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MASTER PLAN FOR GEOTHERMAL AND HYDROPOWER DEVELOPMENT IN ICELAND

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ABSTRACT

Iceland is very rich in renewable energy resources in comparison to the need of the country, mainly hydro power and geothermal. Energy usage, was, however, very limited through the centuries but increased rapidly during the last century. Presently these resources supply over 70% of the countries use of primary energy which is world's highest share of renewables in a national energy budget. Still only a small fraction of these energy resources has been utilized. The Icelandic Government decided in 1997 to develop a Master Plan for all potential power projects in hydro and geothermal. All proposed projects should be evaluated and categorized on the energy efficiency and economics but also on the basis of the impact that the power developments would have on the environment. The work was organized by a Steering committee of 16 members and some 50 experts nominated for four working group. The Master Plan is comparable to the planning of land use and land protection. It was not supposed to go into the details required for environmental impact assessment (EIA), but still finding those projects that are best suited for developments based on energy production, economy and protection of the nature.

It is expected that some 100 projects will be evaluated and ranked in the Master Plan. The work is divided into phases. The first phase was completed in 2003 and work on phase 2 is underway. Forty three proposed projects, 19 hydro and 24 geothermal, were evaluated and ranked during phase 1.

1. INTRODUCTION

Iceland is an island in the North Atlantic just south of the Artic Circle. The island lies across the Mid Atlantic Ridge, the rift zone along the constructive boundaries between the American and the Eurasian tectonic plates which move apart at an average rate of 2 cm per year. Iceland resides on a mantle plume and a hot spot in the rift zone and has been formed in frequent volcanic eruptions continually from Miocene time to present. This explains why this part of the ridge rises above sea level and forms an island of an area larger than 100.000 km^2 . The highest mountains rise to an elevation of 2000 m and over 50% of the country lies above an elevation of 400 m a.s.l. Several large icecaps are found in the highlands. The presently active zone of rifting and volcanism crosses Iceland from southwest to northeast. Volcanic eruptions are very frequent in this zone and take place typically every few years. The Icelandic crust is therefore very young on the geological time scale and rocks on surface range in age from zero near recently active volcanoes to 15-16 million years in the coastal areas furthest away from the volcanic zone.

Iceland has abundant energy resources, both hydro and geothermal. The hydro power is associated with the high precipitation and the mountainous terrain of the country. The ice caps can be considered as water reservoirs and glacial rivers constitute the highest hydropower capacity (Fig.1). The geothermal resources are closely associated with the volcanic activity. Traditionally the geothermal fields are divided into *high-temperature fields*, where temperature above 200°C is found above 1 km depth and *low-temperature fields*, in which temperature is lower than 150°C in the uppermost kilometre. Some 30 high temperature fields have been outlined in Iceland, all within the active volcanic zone as shown in Figure 2. The low temperature activity is highest on the flanks of the volcanic zones but some low temperature resources are found in most parts of the country.

