in the south-west part of Iceland)............................. 22

Figure 13: Overview of the data input for the NEEDS method and how CORINE categories and species richness data are integrated to the method................. 28

Figure 14: Map of Iceland, including the study site and the 25 randomly selected areas. 30

Figure 15: CORINE level III categories for the Hengill area. 32

Figure 16: CLC changes in Hengill study site from the year 2000 to 2006 36

List of Tables

Table 1: An example of chemical composition of geothermal steam-phase from two boreholes in Nesjavellir 7

Table 2: Examples of CORINE categories that are linked with expected species richness and PDF with reference to Swiss Lowlands 27

Table 3: Results of the analysis of fourteen CORINE level III categories found in Hengill study site. 33

Table 4: Results of analysis of the seven level III CORINE categories in 10x10 km square containing Hellisheiði power plant linked with number of species (pr m^2*) and PDF.* 35

Table 5: Results of the analysis of the study site and the randomly selected spots with respect to CLC-changes (2000-2006).. 38

Table 6: ΔPDF_H *results of land conversion from Table 5 adjusted to the size of the area*………………………………………………………………………………………….40

Glossary

CHP – Combined Heat and Power

CLC – CORINE Land Cover

CORINE - Coordination of Information on the Environment

EIA – Environmental Impact Assessment

GHG – Green House Gas

GIS – Geographical Information System

GWP – Global Warming Potential

MW – Megawatt, the production capacity of electrical generators

MWth/MWt – Megawatt thermal, refers to production of thermal power.

MWe – Megawatt electrical, refers to production of electric power.

MWh – Megawatt hour, refers to a megawatt used continuously for one hour.

NEEDS – New Energy Externalities Developments for Sustainability

PDF – Potentially Dissapeared Fraction

Organizations and institutions:

EU – European Union

NEA – National Energy Authorities (IS: Orkustofnun)

NLSI – National Land Survey of Iceland (IS: Landmælingar Íslands)

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Last but not least, I would like to give special thanks to my family and friends for their endless support and for giving me the motivation I needed.

1 Introduction

1.1 Geothermal energy and external effects

Energy issues have been a matter of debate over the last decades. Oil crisis and elevated prices seem to have provided impetus towards a future which is less dependent on finite resources. In later years environmental issues, such as global warming, have also started to play a role in the energy debate. Subsequently many countries have started to look towards alternative energy options.

In Iceland over 70% of primary energy consumed is produced from renewable energy, mostly hydro- and geothermal sources. The amount of total use and the proportional share of renewable energy in the national mix have been growing considerably since 1945 (National Energy Authority, 2009). Raised oil and coal prices in the 20th century influenced the government to introduce incentives to facilitate a switch from these non-renewable energy sources to geothermal for heating purposes. Additionally, during last decades increased energy demand from energy intensive industry (ferrosilicon plant and several aluminum smelters), has led to rapid increase of hydro- and geothermal exploitation (*e.g.* Ragnarsson, 2006). Hence, worldwide exploitation of geothermal resources has multiplied the last decades. Icelanders have however been using geothermal heat through the centuries. For Icelanders this resource was especially important due to the cold weather conditions. Hot springs were used *e.g.* for bathing, cooking and washing. Additionally, various elements and compounds, mostly sulfur, are to be found around geothermal sources that were previously utilized for different purposes (Þórðarson, 1998).

In the late 1920s warm water was, for the first time, pumped from Laugar (located within Reykjavík city limits) which marks the beginning of Reykjavík's heating utility. Shortly before 1930 the first attempt was made to produce electricity with steam in Hveradalir, an area located close to Reykjavík (Þórðarson, 1998). According to Pálmason (2005) these initiatives were the first undertakings that lead to the municipal district heating service, later entering the power production industry, now called Reykjavik's Energy. Since these first initiatives of geothermal use, Iceland has taken a position on the cutting edge in the field of geothermal energy technology and has since 1978 hosted the United Nations University Geothermal Training Program (Pálmason, 2005).

Currently, seven geothermal power plants are operating in Iceland with the installed generation capacity of 575 MWe. Four of these are combined heat and power (CHP) plants. In the year 2008 electricity production using geothermal sources added up to 4.038 GWh which equals to 14.530 TJ (National Energy Authority, 2010a). The aluminum industry is by far the largest user of electricity today using 73,7% of all electricity production in Iceland. Plans for further additions in the exploitation of geothermal power are currently on the drawing board (National Energy Authority, 2009; VSÓ, 2007).

Geothermal energy is, in general, considered as an environmental friendly alternative for finite fossil energy. In that regard carbon dioxide emissions from geothermal power plants are substantially less than emissions from conventional power plants that use carbonated fossil fuels (Figure 1) (Ármannsson, Fridriksson & Kristjánsson, 2005).

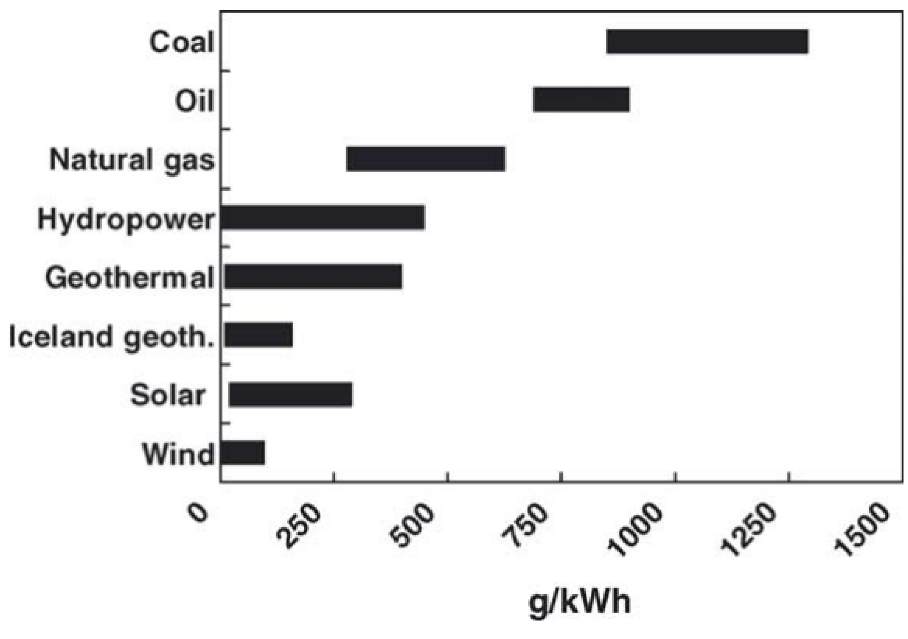


Figure 1: Emission ranges of CO_2 (in grams per kilowatthours)from different energy sources (Ármannsson, Fridriksson & Kristjánsson, 2005 with permission).

According to Icelandic law no. 106/2000 when planning for a geothermal power plant, with installed generation capacity of ≥ 10 MW_e and with thermal input of ≥ 50MW_{th}, it is obligatory to undergo an environmental impact assessment (EIA). So far most EIA results show no or insignificant environmental impacts from geothermal power plants (Reykjavík Energy, 2003; VSÓ, 2007). However, there seems to be a rising concern among the general public that there might be potential negative impact from geothermal power plants, mainly as regards increased sulfur smell in towns adjacent to geothermal fields, higher awareness regarding health impacts and the perception of diminished recreational value near these areas *(e.g.* Björnsdóttir, 2009; Stefánsson, 2009; Hafsteinsdóttir, 2009). Different actors have also expressed their concerns because of the visual impact of the newest geothermal power plant, Hellisheiði, east of Reykjavik (Figure 2). Additionally, in 2008 changes in vegetation around two geothermal power plants were reported (The Icelandic Institute of Natural History, 2008a; The Icelandic Institute of Natural History, 2008b). The possible underestimation, in the EIAs, of the environmental load and the magnitude of the disturbance in relation to geothermal power plants lead to a new detailed research aimed at investigating actual external effects from geothermal power plants and their cost. The project was sponsored by the Icelandic Research Fund in 2005 – 2009, resulting in a report by Frisbæk *et al.* [3] titled External Impacts from Geothermal Energy Plants in Iceland, hereafter referred to as the *Externalities Project*. The report emphasizes several impacts on health, human assets, land cover and vegetation changes.

Figure 2: Effluent pipeline from Hellisheiði power plant, seen from the highway (photograph: Guðrún Lilja Kristinsdóttir)

[3] An unpublished report by Fanney Frisbæk, María H. Maack and Guðrún Lilja Kristinsdóttir. The reprt was supported by the Icelandic research fund in 2005 with the project number: 0500450021

This thesis attempts to explore potential effects from geothermal power plants on their surrounding environment, with special focus on changes in land cover. This is done by testing a new method which uses relative species richness as an indicator of potential land quality changes within the impact zone. Hence, if changes in land use have negative impact on the relative species richness the quality of the land declines. This simply means that ecosystems disturbed from being in balance with their natural conditions, may loose their natural resilience (Frischknecht *et al.*, 2006).

This project applies methods developed by a larger European pilot project, called NEEDS (New Energy Externalities Development for Sustainability). NEEDS is aimed at linking Life Cycle Analysis (LCA) of various types of power plants and their environmental impacts and lastly to express the impacts in monetary costs (NEEDS, anon.nd.). The assessment approach used in this thesis was proposed within the Icelandic part of the NEEDS project. Figure 3 shows the interrelation of this study to the Externalities project and the NEEDS project, where the NEEDS project introduced a particular methodology and parts of that methodology were then used by this study and the Externalities Project.

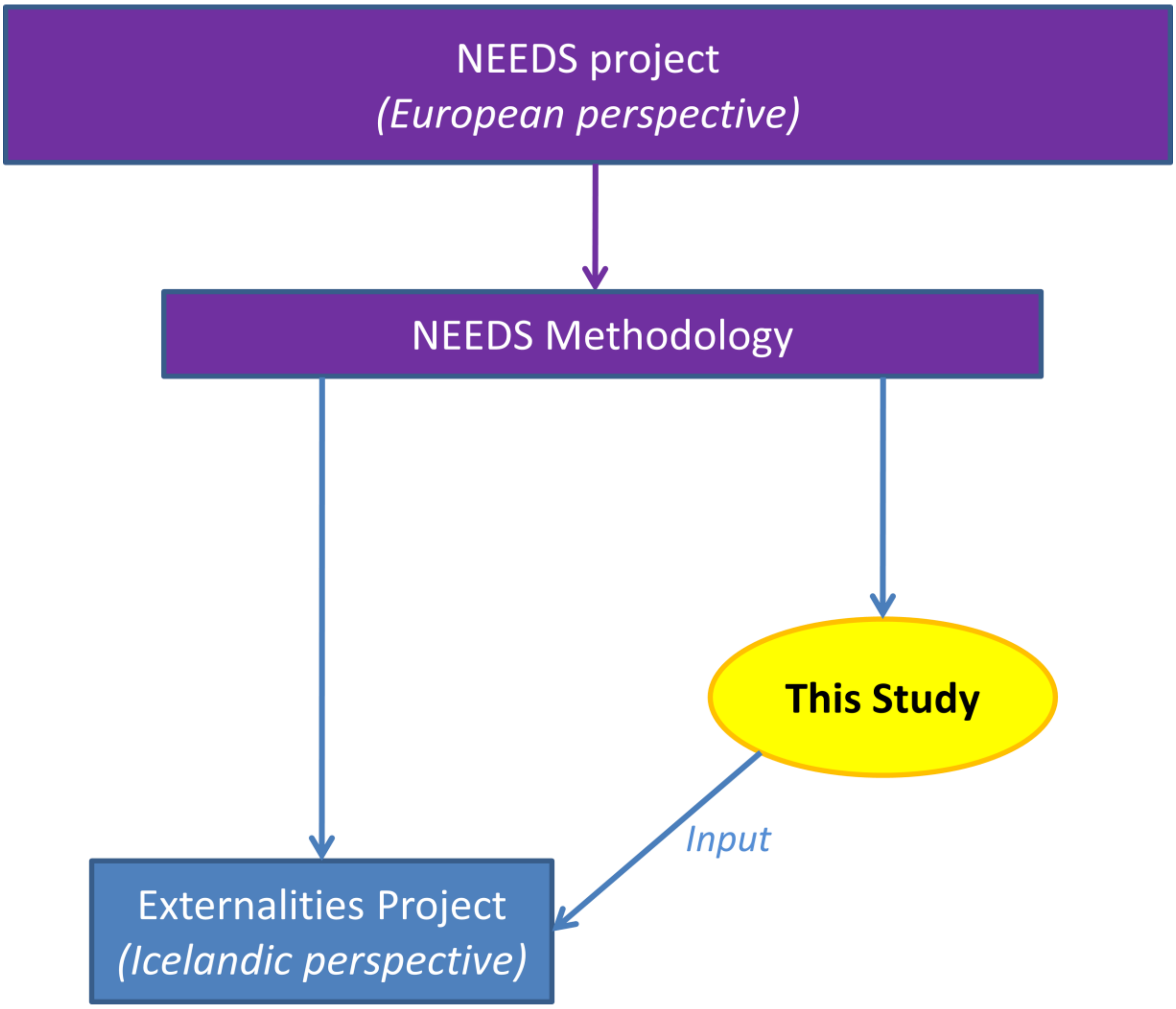


Figure 3: Links between this study, the Externalities project and the NEEDS project.

The method applied in this thesis is one of the tools generated within the NEEDS project and is called ‘Assessment of biodiversity losses’. This assessment approach was developed first in Switzerland and then extended to harmonize with pan-European conditions and is essentially supposed to quantify changes that can be seen in the quality of land by accounting for changes in relative species richness (Frischknecht *et al.*, 2006).