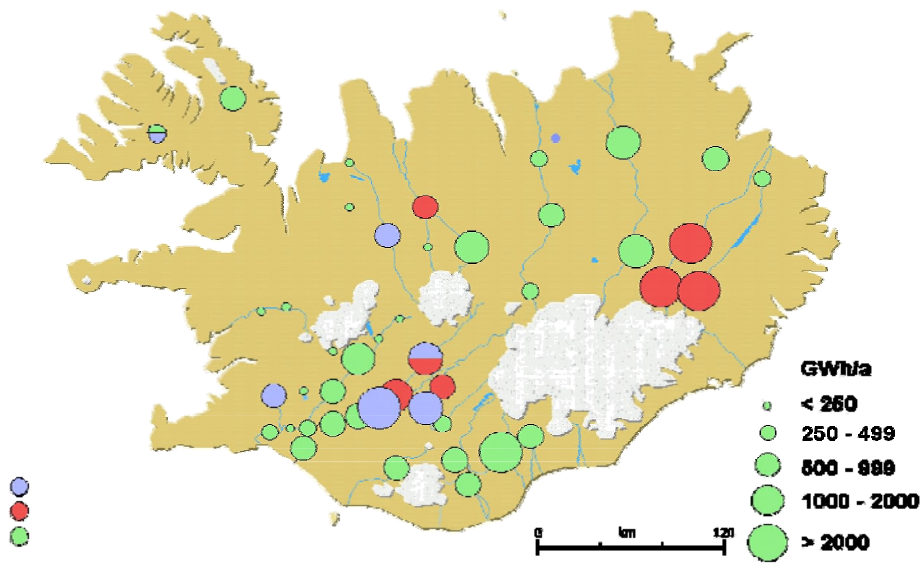

FIGURE 1: Hydropower resources of Iceland. Existing power plants (>10 MW) are shown as blue bullets, planned power plants as red and potential projects as green bullets

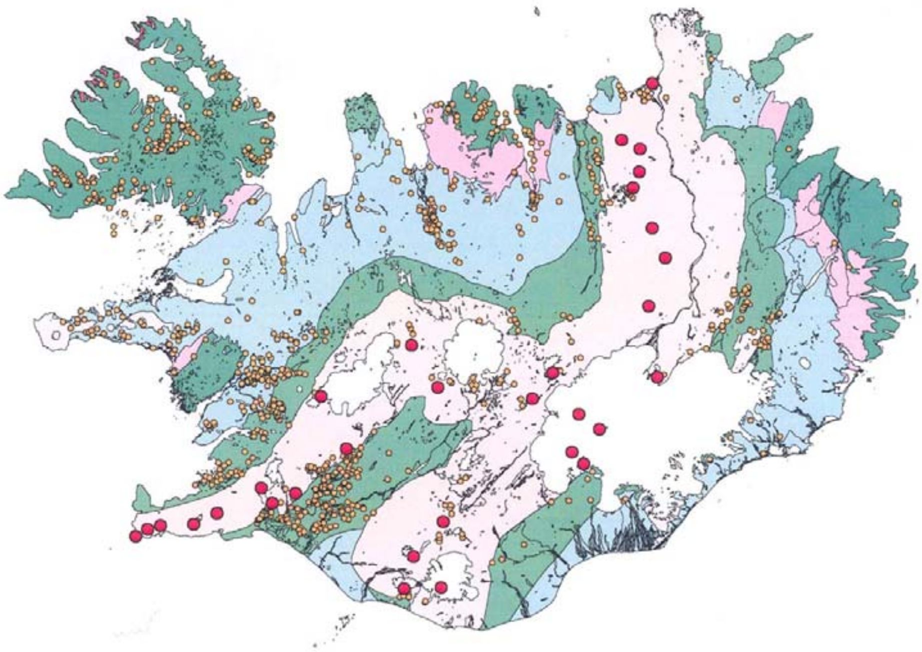

FIGURE 2: Geothermal map of Iceland. High temperature fields inside the active volcanic zone are shown as red circles, and hot and warm springs as yellow circles

2. ENERGY CONSUMPTION IN ICELAND

The utilization of the energy resources of Iceland was very limited through the centuries. Hot water from warm springs was, however, used locally in some areas for bathing, cooking and washing and sulphur was mined from a few of the high temperature areas and exported to Denmark. It was, however, not until the late 19th and early 20th century the Icelanders started to make an effort to utilize the hot springs and experiment with different utilizations schemes. This included heating of farmhouses, swimming pools and soil heating for growing vegetables. The first large development occurred in 1930 when a district heating system started operation in Reykjavik supplying hot water to a hospital, a school, a swimming pool and some 70 homes. The utilization grew gradually over the next decades. Initially the geothermal development focused on the utilization of low temperature resources, for space heating. Later utilization of the high temperature resources for electrical generation, space heating and some industrial uses followed.

Electric power was first produced in 1899 and the first hydro power turbine started production in 1904. Installed capacity was 9 kW. The power plant was built and owned by a carpenter and the energy was used in his workshop, in his household and in few neighbouring houses. Several small electric power plants became operative during the next decades, most of them driven by hydro. In 1934 the total installed capacity was about 5 MW in 38 power stations. The electrification of the country continued both in urban areas and rural areas. The first power intensive industrial user was the State Fertilizer Plant in 1953 and the first aluminium smelter started production in 1970.