1.2 Objectives

This study aims to deploy the proposed NEEDS methodology to:

- assess changes in land quality as a result from geothermal power plants
- evaluate if the methodology is applicable to local conditions in Iceland

The study is carried out as a case study at the Hengill geothermal area in southwestern Iceland (*cf*. Figure 9 and Figure 10). The NEEDS methodology is based on an approach that correlates data from the land mapping method CORINE[4] as well as species richness data from Central Europe. This methodology will be used here to assess changes that occur between the years 2000 and 2006. Furthermore, in order to validate the method, the result of the study site will be compared to randomly selected reference areas around Iceland.

[4] Coordination of Information on the Environment

2 Background

2.1 External effects of geothermal power plants

2.1.1 Chemicals in geothermal steam

Geothermal water originates from precipitation which seeps through the ground and becomes groundwater. When the water is heated by subterranean magma pockets it dissolves material from the bedrock and accumulates minerals due to chemical reactions with the surrounding rock. The chemical composition of the suspended matter highly depends on the permeability, type and temperature of the surrounding rock. Geothermal water in high-temperature areas therefore contains more dissolved chemicals than water from low-temperature fields (Pálmason, 2005).

When pressure drops, water changes phases and steam is formed. The gases (previously dissolved in the water) are partly transferred to steam but a large part of the dissolved chemicals stays suspended in the geothermal water or petrifies. The composition of the steam and the ratio of gases can differ greatly, not only between different geothermal areas but also between different boreholes (Table 1) in the same geothermal area (Pálmason, 2005). When geothermal energy is harnessed, steam and water flows with great amount of pressure from deep within the bedrock up to the surface. This flow results, not only in renewable energy, but also in emission of chemicals, previously accumulated in the geothermal steam and water (Pálmason, 2005).

Table 1: An example of chemical composition of geothermal steam-phase from two boreholes in Nesjavellir (based on information from Pálmason (2005).

	Nesjavellir (NG-10)	Nesjavellir (NJ-11)
KJ/kg	1180	1600
Temperature (°C)	180	180
Steam (mg/kg):		
CO_2	2,033	2,498
H_2S	695	1219
H_2	8	69,1
Ar + O_2	3,4	2,3
N_2	201	78,4
CH_4	8,8	7,4

Geothermal steam is difficult to analyze, but the main chemicals found in the steam are displayed in Table 1. In this context, geothermal fluids can be defined as primary and secondary geothermal fluids. Primary fluids are found in the convention cell's bottom (base-depth), when these fluids ascend up towards the surface there can occure a fluid phase separation and further fluid mixing which eventually forms so called secondary geothermal fluids (happens *e.g.* during depressurization, phase separation of saline fluids). These two fluid categories have different chemical composition which is also affected by the composition and the physics of the surroundings. Among the most common elements are: Na, Ca, Cl and K and the compound SiO, but there are also trace elements *e.g.* arsenic (As), mercury (Hg), boron (B), cadmium (Cd) and lead (Pb) (Arnórsson, Stefánsson & Bjarnason, 2007). Many of these emission compounds have the potential to impact their surroundings and some of them are even green house gasses. In order to put these elements into context, their possible impacts on vegetation will be examined through two different impact routes based on published studies; primary effects and secondary effects.

2.1.2 Primary effects on vegetation

Primary effects of geothermal steam on vegetation are here defined as the direct effect that a compound has on the surrounding vegetation *e.g.* bioaccumulation and toxicological effects. Bioaccumulation is a process where organisms absorb a toxic substance at a faster rate than they can dispose of it. Thus, the particular toxic substance gets accumulated in the organisms' tissue. The concentration of these toxic substances may also increase throughout the food-chain (Botkin & Keller, 2007; Walker *et al.*,2006). Majority of the trace elements found in geothermal emission are heavy metals which can easily build up in sediments and have the tendency to bioaccumulate in organisms (Efla, 2009; Botkin & Keller, 2007; Walker *et al.*, 2006).

A toxicological effect often follows a so called dose-response curve. The dose-response approach is based on linking human, plant and/or animal physiological response to environmental load or pollution stress. Hence, a particular level of pollution (dose) results in a particular response (Figure 4), such as changes in reproduction, growth rate and mortality (Walker *et al*, 2006). When an environmental load (*e.g.* pollution) occurs the most sensitive species are the first ones that are affected. In that context, Loppi & Nascimbene (1998) point out that lichens and moss species are indicative organisms mostly because they obtain the largest part of their nutrition through rain and air and are therefore easily exposed to changes in the environment (Loppi, Giomarelli, & Bargagli, 1999). Lichens have, due to their sensitivity, been used in bio-monitoring ever since the beginning of the 20th century, when a lichens *zonation* was noted in the geothermal area of Larderello in Italy (Loppi & Nascimbene, 1998). Further direct phytotoxic effects of geotheremal emission substances (*e.g.* boron and hydrogen sulfide) have been demonstrated on vegetation surrounding geothermal power plants in Italy (Bussotti, *et al.*, 1997; Paoli & Loppi, 2008; Loppi & Nascimbene, 1998).

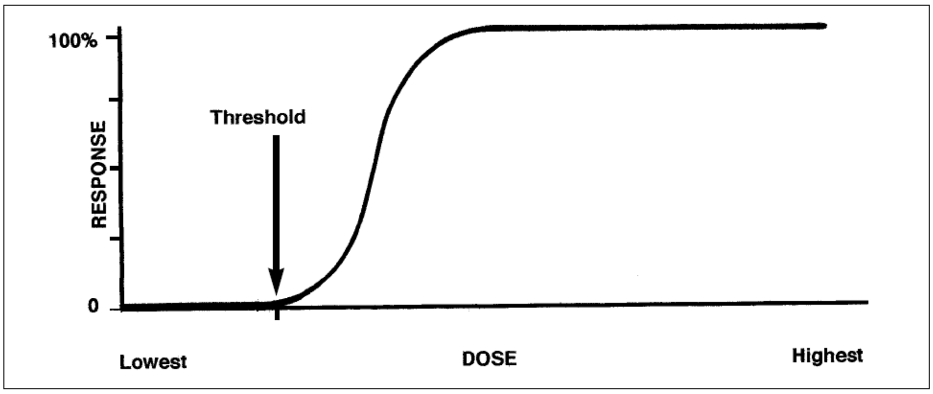


Figure 4: An example of a dose response curve, where a particular dose or toxic stress (x-axis) results in a particular response (y-axis) (NIH, anon nd).

In Iceland, moss has an extensive spread (especially in lava fields) and has been used as an environmental indicator for a long time, for example to monitor heavy metals in the environment (Magnússon, 2002). Recent observed vegetation damage around geothermal power plants in Iceland showed a considerable damage to moss (Efla, 2009). The results of Efla (2009) were though to be inconclusive mainly due to the fact that there has not been any dose-response testing in Iceland for the species living in the area (see further in chapter 3.2).

2.1.3 Secondary effects on vegetation

Secondary effects of geothermal steam on vegetation are here described as effects that are indirect *e.g.* by emitted compounds that are potential green house gases (GHG). In many aspects there is a growing concern regarding secondary effects of emitted GHGs in the world (rising sea level, changes in climate, *etc.*). Changes in the biosphere such as earlier flowering of certain plants can for example cause a chain reaction that can affects all levels of that particular ecosystems and are many species faced with increased stress and might even become extinct in certain areas (Botkin & Keller, 2007). Emission of GHG's from geothermal power plants, are relatively low compared to other sources of energy (Figure 1). In the Icelandic Inventory Report for the emissions of greenhouse gases in the country, emissions from geothermal energy exploitation are considered to be moderate, only five percent (Hallsdóttir *et al.*, 2010). Eventhough emission from geothermal energy exploitation has increased by 208%, between years 1990 and 2010, its share in the nation's emission is relatively low (Figure 5). Geothermal energy has, by contrast with fossil fuel produced energy, less emission and therefore less global warming potential. Still, it's important not to ignore the possible environmental impacts related to construction of a geothermal power plant.

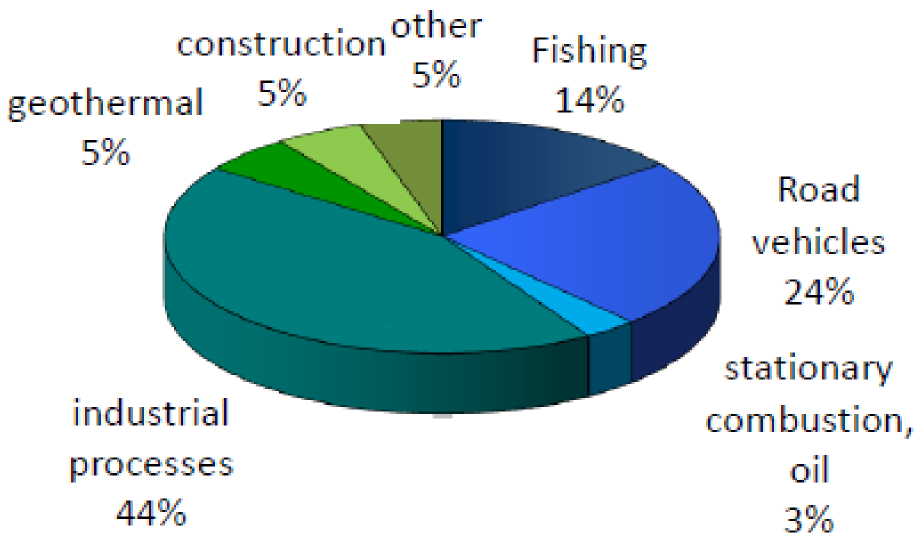


Figure 5: Distribution of CO2 emissions by source in Iceland in 2008 (Hallsdóttir et al., 2010 with permission).

2.2 Assessment methods in Iceland

2.2.1 Environmental Impact Assessment

One of the goals of this study is to propose a method that could be used in conjunction with Environmental Impact Assessment (EIA). In that way, the possible underestimation of environmental load and the magnitude of the disturbance in relation to geothermal power plants could be minimized. EIA is a process to identify and predict the impact of a particular project on the environment. It is a technique where the idea is to collect information regarding environmental effects which can then help the planning authorities to take informed decisions (Glasson, Therivel & Chadwick, 2005). The goal of conducting an EIA is to get an overview of all possible environmental impacts and to make sure that the planned projects have as insignificant impact as possible. Potential stakeholders and the general public is allowed comment and possibly influence the pending projects (Environmental Impact Assessment Act no. 106/2000).

The EIA includes quantitative descriptions and analysis, such as counting (of birds, plants *etc*), mapping and describing the potential impact that a particular project may cause (Þóroddsson, 2009; Environmental Impact Assessment Act no. 106/2000). The process of EIA is rather demanding and is based on many different steps, the major ones are shown in Figure 6. Firstly the key impact categories are described and baseline studies conducted. In the aspect of the biosphere includes mapping and description of different categories of organisms in the area. After these initial steps the potential impacts are predicted and assessed. In some cases the mitigation measures are idendified, such as need for restoration of disturbed land. After the project is finished, monitoring of the environmental effects starts by for example monitoring changes in the environment that could lead to negative effects (Glasson, *et al*., 2005; Icelandic National Planning Agency, anon.nd; Wathern, 2001).

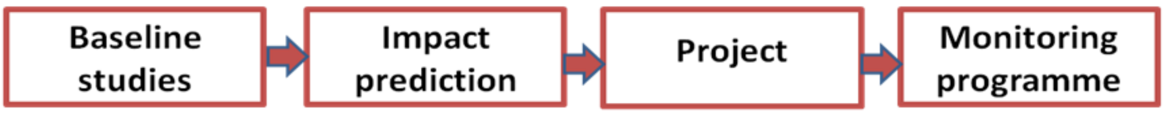


Figure 6: Simplistic view of the major EIA steps (Source: Wathern, 2001).

Strategic environmental assessment (SEA) is a method that expands the concept of EIA from projects to policies, plans and programmes (Glasson, *et al*., 2005). In 2006 Icelandic laws regarding SEA were legalized and those responsible for the assessment have to consult with the National Planning Agency throughout the process (Strategic Environmental Assessment Act no. 105/2006; Icelandic National Planning Agency, anon.nd).

2.2.2 CORINE categorization approach

The NEEDS methodology uses CORINE data as an input for categorizing analyzed areas (further described later). Environmental issues are not limited by countries borders which creates basis for cooperation in monitoring changes in land use. CORINE is a pan-European classification project aimed at applying identical method to analyze satellite pictures (*e.g.* SPOT 5) in order to map land cover types in different European countries, and by that acquire comparable data for the whole region. Originally there were 26 European countries that used the CORINE method. Since the EU membership has grown, more nations have joined the project each year, even reaching outside the EU. The method was first used in 1990 and updated in 2000 and 2006. To map land cover types CORINE uses both land cover and land use as an input for assessing and classifying land (The European Commission, 2000; Pleijel, 2007; Árnason & Matthíasson, 2009). Certain changes in land use are undesirable and to be able to monitor and achieve comparable data from different countries it is important that the categorization follows the same rules in all countries. By doing so, comparison between different countries will be possible and thereby an overview of the development and changes within and between categorized areas can be achieved (The European Commission, 2000, European Environment Agency, 2006).

According to the The European Commission (2000) and the European Environment Agency (2006) the most important criterions of CORINE are:

- The scale of CORINE is 1:100 000
- The smallest mapping unit area is 25 hectares and the thinnest area 100 meters

- Thematic accuracy is estimated to be 87% ± 0.5% [5]

- The categories are devided into three levels as presented in Figure 7.

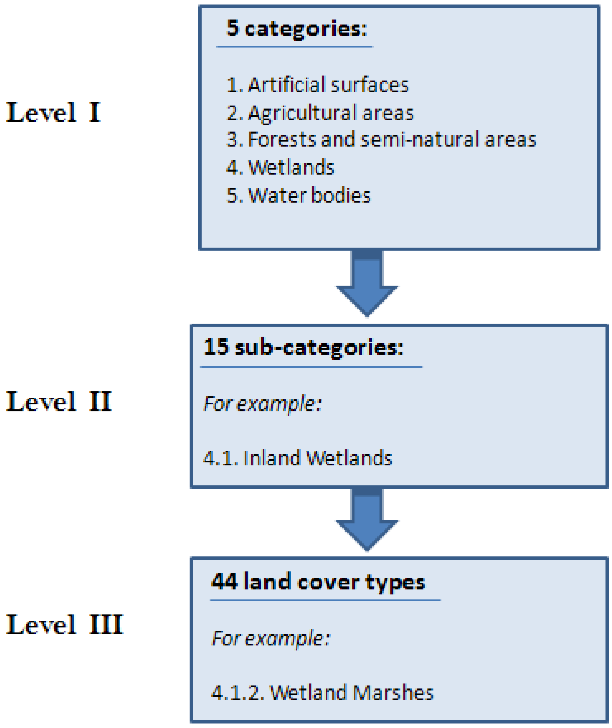


Figure 7: Categories structure of the CORINE method, further detailed information on the categories can be found in Appendix A (Source: Feranec et al., 2010; Árnason & Matthíasson, 2009 and The European Commission, 2000).

According to Árnason & Matthíasson (2009) the National Land Survey of Iceland (NLSI) formally became a member of the CORINE program in 2007. A process was then initiated to classify all land in Iceland corresponding to type and use of the land, aligned with respect to the European standard and guidelines from the European Environment Agency. The country was categorized for the year 2006 but later also included the change from the year 2000, CLC[6]-change $_{2000\text{-}2006}$ (Árnason & Matthíasson, 2009). The main data for the

[5] Means that in more than 87% incidents a particular point/place is in the right CORINE category.

[6] CLC – CORINE Land Cover

CORINE categorization are SPOT satellite images taken the years 2000 and 2006 provided by the European Environment Agency. A selection of SPOT-5 satellite pictures, which NLSI has compiled in collaboration with other institutions, is included. Other set of data used for Iceland is obtained from a project called Nytjaland (EN: usable land) aiming at assessing and mapping land use in Iceland (Árnason & Matthíasson, 2009; Nytjaland, anon.nd).

Árnason & Matthíasson (2009) consider the major disadvantage of the CORINE method to be the generalization and low resolution of the method. They further point out that the data is also simplified in many cases which can influence numerical results (*e.g.* small categories can vanish in comparison to the large categories). Another weakness is that the analyzis is conducted every 6 years, which is considered to be short in regards to slow natural changes occurring over long time periods. However, apparent advantages of CORINE are the potentials of assessing large areas in a short time, with relatively low cost. Accessibility of the CORINE data is furthermore a certain stimuli for the development of new approaches to assess the European landscape in the different contexts *e.g.* economic accounting, modeling, environmental issues and species richness (*e.g.* Heines-Young & Weber, 2006; Webber, 2007; Feranec, *et al.*, 2010). Mander *et al* (2005) points out that the usefulness of landscape metrics with respect to for example species richness monitoring is controversial especially because of the fact that results are scale and map-dependent. Nevertheless, numbers of studies have documented the correlation between species richness and landscape variables. Some conclude that the composition of landscapes is one of the most important factors explaining regional species richness (Wagner *et al*, 2000; Dale *et al*, 2000; Mander *et al*, 2005). One of those using species richness is Koellner (2001) who correlated meta-analysis of species richness with CORINE categories, when developing an approach that was further implemented in the NEEDS project (see chapter 4). The stimuli for evaluating the NEEDS methodology for Icelandic conditions was the accessability of the CORINE data and the interest to explore if it was applicable. Also, because EIA is the only required environmental assessment that a project, as a geothermal power plant, has to undergo before construction it’s interesting to investigate if the NEEDS method could be a part of that process.

The NEEDS method can be considered as large scale or broad research whereas vegetation research is usually more small scale and considered as detailed research (spanning everything between ecosystem researches to physiology functions within the plant cell). The NEEDS method (and other methods where typological data is correlated with biological field-research) can be considered as an attempt to bring together large scale and small scale research fields (Figure 8). These methods are all relatively new and show an important initiative which creates a basis that can then be developed further. These methods mark the first step towards better and more specific/detailed monitoring systems.

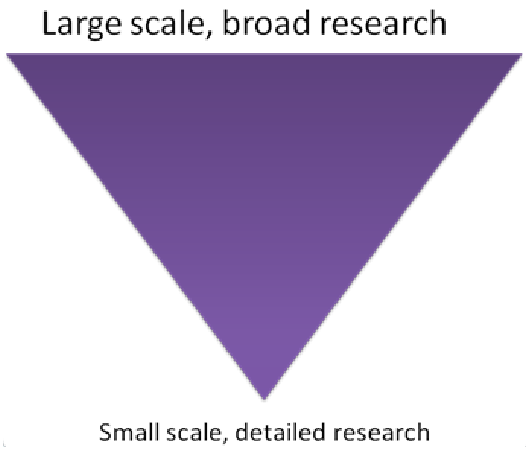


Figure 8: The connection between Large scale and small scale research (picture by Guðrún Lilja Kristinsdóttir).

3 Study site

3.1 Physical settings

3.1.1 Geothermal areas in Iceland

Iceland is situated on the Mid-Atlantic Ridge which is an ocean ridge between two tectonic plates; the Eurasian plate and North American Plate. This results in a belt of active volcanic fractures across Iceland. The volcanic activity gives rise to magma intrusions in subterranean pockets which leads to high geothermal activity. According to Þórðarson (1998) there are around 20-30 high temperature areas in the country, all situated in the fracture zone which means that many of them are far from inhabited areas. On the other hand, there are around 250 low temperatures areas and associated with them are over seven hundred hot springs (Figure 9). These areas are distributed all over the country since they are not directly linked to the fracture zone (National Energy Authority, anon.nd).

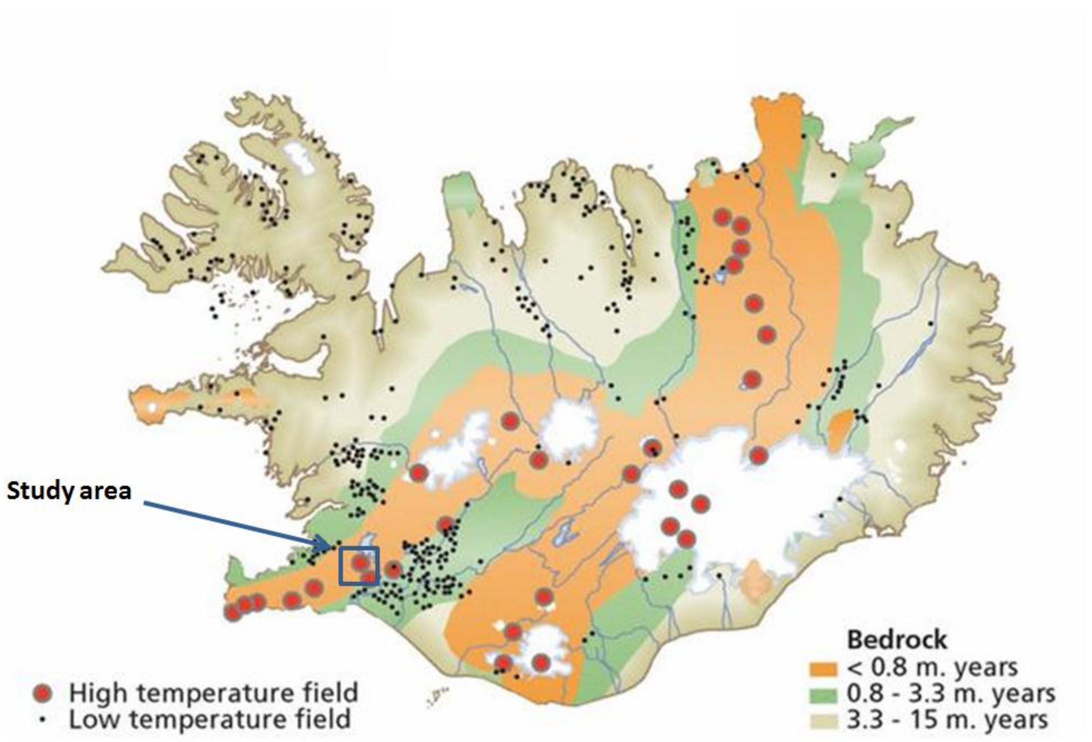


Figure 9: Distribution of high- and low temperature geothermal fields in Iceland. The study site is located in the southwest of the country, indicated with a square (National Energy Authority, anon.nd with permission).

3.1.2 The study site: Hengill area

The study site is one of the largest high-temperature areas in Iceland with an areal size around 140 km^2 known as the Hengill geothermal area (Figure 9 and Figure 10) The capacity of the area is predicted to be 700MW of installed generation capacity and even more in heat production (National Energy Authority, 2010b).The Hengill geothermal area was selected as a case study area for the Externalities project, and consequently this study, as there are two geothermal combined heat and power plants (CHP)[7] within the area. These plants will be referred to as; Hellisheiði, which was inaugurated in 2006 and Nesjavellir which is a well established CHP in operation since 1990 with 120 MW of installed generation capacity and thermal input of 300 MWth. Hellisheiði power plant has installed generation capacity of 213 MW and thermal input capacity of 400MWth (National Energy

[7] Combined heat and power plants: Geothermal energy plants that both produce electricity as well as hot water for district heating at significantly higher efficiency than can be achieved by solely generating electricity or supplying heat

Authority, 2010a; Reykjavík Energy, 2010a; Reykjavík Energy, 2010b; National Energy Authority, 2010b).

The preperation for Nesjavellir power plant began as early as 1947. In 1964 the Reykjavik District Heating bought Nesjavellir and began their research. Construction of the power plant itself began in 1987 which resulted in launching operation on the 29th of September 1990. The first power plant had four holes that generated around 100MWth producing approx. 560 liters of hot water per second. In 1995 the fifth hole was connected increasing the production capacity to 840 liters per second (equal to ca 150MWth of geothermal power). The power plant was designed with co-generation in mind; therefore in 1998 the first steam turbines were installed, which are 30MWe each (Reykjavík Energy, 2006; Pálmason, 2005). Further drilling and enlargement of the power plant then increased the operation capacity of the station which is today 120MWe for electricity and produces 1800 liters per second which equals to 300MWth. A total of 26 holes have been drilled (5 of which permanently closed), the depth of the holes ranges from 1000-2200 meters with a temperature up to 380°C. Forecast for the area indicates that, assuming average maximum production of 400 MWth, the present processing area will be able to continue for at least 30 years, after which it can be assumed that the influx of water will not fulfill this magnitude of exploitation (Reykjavík Energy, 2006; Pálmason, 2005). Reykjavík Energy started drilling boreholes for the second geothermal power plant, Hellisheiði, in the Hengill area in 2002. Hellisheiði then started operation in 2006 and when it will be used for its full capacity the electricity production will be around 300MWh and 400 MWth of thermal input (for district heating) (Reykjavík Energy, 2010b).

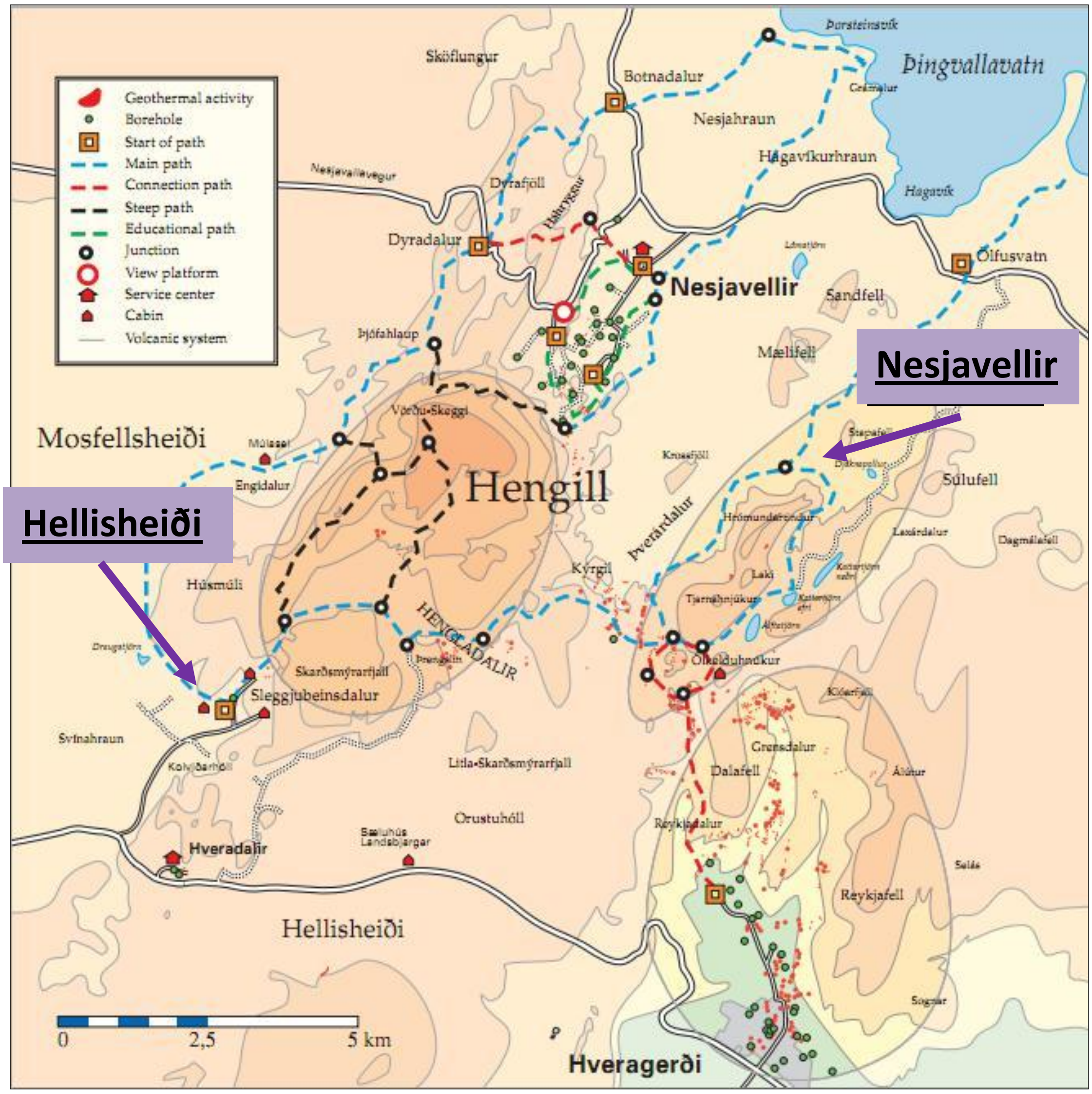


Figure 10: Geographical map of Hengill area displaying the two geothermal power plants in the area, i.e. Hellisheiði and Nesjavellir geothermal power plants are highlighted (Reykjavík Energy, 2006; National Energy Authority, 2010a with permission).