An overview of the primary energy consumption in Iceland during 1940 until 2004 is depicted on figure 3. It shows a dramatic increase in the energy consumption from about 5 to 140 PJ per year. It also shows that in 1940 most of the energy was obtained by burning coal. In 2004 on the other hand 55% of the consumption is geothermal, 16% is hydro and the rest is mainly oil for the transportation sector and the Icelandic fishing fleet. The developments during this 64 years period can be divided into phases. The first one being until 1970 when the main emphasis was on the electrification of the country, mainly by hydropower and replacement of coal, turf and wood in space heating by geothermal where it was easily accessible and oil electricity in other areas. The second phase started in the late 1960's when power intensive industry became a large user on the electric market. The third phase is related to the oil price crisis in the 1970's. Due to the dramatic rise in the oil prises the Icelandic Government launched a major effort to replace oil in space heating with geothermal and electric energy. At his time oil served about 50% of the space heating market and geothermal about 40 %. The effort was very successful. Ten years later oil heating was down to 5 % and presently geothermal energy serves almost 90% of the market. The fourth and the final phase which is still ongoing is the large expansion of the power intensive industry after 1995, which in 2004 consumed about 60% of electricity generated in Iceland.

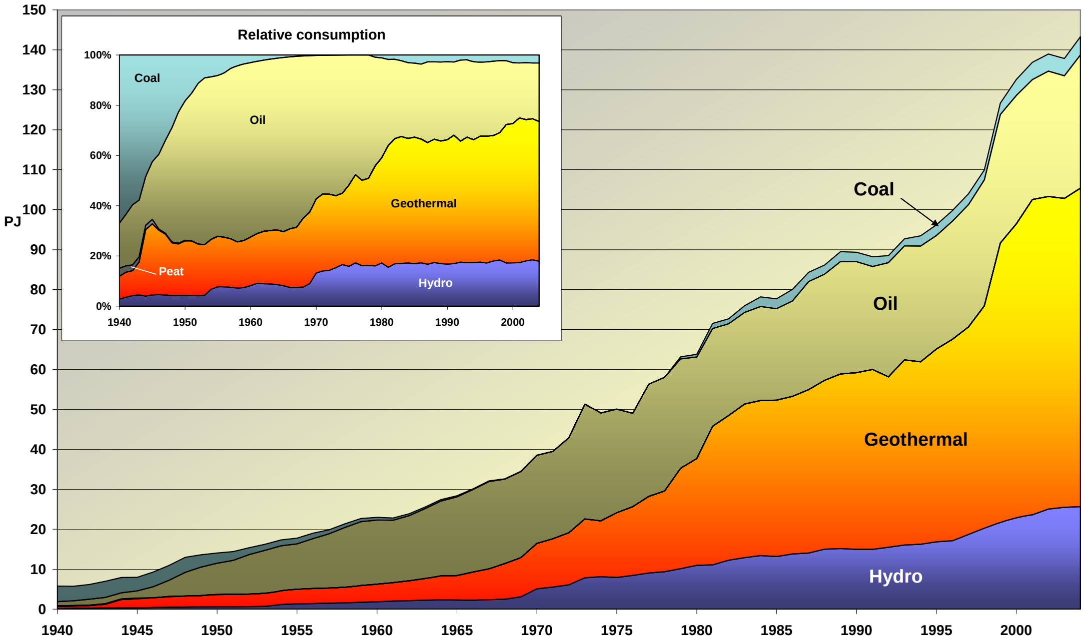

FIGURE 3: Primary energy consumption in Iceland 1940-2004. Source: Orkustofnun (National Energy Authority)