3.2 Vegetation

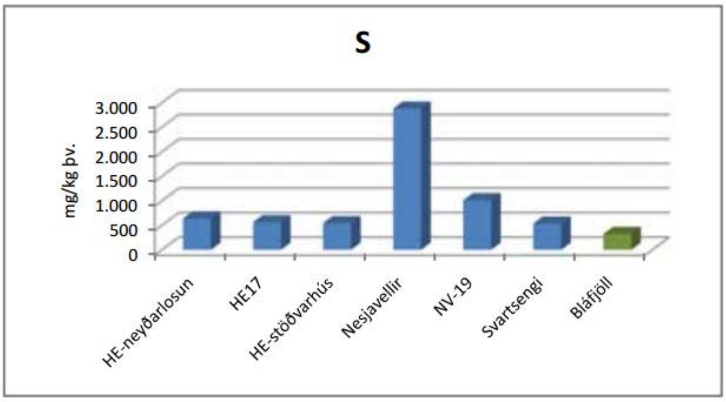
Vegetation maps were made for the Hengill area by The Icelandic Institute of Natural History in order to map the area before research-drilling started in the Hellisheiði area in 2002. For some parts of the area, detailed information regarding the vegetation were collected (Guðjónsson, *et.al.*, 2005). According to Guðjónsson, *et.al.* (2005) the vegetation in the Hengill area is rather monotonous with few but dominant/characteristics plant communities (moss heath 58%, grasslands 20%, dwarf-shrub heath 2% and eight other types of plant communities that account for less than 1% cover). The lowlands are mostly continuously vegetated but at higher elevation the vegetation becomes more discontinuous and is growing on a thin soil layer. Guðjónsson, *et al.*(2005) point out that in some cases are indications of vegetation recession even though pasturage of sheep has decreased substantially the last decades. They further point out that in some parts, there seems to be no vegetation progress occurring.

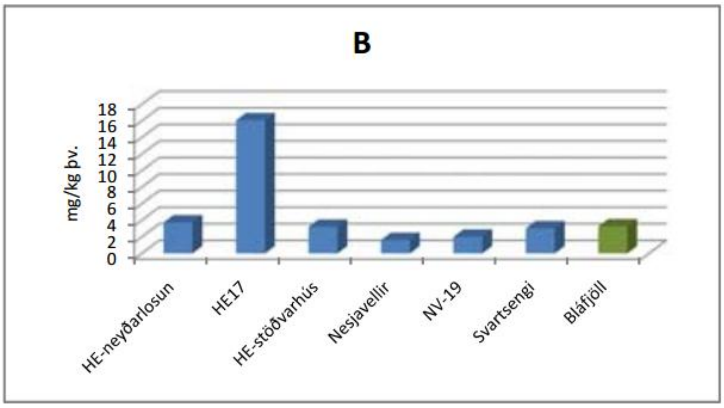
During the fall of 2008 it was reported that the moss covering lava field around the Hellisheiði geothermal power plant was highly damaged and soon after that other areas adjacent to geothermal power plants reported damage (Figure 11). The case got substantial news coverage and concerns escalated that the impact of geothermal power plants had previously been underestimated.

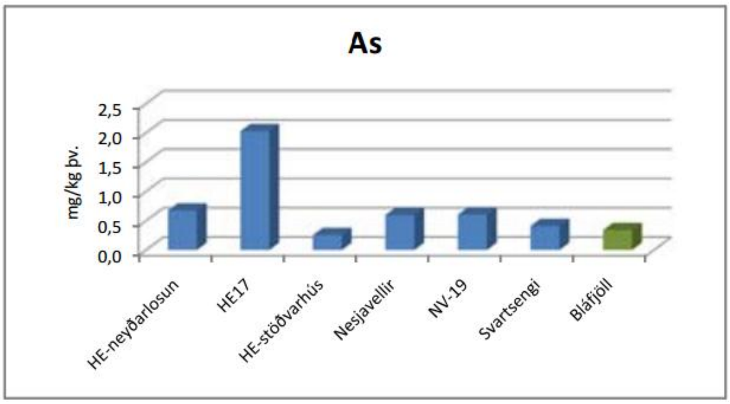
Figure 11: Dead moss in the neigbourhood of Reykjanes power plant in about 300 m distance from the source (Efla, 2009 with permission).

Subsequently Reykjavík Energy employed researchers to investigate these damages. Moss damage was apparent in a radius up to 700m from Hellisheiði power plant in the prevailing wind direction (Efla, 2009). There were also observed vegetation damages in Nesjavellir where the concentration of sulfur and mercury was highest (Figure 12). For chemical analyses of moss sample a special focus was set on hydrogen sulfide, arsenic, boron and mercury given that they are considered to be pollutants. Results further show significant difference between the concentration of sulfur in moss around geothermal power plants and the reference area (Bláfjöll, approximately 14 km south-west of the Hellisheiði power house), which indicates that sulfur, in various forms, has accumulated in the area around the power plants (Figure 12). Efla (2009) implies in their report that H_2S is at least partly to blame for the vegetation damages.

It is noticeable that concentration of sulfur in the vegetation samples from around Nesjavellir is much higher than around other geothermal power plants. Efla (2009) suggests that one of the explanations can be lack of measures to reduce pollution from the power plant. They also mention other possible reasons such as the one that Nesjavellir has been running for 20 years, from 1990, and it’s possible that the chemicals have bioaccumulated in the vegetation.







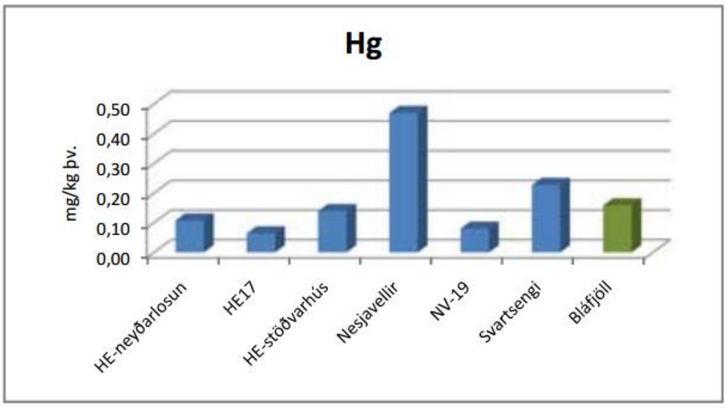


Figure 12: Results from moss chemical measurements (mg/kg, dryweight) at different locations in southern Iceland, with Bláfjöll (green column) as reference site. Three sampling spots were selected around Hellisheiði power plant (HE-neyðarlosun, HE-17 and HE-stöðvarhús). Two sampling spots were selected for Nesjavellir power plant (Nesjavellir and NV-19) and one for Svartsengi (a geothermal power plant in the south-west part of Iceland) (Efla, 2009 with permission).

4 Methodology

4.1 NEEDS methodology to evaluate land quality changes

4.1.1 Structure

As earlier stated, the NEEDS methodology is based on an approach developed by Koellner (2001) focussing on the correlation of CORINE data and a meta-analysis of species richeness in Central Europe. The meta-analysis has information about species diversity (plants, moss and mollusks) from 5581 sample plots which was then used to calculate characterization factors for 53 CORINE land cover categories. Koellner's approach was then further developed as to fit into cost and benefit analysis of various energy strategies in the NEEDS project. This study aims to deploy the NEEDS method to estimate the extent of land quality changes as a result from geothermal power plants at the Hengill area. This is done by analyzing the changes in land cover using the species richness data base developed by Koellner (2001) and then further expanded by Koellner & Scholz, 2008). The NEEDS method was chosen because of its apparent advantages for assessing large areas in a short time, with relatively low cost. Accessibility of the CORINE data for the Icelandic region is furthermore a certain stimuli to test this method and explore its possibilities. Although controversial, this study is set to use species richness data from Central Europe and apply it to Icelandic circumstances. No field research was conducted. Hence, the applied method introduced and adapted in the NEEDS project will be applied here as to assess potential changes in land cover around geothermal power plants[8].

[8] Geothermal energy plants were not included in the LCA series within the NEEDS project but modules for harnessing solar energy, wind, marine movements, carbonated fuel and others were compiled and their eventual externalities estimated and compared in future scenarios for Europe in the 21st century (Frischknecht *et al.,* 2006).

4.1.2 Land cover changes as a result from land use changes

The NEEDS methodology looks at changes in land cover by using indicators to evaluate changes in relative species richness before and after construction/operation of a particular power plant. Koellner and Schloz (2007; 2008) linked the information they had compiled on species richness to typology based on the CORINE classification (Koellner & Schloz, 2008; Koellner & Schloz, 2007). Frischknecht *et al.* (2006), who developed the method 'Assessment of Biodiversity Losses' within the NEEDS project, used the carecterization factors produced by Koellner and Schloz (2007; 2008) as an input for the concept of Potentially Disappeared Fraction (PDF). PDF is used to measure changes in numbers of species in a particular land use type relative to the number of species in a comparable reference state (Equation 1). This is done in order to transform an absolute number into a relative number by using regional species richness in a particular area.

$$PDF = 1 - \frac{S(use)}{S\,(reference)} \qquad \text{Equation 1}$$

where S(use) represents the number of species richness of an occupied or converted land use type and S(reference) is the number of species in a reference area type (Frischknecht, *et al*, 2006). The CORINE land cover types are thus correlated with information of relative number of vascular plant species in each land types. In that way a particular land cover type represents a particular number of species, which can then be an indicator for land quality (Frischknecht, *et al.,* 2006). In the NEEDS project the Swiss Lowlands[9] were selected as a basis for all reference and the land use types are categorized by using the CORINE land cover classification method, *cf.* Table 2. The Swiss Lowlands are used as a reference site because the characterization factors were created through a meta-analysis with data from the Biodiversity Monitoring Switzerland (Koellner & Schloz, 2008).

[9] The area of the reference category Swiss Lowlands consists of 8.2% high intensity forest, 17.6% low intensity forest, 52.8% high intensity agriculture, 9.3% low intensity agriculture, 1.3% lakes, 0.3% non use, 5.8% high intensity artificial and 4.8% low intensity artificial (Koellner, 2001; Koellner&Schloz, 2008).

Table 2: Examples of CORINE categories that are linked with expected species richness and PDF with reference to Swiss Lowlands (modified from Deliverable D.4.2. - RS 1b/WP4, "Assessment of Biodiversity Losses" from the NEEDS project)

CORINE No.	**Type**	**Number of Species per m²**	**Potentially Disappeared Fractions (PDF) with Reference to Swiss Lowlands**
322	Heath land	14,2	0,65
412	Peat bog	7,2	0,82
121	Industrial area part (with vegetation)	9,5	0,76
311	Broad-leafed forest	10,8	0,73
211	Pasture/meadow	7,5	0,81
	Swiss Lowland (reference site)	*40*	*0,00*

The positive PDF values presented in Table 2 can be interpreted as a decline in relative species richness, indicating that following land use types hold less species per m^2 than the reference area does. For example, it can be expected that a CLC 322 category ('Heath land') has 65% less species than the reference site 'Swiss Lowland'. The species number of a specific CORINE category is standardized for 1 m^2, thus the PDF fractions are always a percentage of the relative species richness to the Swiss lowlands first transforming the absolute species number in $S_{(use)}$ into a relative number. Later the changes can be followed up as relative changes to what was the natural state of the land as compared to what it becomes at later stages (Frischknecht, *et al.*, 2006). In order to calculate resulting PDF's for land conversion from one land use type to another the following equation is used:

$$\text{PDF (Land conversion)} = \text{PDF2} - \text{PDF1} \qquad \text{Equation 2}$$

where PDF1 corresponds to the PDF value of the land before (land use) changes, and PDF2 represents the PDF value of the land after (land use) changes (Frischknecht *et al.*, 2006). Figure 13 illustrates the interrelation of the different components in the NEEDS methodology.