3. MASTER PLAN FOR THE DEVELOMENT OF ENERGY RESOURCES

3.1 A Need for a Master Plan

Iceland is very rich in renewable energy resources for heat and electricity generation. The potential generating capacity of hydro and geothermal has been estimated 50 TWh/year. The present generation is only 17% of the estimated potential. Earlier developments were focused on meeting the basic energy needs of the society for space heating and electricity for the general market. Through the years it has become more and more evident that utilization of the energy resource (as other developments) must take into account not only the energy needs and the economical aspects of the developments but also a range of other interests as well. This includes other use of land and the impact of the development on the environment, and cultural heritage. The first step towards such an evaluation was undertaken by a collaboration committee of specialists from the Ministry of Industry, the National Power Company, Orkustofnun (the National Energy Authority) and the Nature Conservation Council. This committee was active during the 1970's to the 1990's. It discussed plans for various electrical power plants with special emphasis on the natural conservation aspects of the developments. It was commonly mentioned during this meetings that a general view on the energy policy and the nature conservation policy was needed for the country. The need for a general plan on energy developments became even more important by 1994 when the Parliament of Iceland passed the first Act on Environmental Impact Assessment.

The Icelandic Government published a white paper on sustainability in Icelandic society in 1997 (Government of Iceland, 1997). There the need of the development of a long term plan for energy use in Iceland was once again stressed.

3.2. The Master Plan

Following the white paper it was decided by the Government to develop a master plan for the utilization of the energy resources both hydro and geothermal as a part of its goal for sustainable developments. The logo selected was MAN-UTILIZATION-NATURE. The vision behind the master plan was to prepare an overview on the various potential energy projects in hydro and geothermal and evaluate and rank them based on their energy and economic potential and the estimated impact that each project would have on nature, environment and society.

The master plan should be based on the best available scientific information and conclusions should be transparent and reproducible and made available to the public. It was considered of vital importance to establish public confidence in the evaluation process and therefore the National Association for the Protection of the Icelandic Environment (an NGO) was assigned to establish a forum for the public and interested parties to discuss and exchange information in open meetings and workshops, and to cooperate with the media. Information on the work was also accessible on interactive websites.

The master plan should define those power projects that rank high from economical point of view and have a minimum negative impact on the environment and positive impact on the society. Such a score card for the energy projects helps decisions makers to filter out which of proposed projects are likely to become controversial and disputed and which one not. It also directs the attention to those project areas that should be protected and left untouched by human developments.

3.3. The Organization of the Master Plan.

The Ministry of Industry is responsible for the master plan in co-operation with the Ministry for the Environment. A special Steering Committee of 16 members for the first phase of the project was established in April 1999. In its function it was supported by about 50 experts working in four different working groups.

The members of the Steering Committee were appointed by the ministers of industry and the environment. It included representatives of the two ministries and their key institutions, the chairmen of each of the four workgroups, people involved in local government and representatives of tourist industry and of NGO’s. The committee was chaired by Mr. Sveinbjörn Björnsson, director of the Resource Department of Orkustofnun and former rector of the University of Iceland. The duty of the Steering committee was to define the project and to coordinate the work and the working methods of the working groups which carried out the main part of the work. The working groups collected available data on the various projects and project areas and suggested further data collection and needed exploration work which was then evaluated by the Steering committeee and passed on to the Ministry of Energy for decision and execution. The Steering Committee worked jointly with the working groups in finding ways for their evaluation of the proposed energy projects. The conclusions of each of the working groups were analysed by the Steering Committee and their ranking of the projected evaluated and combined to define a general ranking table for all the energy projects evaluated by the working groups. The Steering Committee held monthly meetings and called regularily for public meetings to inform on the progress of the master plan and to obtain suggestions and comments from interested parties. The public meetings were not only held in Reykjavík but also in the regions of proposed power projects to ease the participation of all interested citicens.

Orkustofnun was the main organizing agency and Dr. Hákon Adalsteinsson, chief project manager, at the Resource Department at Orkustofnun worked closely with the Steering Committee and its chairman during the development of the master plan. In between Steering Committee meetings the chairman and the two ministrial representatives operated as an executive board of the committee.

4. THE DEVELOPMENT OF THE MASTER PLAN - PHASE 1

The government expected in 1997 that the master plan would be completed in year 2000. Preparations were, however, delayed and the work did not start until 1999, so it was evident that the initial time limit could not be met. It was also clear that the development of the plan was not a straight forward process. A similar work had not been carried out before in Iceland and the only foreign example known to the Icelanders was the Norwegian Master Plan for hydropower developments which was first developed in 1984 (The Environmental Protection department, 1984).