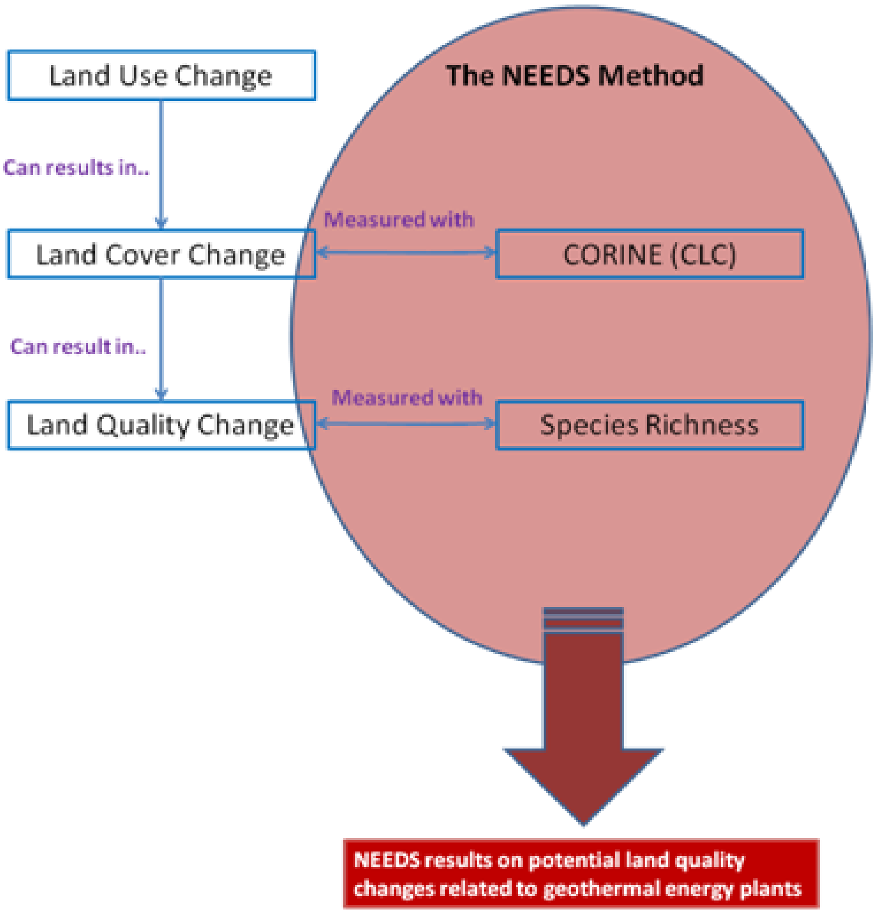


Figure 13: Overview of the data input for the NEEDS method and how CORINE categories and species richness data are integrated to the method

4.2 Data

4.2.1 CORINE Land Cover

The NEEDS methodology uses CORINE land cover data as an input. CORINE data was retrieved from the National Land Survey of Iceland. Personal communication with their experts was quite helpful in establishing the data and information of suitable software (in this study Quantum GIS was used). The land cover of the Hengill area was explored using the CORINE land cover data set for the years 2000 and 2006. CORINE data is not available before the construction of the Nesjavellir power plant. Consequently calculations of changes before and after the power plant's construction will only be made for the Hellisheiði power plant.

4.2.2 Species richness

Koellner and Scholz (2008) contributed a list of CLC categories, where they indicate the number of species to be expected in each category. They developed these characterization factors within the framework of LCA by conducting an extensive meta-analysis, with empirical information on species richness from Central Europe. The characterization factors were, as previously stated, calculated from information on species richness from 5581 sample plots for 53 different CORINE land cover categories. Vascular plants species were chosen as a proxy for the total species richness due to the fact that there is available reliable data for a wide variety of land use types. It was not possible to incorporate data on all species groups, but the species richness of vascular plant species correlates highly with other species groups. Furthermore, to check for correlation, assessment of number of moss and mollusk species was made and threatened plants were also considered (see complete list in Appendix B) (Koellner & Scholz, 2008). This relative species richness data was compiled and calculated with data from biologists' field research in central Europe. Comparable data has not been established for Icelandic circumstances, but in order to display the method this data and the European characterization factors will be used.

4.3 Validation

In order to use the NEEDS method for Icelandic circumstances, validation of the method is critical. The validation is carried out by selecting 25 random areas (excluding glaciers) from an Icelandic 10x10km grid system to compare with the changes observed in the study site (Figure 14).

For the analysis and comparison of the CORINE data a program called Quantum GIS was used for calculations. Two Layers were used: (1) CLC-change between the years 2000-2006 to achieve information regarding size of change and categories and (2) Icelandic 10x10km grid system.

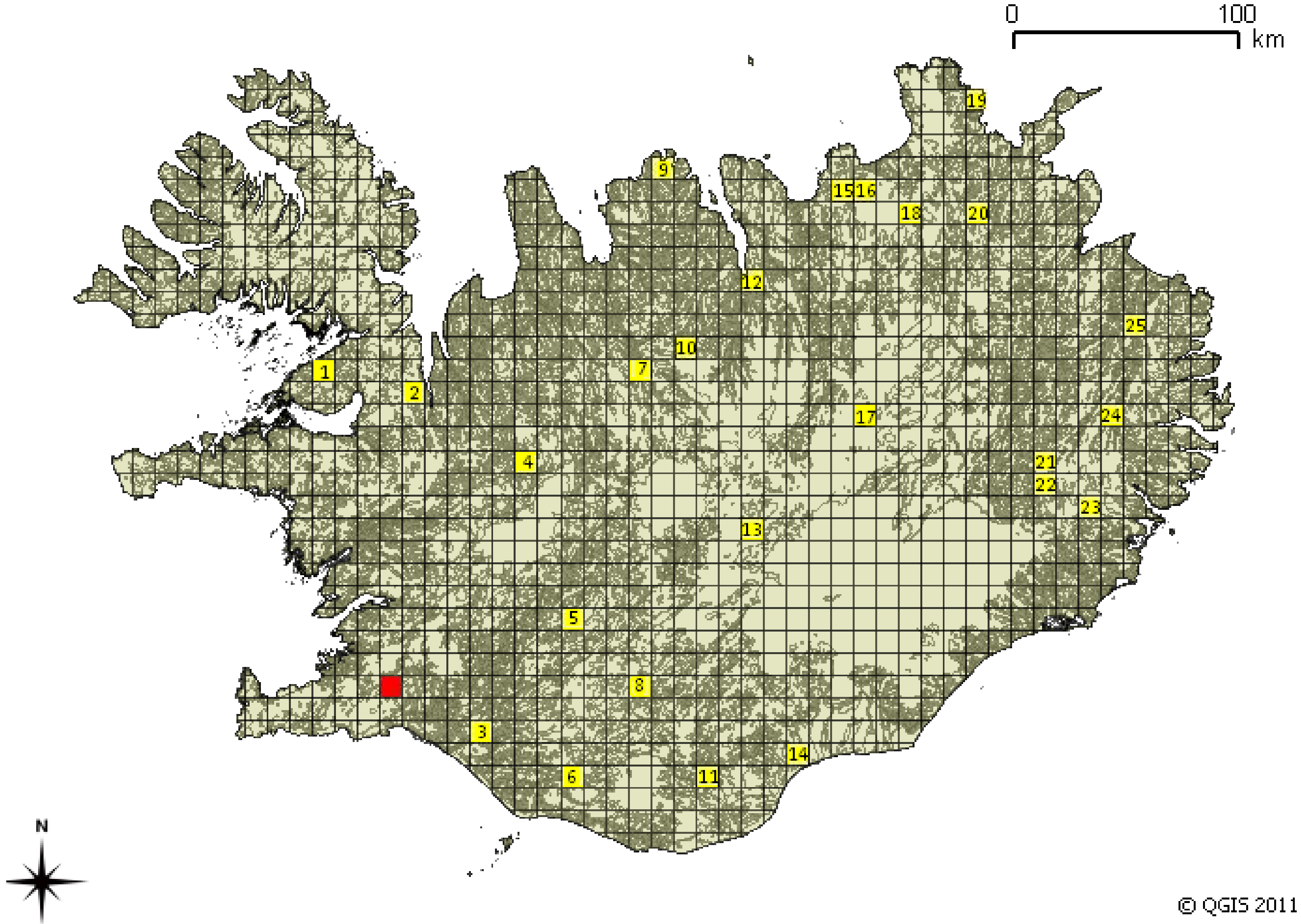


Figure 14: Map of Iceland, including the study site (red square) and the 25 randomly selected areas (yellow squares, marked by numbers for identification). This map was created using data from CORINE 2006 and the Icelandic 10x10km grid system.

5 Results

5.1 CORINE-analysis of the Hengill area

As a first step to assess land quality changes, with the NEEDS methodology, the study area was assessed and categorized according to the CORINE classification. By using available data from National Land Survey of Iceland the land cover of the Hengill area was devided into fourteen level III categories (*e.g.* Figure 15, Table 3, Appendix A). Six of them (*i.e.* CLC; 313, 321, 322, 324, 332, 333) are sub categories of the level I category representing 'Forests and semi-natural areas'. Categories belonging to this sub-group cover large parts of the study area and are further described in Table 3. Two of the level III categories CLC 412 and 512 are sub categories belonging to level II category representing 'Wetlands' and 'Water bodies'. The remaining five categories *(i.e.* CLC; 112, 121, 131, 141, 142) belong to level I category representing 'Artificial surfaces'. CLC 231 is the only level III category in the area that belongs to the category representing 'Agricultural areas' (see further layout of categories in Appendix A). The level III category 'Industrial and commercial units' (CLC 121), where geothermal power plants are categoriezed, refers to areas that are for the most part manmade and barren. In general, category 121 has a range over; (1) Industrial areas, factories, power plants (hydro and geothermal) and transformer plants, (2) Research- and development institutions, (3) Big shopping- and exhibition centers, (4) Universities, schools, hospitals and parking lots associated with these buildings.

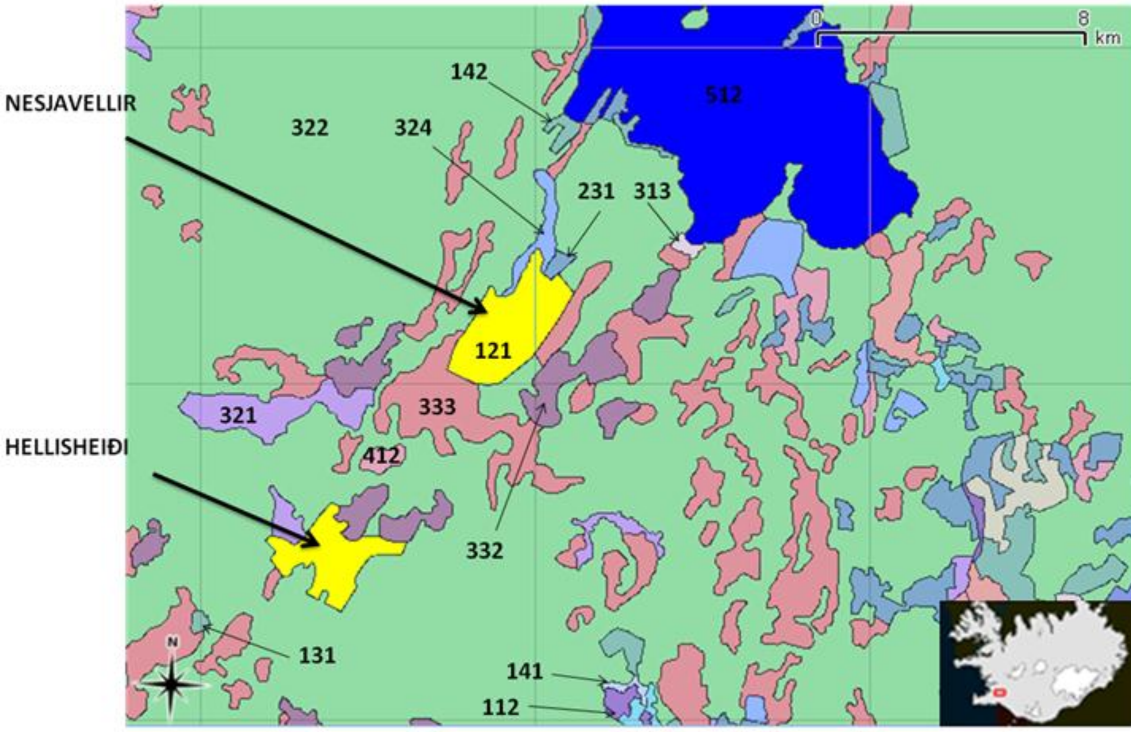


Figure 15: CORINE level III categories for the Hengill area. The yellow colored area represents the geothermal development areas categorized as 'Industrial and commercial units' (CLC 121) (This map was created using data from CORINE 2006 and the Icelandic 10x10km grid system).

When the 10x10 km grid was applied to the CORINE categorization of the study area the area fell roughly into four 10x10 km squares (Figure 15). In order to examine how the different CLC-categories were distributed and their proportion of the area, these four 10x10 km squares were analysed by using Quantum GIS and two layers; CLC-categories and the Icelandic 10x10 km grid system (Table 3).

Table 3: Results of the analysis of fourteen CORINE level III categories found in Hengill study site (Source: based on CLC data and 10x10 grid system, results from the Quantum GIS application)

CLC level II categories	***CLC level III categories***	**Type**	**% of the Hengill area**
Water bodies	512	Water bodies	9%
Wetlands	412	Peatbogs	1%
Open spaces with little or no vegetation	333	Sparsely vegetated areas	12%
	332	Bare rock	3%
Shrub and/or herbaceous vege-tation	324	Transitional woodland/shrub	1%
	322	Heath land	66%
	321	Semi-natural grassland	2%
Forests	313	Mixed forests	0%
Pastures	231	Pastures	1%
Artificial, non-agricultural vegetated areas	142	Sports and leisure facilities	1%
	141	Green urban areas	0%
Mine, dump and construct-ion sites	131	Mineral extraction sites	0%
Industrial, commercial and transport units	121	Industrial units	3%
Urban fabric	112	Discontinuous urban fabric	0%

The results show that the largest part of the study area is covered by 'heath land' (66%), which is a little higher percentage than the results of Guðjónsson, *et.al.* (2005) where the vegetation cover of moss heath was concluded to be about 58%. 'Water bodies' and 'sparsely vegetated areas' cover 9-12%, 'industrial units' (including the geothermal power plants), 'bare rock' and 'semi-natural grassland' cover 2-3% of the study area. Most of the remaining area (≈4%) may be divided between the remaining categories ranging from 0-1% ('Peatbogs', 'Transitional woodland/schrub', 'Mixed forests', 'Pastures','Sports and leisure facilities', 'Green urban areas', Mineral extraction sites' and Discontinuous urban fabric').

5.2 Quantification of land cover changes

For quantifying land cover changes between the years 2000 and 2006, species numbers provided by Koellner & Scholz (2008) were transformed into a relative number by using the relative regional species richness of the Swiss Lowlands as a reference. PDF (potentially disappeared fraction) calculations are for demonstration purposes calculated for CLC 322 (calculations for the other CLC-categories can be found in Table 4), which is the only CLC-category that displays changes within the Hellisheiði area (Figure 16) between years 2000-2006. CLC 322 has a relative species richness of 14,2 and the Swiss Lowlands are used as a reference site whith relative species richness of 40:

$$PDF = \frac{S(use)}{S(reference)}$$

$$= \frac{14{,}2}{40}$$

$$= 0{,}65$$

which means that 65% of species potentially disappear with reference to the 'Swiss Lowlands', this result is later used for calculating PDF for Land Conversion. The results from the PDF calculations for the areas in the 10x10 km area containing Hellisheiði power plant are compiled in Table 4.

Table 4: Results of analysis of the seven level III CORINE categories in 10x10 km area containing Hellisheiði power plant linked with number of species (pr m^2) and PDF (Sources: Koellner and Scholz, 2008).

CLC	Type	Number of species per m^2	PDF with reference to Swiss lowlands
333	Sparsely vegetated areas	19,8	0,51
332	Bare rock	8,7	0,78
321	Semi-natural grassland	18,3	0,54
322	Heath land	14,2	0,65
324	Transitional woodland/shrub	17,2	0,57
231	Pasture/meadow	7,5	0,81
121	Industrial area (with vegetation)	9,5	0,76
	Swiss lowlands (reference site)	*40*	*0,00*

Table 4 demonstrates the link between each CLC-category found in the 10x10 km square containing Hellisheiði power plant and number of species estimated per square meter. The PDF demonstrates, in %, the potential species decline with reference to the Swiss Lowlands. The PDF value for each CLC-category in the study site is then further used to calculate the PDF for land conversion. Figure 16 shows the change in land cover change, observed in the CORINE data for the conversion from CLC 322 (*i.e.* Heath land) to CLC 121 (*i.e.* Industrial area). This change occurs due to the construction of the Hellisheiði geothermal power plant.

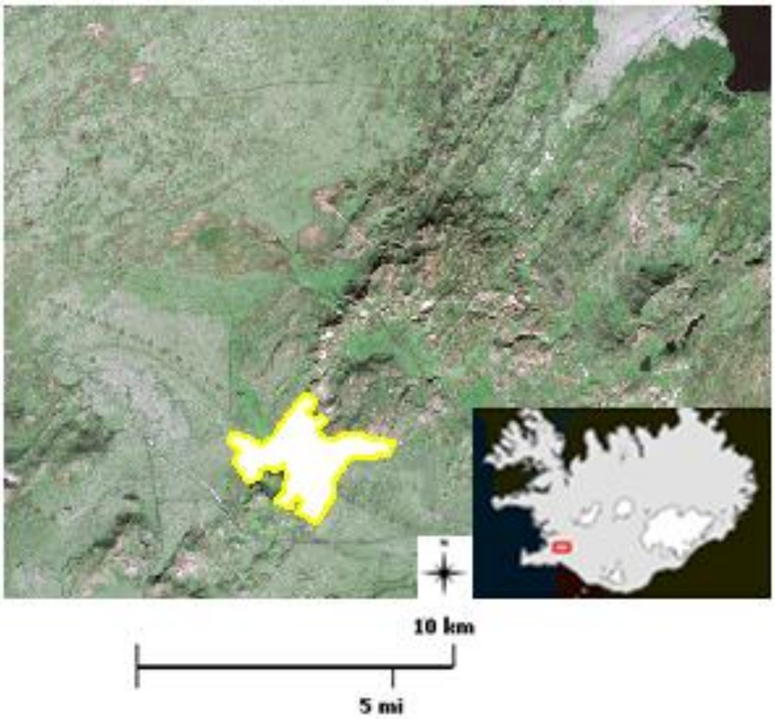


Figure 16: CLC-changes in Hengill study site from the year 2000 to 2006. The yellow/white spot shows the land cover change from CLC 322 to CLC 121 (modified from the web-based CORINE application. (National Land Survey of Iceland, 2010)).

Since the only change that occurs in the 10x10km square where Hellisheiði power plant is located, is the conversion from CLC 322 to CLC 121 the PDF for land conversion is calculated. In order to achieve that Equation 2 was appliled on the information obtained in Table 4:

$$\text{PDF (Land conversion)} = \text{PDF2} - \text{PDF1}$$

$$= 0{,}76 - 0{,}65$$

$$= 0{,}11$$

where PDF1 is the previously calculated value for CLC 322 and PDF2 the value for CLC 121. Hence, the result of the PDF calculations indicate a total decline of species between 2000 and 2006 to be 11% within the 509,57 hectares area of the study site, where Hellisheiði power plant was constructed, transforming the area from natural heath land to an industrial site.

5.3 Validation for Icelandic circumstances

To validate the NEEDS methododology used in this study the calculated results of the study area were compared with 25 randomly selected 10x10 km reference areas over Iceland. Glaciers were excluded. The comparisons analysis reveals that changes occur in eight areas (including the study site) during the time span studied. The changes differ in areal cover and the CLC transition. The results furthermore show both positive and negative PDF changes (Table 5). However, it is clear that the study site displays the highest decrease of relative species richness, or 11%, whereas the other areas display a change between: 26,1% increase and a 9,6 % decline of of relative species richness. Note that no change was observed in a total of eighteen of the reference areas (Table 5).

Table 5: Results of the analysis of the study site and the randomly selected spots with respect to CLC-changes (2000-2006), the percentages describe the decrease or increase of relative species richness. The numbers in the second column indicates the coordinates on the 10x10 grid and the areas are numbered according to Figure 14.

	Name of area	CLC-category changes 2000-2006	Area of change (ha)	PDF_00	PDF_06	$PDF_{Land\ conversion}$ (%)
Study site	*10KM_38_39*	322-121	509,57	0,55	0,76	11
Area 1	*10KM_35_53*	None				
Area 2	*10KM_39_52*	None				
Area 3	*10KM_42_37*	None				
Area 4	*10KM_44_49*	None				
Area 5	*10KM_46_42*	None				
Area 6	*10KM_46_35*	335-512	38,83	1	0,81	-19
		335-332	25,25	1	0,78	-21,8
Area 7	*10KM_49_53*	None				
Area 8	*10KM_49_39*	None				
Area 9	*10KM_50_62*	None				
Area 10	*10KM_51_54*	None				
Area 11	*10KM_52_35*	511-331	45,69	0,81	0,73	-8
		331-511	138,05	0,73	0,81	8
Area 12	10KM_54_57	None				
Area 13	*10KM_54_46*	None				
Area 14	*10KM_56_36*	511-331	1438,48	0,81	0,73	8
		331-511	983,66	0,73	0,81	8
Area 15	*10KM_58_61*	None				
Area 16	*10KM_59_61*	None				
Area 17	*10KM_59_51*	None				
Area 18	*10KM_61_60*	None				
Area 19	*10KM_64_65*	None				
Area 20	*10KM_64_60*	None				
Area 21	*10KM_67_49*	322-133	26,2	0,55	0,61	6
Area 22	*10KM_67_48*	322-133	35,67	0,55	0,61	6
Area 23	*10KM_69_47*	None				
Area 24	*10KM_70_51*	322-324	53,17	0,55	0,57	2
Area 25	*10KM_71_55*	322-324	293,98	0,55	0,57	2

Of the 25 randomly selected areas, changes were discovered in eight areas (including the study site), the changes are influenced by many different factors *e.g.* constructions, glacier regression and woodlands establishments. Since the results of the $PDF_{Land\ conversion}$ for the reference sites differ both in size of the affected area as well as in the magnitude of increase/decrease, the study site shows the highest percentage of species reduction. The differences and variations of the results make the comparison between the study site and reference areas difficult. In order to make the results comparable Equation 3 and 4 were used to obtain one particular value for whole areas (10x10 km) estimated from the areas where CLC-change is detected:

Step 1

$$\mathrm{PDF}_H = \frac{\mathrm{PDF}_1 * \mathrm{A}_1 + \mathrm{PDF}_2 * \mathrm{A}_2}{\mathrm{A}_{TOTAL}}$$ *Equation 3*

where A represents the area that shows changes and A_{TOTAL} stands for the whole area (10x10 km). This equation displays a weighted average of PDF for each area and is done for both data from 2000 and 2006.

Step 2

In order to estimate change in PDF for whole areas (10x10 km) Equation 4 is derived from Equation 3 (see further derivation steps in Appendix C):

$\Delta PDF_H = PDF2_H - PDF1_H$

$$= \left(\frac{\mathrm{A}_1}{\mathrm{A}_{TOTAL}} \Delta\mathrm{PDF}_1\right) + \left(\frac{\mathrm{A}_2}{\mathrm{A}_{TOTAL}} \Delta\mathrm{PDF}_2\right)$$ *Equation 4*

where PDF_H is weighted average of PDF for each area (outcome from Equation 3). Consequently we only need to consider those areas where $\Delta PDF \neq 0$. By analyzing the results with this approach comparable values are obtained for the study site and the reference areas for the change between 2000 and 2006 (Table 6).

Table 6: ΔPDF_H, results of land conversion from Table 5 adjusted to the size of the area.

Areas	**ΔPDF$_H$ (%)**
Study site	0,00561
Area nr. 6	-0,00129
Area nr. 11	0,00074
Area nr. 14	-0,00364
Area nr. 21	0,00016
Area nr. 22	0,00021
Area nr. 24	0,00011
Area nr. 25	0,00059

When exploring the results in Table 6 it is aparent that the change occurring in the study area is larger than the change in the reference sites. Also, calculations show that the reference areas[10] have on average ΔPDF_H equal to -0,00013 and standard deviation equal to +/-0,000819. Assuming that the ΔPDF_H for the reference areas follows normal distribution, the probability of ΔPDF for the study area being ≥ 0,00561 is close to 0 ($\mathbb{P}$ ($\Delta PDF_{STUDY} \geq 0{,}00561 = 1{,}33*10^{-12}$)). This indicates that the probability of a change, by natural causes, the same size or larger as the one occurring in the study site (with the construction of the Hellisheiði power plant) is almost 0.

[10] Including reference areas where $\Delta PDF_H = 0$

6 Discussion and Conclusions

In Iceland, many reports on Environmental Impact Assessment (EIA) state low probability of significant impacts from geothermal power plants, on the surrounding vegetation (*i.e.* VGK, 2000; Efla, 2009; The Icelandic Institute of Natural History, 2008a; The Icelandic Institute of Natural History, 2008b). However, numerous researches show that there are trace elements in geothermal fluids that have the potential of bioaccumulating in the adjacent environment and damaging surrounding vegetation, especially in sensitive areas (*e.g.* Efla, 2009; Botkin & Keller, 2007; Walker *et al.,*2006). Heath land, which largely characterizes the study area, is currently in an early succession with low species richness. This suggests that the area has less resilience than other more developed ecosystems for environmental loads. This is in line with results from *e.g.* Loppi, Giomarelli & Bargagli (1999) and Efla (2009) showing apparent vegetation damages in the vicinity of geothermal power plants. EIA depends, to a large degree, on basic research of the environmental status of the land before human exploitation starts. Such research is expensive and largely lacking for sites selected for energy exploitation in Iceland. With regard to vegetation a simpler approach is to look more generally at vegetational conditions on comparable geothermal sites. Map dependent indices are becoming widespread and within the European Comission the use of CORINE data-sets are increasingly used with species richness indices as demonstrated by numerous researches (*e.g.* Frischknecht *et.al.*, 2006; Koellner & Scholz, 2008; Gimona *et.al.*, 2009). However, several researches (*e.g.* Mander *et.al.*, 2005 and Gimona *et.al.* 2009) have pointed out that the usefulness of landscape metrics as indicators for monitoring biodiversity is debated.

The NEEDS method set out to assess changes in land quality displayed decrease of the quality indicator, *i.e.* the PDF value. Due to the construction of Hellisheiði power plant the relative species richness declined by 11% in an area of 509,57 ha. This change is larger than the ones observed in the reference areas (from 21,8% increase in relative species richness to 8% decline). By calculating ΔPDF_H for the reference areas and comparing to the study site it can be concluded that the probability of the observed land quality decline in the study site, by natural causes, is close to zero. It can therefore be assumed that according to this method the construction of the Hellisheiði power plant has substantial impact on the relative species richness of the area and thereby the land quality of the area. However, the NEEDS methodology is constrained by certain limitations that can skew the outcome and in order to verify these results for Icelandic conditions more detailed data is needed. It would for example be of use to establish a meta-analysis, such as the one conducted by Koellner & Scholz (2008) for Icelandic conditions. Their meta-analysis included mainly data from regions with intensive use (e.g. agriculture, forestry and urban land). The validity of the NEEDS method therefore depends on wheather the species richness can be generalized from regions that differ from the ones used in the meta-analysis. Koellner & Scholz (2008) state that the numbers for species richness should be valid for regions with similar biogeographical situation and land use intensity, therefore it can be considered controversial to use species richness data adjusted to Central Europe for Icelandic conditions where the difference in species richness of these areas differ greatly (*e.g.* Flora of Iceland, 2010; The Swiss Portal, anon.nd, Barthlott *et al*, 2005). If there should be establised a better general foundation for Icelandic conditions where reference habitats are well accepted, then this approach might be more adaptable.