The initial steps in the development of the Icelandic master plan were that Orkustofnun and the power companies compiled reports on project proposals they wished to have evaluated by the Steering Committee. These reports were made available for the public and interested organisations to give them an opportunity to review the reports and offer comments. It soon became evident that the number of proposed projects that should be evaluated and ranked during the master plan work would be about one hundred. Available data for many of the projects areas were scarce and it was obvious that the evaluation of all these projects would call for a large investment in data collection and exploration, before all projects could be ranked. The Steering Comittee, therefore suggested to the government to divide the work into phases. For the first phase 43 energy projects were selected. These were 19 hydropower projects with an energy potential of 16.600 GWh/a and 24 geothermal projects with an energy potential of 18.000 GWh/a. The hydro projects were mainly in glacial rivers in the central highlands whereas most of the geothermal projects were in geothermal fields near to inhabited lowlands. Phase 1 was completed in 2003. (Steering Committee for the Icelandic Master Plan, 2003). The following paragraphs give a summary of the work during the first hase.

4.1. Working group I - Nature, Environment and Cultural Heritage

Working Group I counted 13 experts nominated by the Ministries, relevant institutions and NGO's. The chairman was Dr. Th.E. Thórhallsdóttir, botanist and Professor of the University of Iceland. The working group evaluated what impact proposed power projects would have on Nature, landscape, geological formations, vegetative cover, flora and fauna, as well as cultural heritage and ancient monuments.

The working group reviewed existing data for each proposed project and divided them by quality into three categories; good (A), fair (B) and unsatisfactory (C) and suggested several data collection tasks in order to improve the knowledge base for the project areas. To rank the proposed projects the working group considered several ways of carrying out the evaluation and selected eventually a three step procedure using multi criteria analysis. The first step was to assess site values, then in the second step the impact of the development was evaluated and finally in the third step the proposed projects were ranked from worst to best choice from environmental-cultural heritage point of view using analytical hierarchical process using site values and predicted impacts.

The working group decided to identify the components in the natural environment and the heritage that have a considerable value and divide them into 5 classes, four regarding the environment (1) Geology and hydrology; (2) Species (fauna and flora), (3) Ecosystems and soils, and (4) Landscape and wilderness. The fifth (5) class represented the Cultural heritage. Two of the classes were further divided into subclasses. To evaluate the value of each class and to assess the impact of the power development on these, the valuable properties of the classes were analysed and assessed through 6 attributes i.e. properties that are considered to make the classes valuable. The attributes considered were: (1) Richness-Diversity; (2) Rarity; (3) Size-Pristineness; (4) International responsibility; (5) Information value and (6) Visual or scenic value.

The classes and the attributes define the evaluation matrix shown in table 1. Each of the 30 elements (attributes) in the matrix was evaluated for each power project area. and its value represented by a value number on a non-linear four point scale: 1=insignificant; 2=some; 3=large and 5= very high value. A similar scale was used for the impact with the addition of the 5th score numer 0= no impact. The value score for each class was then found using the weight numbers shown for the attributes in the matrix. Finally the classes were assigned weight factors to reach an unique one number score for each project area. The weight factors were: 25% for Geology and hydrology, 25% for Landscape and wilderness, 20% for Ecosystems and soils, 20% for Species, and finally 10% for Cultural heritage. A detailed account of the work of working group I is given in two publications by Prof. Thórhallsdóttir (Th. E. Thórhallsdóttir, 2006a and 2006b).

TABLE 1: Evaluation matrix for environmental and cultural heritage values of the project areas and for assessment of the impact of the developments. (Numbers indicate weight numbers for the evaluation)

		Attributes					
Classes	**Sub-classes**	**Richness and diversity**	**Rarity**	**Size**	**International responsibility**	**Information value**	**Visular and scenic value**
Geology and Hydrology	Bedrock Sediments Hydrology Rivers and lakes	0.5 0.5 0.5 0.5		0.3 0.3 0.3 0.3		0.2 0.2 0.2 0.2	
Species		0.4					
Ecosystems and soil		0.3	0.3	0.2	0.1	0.1	
Landscape and wilderness	Landscape Wilderness	0.3	0.2 0.2	0.2 0.8			0.3
Cultural heritage		0.2	0.3	0.2		0.3	