A further limitation of the method is the low resolution of the CORINE data-set which according to Gimona *et.al.* (2009) can affect accuracy for assessing land quality. The methodology is for example not able to detect vegetation damages, as the ones occurring in 2008 in the vicinity of Hellisheiði geothermal power plant, as the change is too small scale to lead to a change in CLC-categories. Also, Fahrig and Jonsen (1998) point out that specific characteristics (such as shape, size and location) of land cover in landscape as well as their fragmentation can have impacts on abundance of species richness but are not detectable with CORINE data sets. In that sense, it would be interesting to test accuracy of CORINE for, Icelandic circumstances, as a basis for calculating indices for monitoring purposes of large areas as Gimona *et.al.* (2009) investigated in northeast of Scotland. The advantages of using the remote sensing offered by the NEEDS methodlogy is of vital importance for a country like Iceland which is sparsly populated. Hence, this is a cost-effective method which makes it possible to monitor large areas. This study presents an approach that allows a rough quantification of land use impact but further analysis, such as comparison of satellite pictures and/or information from more detailed vegetation/land use maps might be interesting in order to verify the method and its' ability to predict impacts.

The following conclusion may be drawn:

- According to the results the construction of the Hellisheiði power plant had substantial impact on the indicator values for relative species richness of the area which can be interpreted as a decline of land quality.
- The study site shows much larger changes with respect to decline of indicator values for relative species richness than the reference areas
- The probability of the observed change occurring at the study site by natural causes is close to zero.
- Because of Iceland's unique geology and ecology, the NEEDS method would need to be verified with Icelandic data and circumstances in mind.

Suggested further research

In order to increase our knowledge of geothermal exploitation's effect on vegetation, test spots should be explored before a new geothermal power plant is established and monitor them regularely. Also, it could be useful to establish a dose-response curve for the characteristic species in the area, in order to understand how much concentration of emission compounds local species can tolerate. In this way general insight could be gained as well as site dependent fate of the vegetation.

References

Ármannsson, H.; Fridriksson, Th.; Kristjánsson, B.R. (2005). *CO2 emission from geothermal power plants and natural geothermal activity in Iceland*. Geothermics, 34, 286-296.

Árnason, K., & Matthíasson, I. (2009). *CORINE-Landflokkun á Íslandi 2000 og 2006.* Akranes: Landmælingar Íslands.

Arnórsson, S., Stefánsson, A., Bjarnason, J.Ö. (2007). *Fluid-Fluid Interaction in Geothermal Systems.* Reviews in Minerology & Geochemistry, Volume 65, p. 259-312

Barthlott, W., Mutke, J., Rafiqpoor, M. D., Kier, G. & Kreft, H. (2005) *Global centres of vascular plant diversity*. Nova Acta Leopoldina 92, 61-83.

Björnsdóttir, I. E. (2009, October 9). *Heilsu Hvergerðinga stefnt í hættu.* Morgunblaðið .

Botkin, D. B., & Keller, E. A. (2007). *Environmental Science - Earth as a living planet.* United States of America: Wiley.

Bussotti, F., Cenni, E., Cozzi, A., & Ferretti, M. (1997). *The Impact of Geothermal Power Plants on Forest Vegetation: A Case Study at Travale (Tuscany, Central Italy).* Environmental Monitoring and Assessment ,Volume 45, 181-194.

Dale, V. H., Brown, S., Haeuber, R. A., Hobbs, N. T., Huntly, N., & Naiman, R. J. (2000). *Ecological principles and guidlines for managing the use of land.* Ecol Appl , (10) 639-670.

Efla. (2009). *Rannsóknir á mosa við jarðvarmavirkjun Orkuveitu Reykjavíkur á Hellisheiði.* Reykjavik: Orkuveita Reykjavíkur. Retreived August 2009, from the website: http://rafhladan.is/bitstream/handle/10802/259/Skyrsla%20um%20mosaskemmdir.pdf?sequence=3

Environmental Impact Assessment Act no. 106/2000.

European Environment Agency (2006). *The thematic accuracy of Corine land cover 2000 – Assessment using LUCAS.* Retrieved July 2012, from the EEA website: http://www.eea.europa.eu/publications/technical_report_2006_7

Fahrig, L., Jonsen, I. (1998) *Effect of habitat patch characteristics on abundance and diversity of insects in an agricultural landscape*. Ecosystems 1, 197–205

Feranec, J., Jaffrain, G., Soukup, T., & Hazeu, G. (2010). *Determining changes and flows in European landscapes 1990-2000 using CORINE land cover data*. Applied Geography , (30)19-35.

Flora of Iceland. (2010). *Flóra Íslands.* Retrieved August 30, 2010, from Flóra Íslands: http://floraislands.is/

Frischknecht, R., Steiner, R., Ott, W., Baur, M., & Kaufman, Y. (2006). *Deliverable D.4.2. - RS 1b/WP4, "Assessment of Biodiversity Losses". Europe: New Energy Externalities.* Retrieved November 12, 2009, from: http://www.needs-project.org/RS1b/RS1b_D4.2.pdf

Gimona, A., Messager, P., & Occhi, M. (2009). *CORINE-based landscape indices weakly correlate with plant species richness in a northern European landscape transect.* Landscape Ecol , (24) 53-64.

Glasson, J., Therivel, R. & Chadwick, A. (2005). *Introduction to Environmental Impact Assessment.* Abington: Routledge.

Guðjónsson, G., Egilsson, K., & Skarphéðinsson, K. H. (2005*). Gróður og fuglar á Hengilsvæðinu og Hellisheiði.* Reykjavík: Náttúrufræðistofnun Íslands.

Hafsteinsdóttir, A. (2009, November 14). *Mengun kallar á ákvörðun um viðmiðunarmörk.* Morgunblaðið .

Hallsdóttir, B., Harðardóttir, K., Guðmundsson, J., Snorrason, A. and Þórsson, J. (2010) *Emissions of greenhouse gases in Iceland from 1990 to 2008 – National Inventory Report 2010.* Umhverfisstofnun, UST-2010/05.

Heines-Young, R., & Weber, J. L. (2006). *Land accounts for Europe 1990-2000, towards integrated land and ecosystem accounting.* Copenhagen: European Environment Agency: EEA report, 11.

Icelandic National Planning Agency. (anon.nd). *Umhverfismat áætlana.* Retrieved September 15, 2010, from Skipulagsstofnun: http://skipulagvefur.eplica.is/byggingar-og-framkvaemdir/aaetlanir-hadar-umhverfismati/

Koellner, T. (2001). *Land Use in Product Life Cycles and its Consequences for Ecosystem Quality*. ETH Zürich: University of St. Gallen.

Koellner, T., & Scholz, R. W. (2007). *Assessment of Land Use Impacts on the Natural Environment - Part 1: An Analytical Framework for Pure Land Occupation and Land Use Change.* Switzerland: ecomed publishers.

Koellner, T., & Scholz, R. W. (2008). *Assessment of Land Use Impacts on the Natural Environment. Part 2: Generic Characterization Factors for Local Species Diversity in Central Europe.* The international journal of life cycle assessment 13 (1) , 32-48.

Loppi, S., & Nascimbene, J. (1998). *Lichen bioindication of air quality in the Mt. Amiata geothermal area (Tuscany, Italy).* Geothermics, Vol 27, Issue 3 , 295-304.

Loppi, S., Giomarelli, B., & Bargagli, R. (1999*). Lichens and mosses as biomonitors of trace elements in a geothermal area (Mt. Amiata, central Italy).* Cryptogamie Mycologie, Vol 20, Issue 2 , 119-126.

Magnússon, S. H. (2002). *Þungmálmar í mosa í nágrenni álversins í Straumsvík árið 2000.* Reykjavik: Náttúrufræðistofnun Íslands.

Mander, Ü., Müller, F., & Wrbka, T. (2005). *Functional and structural landscape indicators: upscaling and downscaling problems*. Eco Indic , /5) 267-272.

National Energy Authority. (2009). *Energy Statistics in Iceland*. Reykjavík, Iceland.

National Energy Authority. (2010a). *Jarðhiti* Retrieved June 16, 2010, from NEA: http://os.is/jardhiti/jardhitanotkun/jardvarmavirkjanir/

National Energy Authority. (2010b). *Hengilsvæði*. Retrieved from NEA: http://www.os.is/jardhiti/jardhitasvaedi-a-islandi/hahitasvaedi/hengilssvaedi/

National Energy Authority. (anon.nd). *Háhitasvæði á Íslandi*. Retrieved August 28, 2010, from NEA: http://os.is/jardhiti/jardhitasvaedi-a-islandi/hahitasvaedi/

NEEDS. (anon.nd). *New Energy Externalities Development for Sustainability*. Retrieved December 8, 2009, from NEEDS website: http://www.needs-project.org/

NIH. (anon nd). *National Institutes of Health*. Retrieved April 7, 2010, from office of science education: http://science.education.nih.gov/supplements/nih2/chemicals/guide/pdfs/lesson3.pdf

Nytjaland. (anon.nd). *Nytjaland-Jarðabók Íslands.* Retrieved July 6, 2010, from Nytjaland: http://nytjaland.is/landbunadur/wgrala.nsf/key2/almennt.html

Paoli, L., & Loppi, S. (2008). *A biological method to monitor early effects of the air pollution caused by the industrial exploitation of geothermal energy.* Environmental Pollution, Vol 155, Issue 2 , 383-388.

Pálmason, G. (2005). *Jarðhitabók - Eðli og nýting auðlindar.* Reykjavík: Hið íslenska bókmenntafélag.

Pleijel, H. (2007). *Transboundary air pollution – scientific understanding and environmental policy in Europe.*Pozkal. Studentlitteratur

Ragnarsson, Á. (2006). *Orkunotkun á Íslandi.* Reykjavík: Orkuþing.

Reykjavík Energy. (2003). *Virkjun á Hellisheiði, Rafstöð allt að 120 MW, Varmastöð allt að 400 MW – Mat á umhverfisáhrifum* . Retrieved March 13, 2011, from: http://www.skipulagsstofnun.is/focal/webguard.nsf/5ed2a07393fec5fa002569b300397c5a/5302f4f4d530b5a600256e2a0048c8d3/$FILE/2003090054.PDF

Reykjavík Energy. (2006). *Nesjavellir Geothermal Plant.* Retrieved February 22, 2010, from Reykjavík Energy: http://www.or.is/media/PDF/Nesjavellir_Enska.pdf

Reykjavík Energy. (2010a). *Nesjavallavirkjun.* Retrieved May 25, 2010, from Reykjavík Energy: http://www.or.is/UmOR/Veiturogveitusvaedi/Virkjanir/Nesjavallavirkjun/

Reykjavík Energy. (2010b). *Hellisheiðarvirkjun.* Retrieved May 25, 2010, from Reykjavík Energy: http://www.or.is/UmOR/Veiturogveitusvaedi/Virkjanir/Hellisheidarvirkjun/

Stefánsson, P. (2009, Nóvember 4). *Lungun okkar og heimatilbúin mengun.* Morgunblaðið.

Strategic Environmental Assessment Act no. 105/2006.

The European Commission (2000). *From land cover to landscape diversity in the European Union.* Retrieved May 10, 2011, from the EC website: http://ec.europa.eu/agriculture/publi/landscape/about.htm

The Icelandic Institute of Natural History (2008a, September 8). M*osi drepst við Hellisheiðarvirkjun.* Retrieved April 28, 2010, from The Icelandic Institute of Natural History: http://www.ni.is/frettir/nr/817

The Icelandic Institute of Natural History. (2008b, September 18). *Gróðurskemmdir við orkuverið í Svartsengi.* Retrieved April 28, 2010, from The Icelandic Institute of Natural History: http://www.ni.is/frettir/nr/820

The Swiss Portal. (anon.nd). *Native flora and fauna*. Retrieved August 30, 2010, from The Swiss Portal: http://www.ch.ch/private/00070/00071/00506/00531/index.html?lang=en

VGK. (2000). *Mat á Umhverfisáhrifum, Nesjavallavirkjun áfangi 4B - Stækkun rafstöðvar úr 76 í 90 MW*. Reykjavík: Orkuveita Reykjavíkur.

VSÓ. (2007). *Bitruvirkjun, allt að 135 MW_e jarðvarmavirjkun – Frummatsskýrsla.* Retrieved January 20, 2011 from the website of Reykjavík Energy: http://www.or.is/media/PDF/bi-sk070917.pdf

Wagner, H. H., Wildi, O., & Ewald, K. C. (2000). *Additive partioning of plant species diversity in an agricultural mosaic land scape.* Landsc Ecol , (15)219-227.

Walker, C. H., Hopkin, S. P., Sibly, R. M., & Peakall, D. B. (2006). *Principles of Ecotoxicology.* Coca Raton: CRC Press.

Wathern, P. (2001). *Environmental Impact Assessment – Theory and Practice.* Academic division of Unwin Hyman Ltd.

Webber, J.-L. (2007). *Implementation of land and ecosystem accounts at the European environment agency*. Ecological Economics , 61(4), 695-707.

Þórðarson, S. (1998). *Auður úr iðrum jarðar - saga hitaveitna og jarðhitanýtingar á Íslandi. Reykjavík:* Iðnsaga Íslendinga og Hið íslenzka bókmenntafélag.

Þóroddsson, Þ. F. (2009). *Leiðbeiningar um Mat á Umhverfisáhrifum Framkvæmda*. Retrieved January 24, 2010, from Skipulagsstofnun: http://www.skipulag.is/focal/webguard.nsf/key2/leidbeiningar_um_mat_a_umhverfisahrifum

Appendix A: CLC nomenclature

CLC nomenclature compiled from a publication made through Services of the European Commission - DG AGRI (The European Commission, 2000).

Level 1	Level 2	Level 3
1. Artificial surfaces	1.1 Urban fabric	1.1.1 Continuous urban fabric
		1.1.2 Discontinuous urban fabric
	1.2 Industrial, commercial and transport units	1.2.1 Industrial or commercial units
		1.2.2 Road and rail networks and associated land
		1.2.3 Port areas
		1.2.4 Airports
	1.3 Mine, dump and construction sites	1.3.1 Mineral extraction sites
		1.3.2 Dump sites
		1.3.3 Construction sites
	1.4 Artificial, non-agricultural vegetated areas	1.4.1 Green urban areas
		1.4.2 Sport and leisure facilities
2. Agricultural areas	2.1 Arable land	2.1.1 Non-irrigated arable land
		2.1.2 Permanently irrigated land
		2.1.3 Rice fields
	2.2 Permanent crops	2.2.1 Vineyards
		2.2.2 Fruit trees and berry plantations
		2.2.3 Olive groves
	2.3 Pastures	2.3.1 Pastures
	2.4 Heterogeneous agricultural areas	2.4.1 Annual crops associated with permanent crops
		2.4.2 Complex cultivation patterns
		2.4.3 Land principally occupied by agriculture with significant areas of natural vegetation
		2.4.4 Agro-forestry areas
3. Forests and semi-natural areas	3.1 Forests	3.1.1 Broad-leaved forest
		3.1.2 Coniferous forest
		3.1.3 Mixed forest
	3.2 Shrub and/or herbaceous vegetation associations	3.2.1 Natural grassland
		3.2.2 Moors and heathland
		3.2.3 Sclerophyllous vegetation
		3.2.4 Transitional woodland scrub
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes, sand plains
		3.3.2 Bare rock
		3.3.3 Sparsely vegetated areas
		3.3.4 Burnt areas
		3.3.5 Glaciers and perpetual snow
4. Wetlands	4.1 Inland wetlands	4.1.1 Inland marshes
		4.1.2 Peat bogs
	4.2 Coastal wetlands	4.2.1 Salt marshes
		4.2.2 Salines
		4.2.3 Intertidal flats
5. Water bodies	5.1 Continental waters	5.1.1 Water courses
		5.1.2 Water bodies
	5.2 Marine waters	5.2.1 Coastal lagoons
		5.2.2 Estuaries
		5.2.3 Sea and ocean

Appendix B: CLC-categories and their species richness for Central Europe

The following tables contain a list of CLC-categories and their species richness for Central Europe. The columns indicate which number of species is to be expected in the category, standard deviation minimum and maximum numbers are also given. The columns also list up which species may be endangered for extinction in each CLC-category, number of moss species that are to be expected as well as number of mollusk species such as snails in each habitat (Koellner & Scholz, 2008).

When looking at the mean and the median – the values are very close, which indicates low skewedness of the distribution. Standard error is low as well and is similar for all of the intensity classes. The numbers in each cell are figures that can be used in reference when studying various habitats elsewhere (Koellner & Scholz, 2008).

CORINE Plus ID		S_{plants}						$S_{threatened\ plants}$			S_{moss}			$S_{mollusks}$		
		Mean	Std. Error	Minimum	Median	Maximum	N Plots	Mean	Std. Error	N Plots	Mean	Std. Error	N Plots	Mean	Std. Error	N Plots
	Land-use types															
111	Continuous urban	3.5	0.4	0	3	26	65	0.6	–	1	2.1	0.4	5	7.1	3.6	3
112	Discontinuous urban	9.5	0.4	1	9	32	152	0.6	0.0	3	4.4	0.6	23	4.1	0.5	20
113	Urban fallow	15.5	1.0	8	14	29	27			0			0			0
114	Rural settlement	9.6	0.5	5	10	12	17			0			0			0
121	Industrial units	14.6	6.7	1	16	37	5	0.6	0.0	2	3.3	1.0	4	2.7	1.1	3
121b	Industrial area with vegetation	9.5	0.7	1	9	20	53			0			0			0
122	Road and rail networks	17.7	2.9	1	21	37	18	0.6		1	5.1	0.9	12	5.8	0.9	11
122b	Road embankments	6.4	0.6	1	6	10	13			0			0			0
122d	Rail embankments	14.1	0.7	9	13	28	44			0			0			0
122e	Rail fallow	9.2	0.5	6	9	13	19			0			0			0
125	Industrial fallow	15.7	0.8	8	16	22	26			0			0			0
132	Dump sites	16.8	3.9	11	15	24	3			0	3.1	0.6	3	1	0.4	3
134	Mining fallow	14.8	0.7	11	14	19	10			0			0			0
141	Green urban areas	11.5	0.6	2	12	29	111	0.6	–	1	6.9	–	1	6.2	–	1
142	Sport and leisure facilities	3.8	1.0	1	3	20	18			0	2.8	2.2	2	11.2		1
211	Non-irrigated arable land	9.3	1.6	4	8	21	12	0.6	0.0	2	1.7	0.4	5	1.6	0.4	5
211a	Intensive arable	4.0	0.3	0	4	10	54			0			0			0
211b	Less intensive arable	3.8	0.3	0	3	26	198	0.7	0.1	5	1.1	0.2	15	2.6	0.4	24
211c	Organic arable	10.0	0.5	1	11	15	62			0			0			0
211d	Fibre/energy crops	4.9	0.3	0	5	11	94			0			0			0
211e	Agricultural fallow	16.8	0.5	5	17	32	139	0.6	–	1	4.4	–	1	1.9	–	1
211f	Artificial meadow	11.0	0.5	6	12	16	28			0	1.8	0.2	22	3.3	0.5	23
221	Vineyards	6.7	3.1	2	5	16	4			0	0.6		1	4.8	1.4	4
221b	Organic vineyards	9.1	0.4	5	9	17	48			0			0			0
222	Fruit trees and berry plantations	15.1	2.0	10	16	19	4			0	2.2	1.4	4	4.4	0.5	4
222a	Intensive orchards	13.5	3.1	7	16	17	3	0.6	0.0	2	1.9	0.6	2	3.7	1.3	3
222b	Organic orchards	14	5.3	9	14	19	2			0	0.6		1	4.4	1.9	2
231	Pastures and meadows	15.8	0.7	6	14	35	78			0	2	0.2	60	4.2	0.4	72
	" above 800m	24.7	0.9	10	24	47	86	0.9	0.3	2	5.8	0.6	69	3.3	0.3	70
231a	Intensive pasture and meadows	7.2	0.6	1	7	30	73			0	2.5	0.6	3	3.3	1.3	3
231b	Less intensive pasture and meadows	7.5	0.4	2	6	18	104			0			0			0
231c	Organic pasture and meadows	17.5	0.3	2	17	44	727	0.7	0.1	13			0			0
244	Agro-forestry areas	21.2	3.7	17	21	25	2			0	10.6	5.0	2	2.5	0.6	2
245	Agricultural fallow with hedgerows	20.6	0.7	17	19	25	11			0			0			0
311	Broad-leafed forest	10.8	1.0	1	10	26	31	0.6	0.0	2	7.3	0.7	30	8.1	0.9	29
	" above 800m	9.9	1.2	1	10	26	26			0	7.6	0.9	25	4.7	0.9	21
311a	Broad leafed plantations	7.9	2.0	4	6	16	5			0			0			0
311b	Semi-natural broad-leafed forests	9.3	0.1	1	9	27	1312	0.6	–	1	1.1	0.1	115			0
312	Coniferous forest	6.9	1.1	5	6	10	4			0	9.8	2.9	3	6.2	2.2	3
	" above 800m	13.2	0.8	2	12	29	73			0	10.2	0.6	73	3.7	0.4	66
312a	Coniferous plantations	6.7	0.3	1	6	18	74			0	5.8	0.7	6	3.9	0.4	6
312b	Semi-natural coniferous forests	16.0	0.8	4	14	34	99			0	9.0	0.3	2	4.7	0.9	2
	" above 800m	27.4	1.4	15	29	33	13	0.8	0.1	8			0			0

		S_{plants}						$S_{threatened\ plants}$			S_{moss}			$S_{mollusks}$		
CORINE Plus ID		Mean	Std. Error	Minimum	Median	Maximum	N Plots	Mean	Std. Error	N Plots	Mean	Std. Error	N Plots	Mean	Std. Error	N Plots
313	Mixed forest	9.9	0.6	1	8	28	83			0	5.7	0.4	35	7.3	0.7	36
	" above 800m	19.3	0.5	3	19	36	223			0	9.0	0.6	46	5.7	0.5	46
313a	Mixed broad-leafed forest	12.6	1.1	9	14	18	8			0			0			0
313b	Mixed coniferous forest	7.1	0.3	5	7	11	35			0	6.9	1.2	2	3.1	0.0	2
313c	Mixed plantations	4.3	0.3	2	4	11	61			0			0			0
314	Forest Edge	18.5	1.1	1	18	40	78			0			0			0
321	Semi-natural grassland	18.3	0.5	2	17	49	331	0.7	0.0	19	9.2	0.6	86	3.3	0.3	66
322	Moors and heath land	14.2	1.1	5	13	29	36	0.9	0.3	2	11.1	0.9	30	3.4	0.8	21
324	Transitional woodland/shrub	17.2	1.0	2	18	34	60	0.6	0.0	2	10.3	1.5	16	4.7	1.0	13
331	Beaches, dunes, and sand plains	5.6	2.5	3	6	8	2			0	1.6	0.9	2	1.9	–	1
332	Bare rock	8.7	0.9	1	7	22	42	1.2		1	6.9	0.6	40	1.9	0.4	18
333	Sparsely vegetated areas	19.8	1.4	5	20	42	31	0.6	0.0	6	11.4	1.0	30	2.4	0.6	23
411	Inland marshes	18.0	3.7	9	16	28	5	1.0	0.2	3	4.1	1.6	5	9.4	2.3	5
412	Peat bogs	7.2	0.2	1	7	24	634			0	3.1	–	1	4.4	–	1
511	Water courses	7.5	2.6	2	7	16	5	0.6		1	4.9	1.2	5	1.7	0.7	3
	Total	11.8	0.1	0	10	49	5581	0.7	0.0	78	6.1	0.2	787	4.2	0.1	617
	Intensity classes															
1	Artificial surfaces	9.4	0.3	0	9	37	481	0.6	0.0	7	3.9	0.4	38	4.3	0.6	31
2	Agriculture high intensity	5.8	0.2	0	5	30	524	0.7	0.1	11	1.6	0.1	47	2.9	0.3	58
2	Agriculture low intensity	16.6	0.2	2	16	49	1214	0.7	0.0	19	9.1	0.6	89	3.3	0.3	70
3	Forestry high intensity	5.7	0.2	1	5	18	140			0	5.8	0.7	6	3.9	0.4	6
3	Forestry low intensity	11.0	0.2	1	9	36	1773			0	3.9	0.3	200	6.3	0.4	86
3	Non-use	11.1	0.2	1	10	42	1120	0.8	0.1	15	9.2	0.5	125	3.4	0.4	83
	Regions in Switzerland															
	Alps	19.7	0.2	12	19	33	202	0.7	0.0	172			0			0
	Jura	17.1	0.4	12	18	23	44	0.7	0.1	33			0			0
	Plateau	15.6	0.3	11	15	24	104	0.1	0.0	23			0			0
	Above timberline	10.7	0.2	3	10	22	215	0.2	0.0	177			0			0
	Lakes	0.5	0.1	0	0	1	28	1.0	0.1	87			0			0
	Worldwide diversity regions															
	DZ5 (Swiss Plateau)			8.9		13.3										
	DZ6 (Swiss Alps)			13.3		17.7										

Appendix C: Derivation of Equation 4

Derivation of Equation 4:

Step 1

$$\text{PDF}_H = \frac{\text{PDF}_1 * \text{A}_1 + \text{PDF}_2 * \text{A}_2}{\text{A}_{TOTAL}}$$ *Equation 3*

where A represents the area that shows changes and A_{TOTAL} stands for the whole area (10x10 km). This equation displays a weighted average of PDF for each area and is done for both 2000 and 2006 data.

Step 2

In order to estimate change in PDF for whole areas (10x10 km)

Equation 2 is used to derive Equation 4:

$\Delta PDF_H = PDF2_H - PDF1_H$

$$= \left(\frac{\text{PDF2}_1 * \text{A}_1 + \text{PDF2}_2 * \text{A}_2}{\text{A}_{TOTAL}}\right) - \left(\frac{\text{PDF1}_1 * \text{A}_1 + \text{PDF1}_2 * \text{A}_2}{\text{A}_{TOTAL}}\right)$$

$$= \left(\frac{\text{PDF2}_1 * \text{A}_1 - \text{PDF1}_1 * \text{A}_1 + \text{PDF2}_2 * \text{A}_2 - \text{PDF1}_2 * \text{A}_2}{\text{A}_{TOTAL}}\right)$$

$$= \left(\frac{\text{A}_1}{\text{A}_{TOTAL}}(\text{PDF2}_1 - \text{PDF1}_1)\right) + \left(\frac{\text{A}_2}{\text{A}_{TOTAL}}(\text{PDF2}_2 - \text{PDF1}_2)\right)$$

$$= \left(\frac{\text{A}_1}{\text{A}_{TOTAL}}\ (\text{PDF2}_1 - \text{PDF1}_1)\right) + \left(\frac{\text{A}_2}{\text{A}_{TOTAL}}\ (\text{PDF2}_2 - \text{PDF1}_2)\right)$$

$$= \left(\frac{\text{A}_1}{\text{A}_{TOTAL}}\Delta\text{PDF}_1\right) + \left(\frac{\text{A}_2}{\text{A}_{TOTAL}}\Delta\text{PDF}_2\right)$$