4.2. Working group II - Recreation, Fishing, Hunting and Agriculture

Thirteen experts were nominated for Working Group II, which was chaired by Dr. Haukur Johannesson, geologist and president of the Iceland Touring Association. This working group evaluated the impact on outdoor life and activity. They recognized three main classes: (1) Recreation; (2) Fishing and hunting and (3) Grazing and other land use, and divided them into sub-classes. The value of each class was described an analysed but no score assigned to the value of the classes. The impact of the proposed power development was on the other hand evaluated using an analytical hierarchical process similar to the work of working group I. An evaluation matrix was defined (table 2) and the impact assessed for the sub-classes and assigned to them a scoring number on a non-linear five point scale from positive to negative impact. The scale selected was: +3= positive impact; 0=no impact; -1 small; -3 significant and -5 for major negative impact. The scoring of the sub-classes and then the classes were weighted according to the numbers shown in table 2 to reach a final score for the impact of the proposed projects on the premises of working group II.

4.3. Working Group III - Social and Economical Impact and Regional Development

Working Group III was chaired by Mr. Sigurður Gudmundsson, planning expert at National Economic Institute and the thirteen group members included experts nominated by economical institutes, Icelandic Federation of Unions as well as of Employers, the Planning Agency, the Icelandic Tourist Board, the Association of Local Authorities and others. The task of the working group was to evaluate the impact proposed power projects would have on economic activity, employment and regional development.

TABLE 2: Evaluation matrix for the classes and sub-classes of working group II. (Numbers indicate weight numbers for the evaluation)

Classes	Weight number of classes	Sub-classes	Weight number for sub-classes
Recreation	0.72	Short hiking trips. Long trips to the countryside Birdwatching and nature observations Adventure trips. Pony riding trips. Winter trips Enjoyment	0.10 0.13 0.17 0.10 0.10 0.10 0.17
Fishing and hunting	0.19	Fishing in rivers. Fishing in lakes.	0.3
Other use of land	0.09	Grazing. Other benefits (Useful plants, berries and other)	0.2 0.2

The working group developed a model to simulate the impact and tested it for ten proposed power projects. Their conclusion was that the projects could not be ranked regarding the local impacts of the construction of the power plants. The group evaluated on the other hand the power projects and assessed if the energy produced would be utilized locally and ranked the projects accordingly. The group also developed a model to evaluate the effect of the power development on tourism. This was a comparative study where the tourism was modelled with or without the power development. Power projects which were likely to have the greatest impact, positive or negative, on the tourism could then be identified.

4.4. Working Group IV - Identification of Potential Power Projects, Project Economy

Working Group IV was chaired by Dr. Thorkell Helgason, the director general of Orkustofnun and the six group members were nominated by Orkustofnun, The Icelandic Association of Energy Companies (2), the National Power Company and the Association of Local Authorities (2). The task of working group IV was to identify potential power projects, both hydro and geothermal, and carry out technical as well as economic evaluation of the projects. The working group considered four classes for the size and the economics of the projects. These were: (1) Energy capacity (GWh/a); (2) Capital cost per energy unit produced (kr/kWh); (3) Total profit and (4) Rate of return of investment.

The estimated generating capacity was very different for different projects. Largest was a hydro project with a generated capacity of 4670 GWh/a but smallest was a geothermal project of only 140 GWh/a. The generating capacity of the hydro power plants depends on the flowrate of the river and the reservoir capacity to manage the flowrate evenly throughout the year. The general geothermal power plant analysed by working group IV was a 120 MW plant operated for 7000 h/a. The capacity of the general geothermal plant was therefore 840 GWh/a. Investment cost was based on 2003 prices. Annual operational cost was estimated 0.8% and 2% of investment cost for hydro and for geothermal, respectively. Energy prices were estimated for priority and non-priority sales and total profit was estimated for 50 years of operation. The economical calulations showed that the capital cost per energy unit produced was very similar for the projects proposed for the first phase of the master plan. To rank the projects it was therefore decided to look neither at total investment nor capital cost per energy unit but to define an index of total profit for the projects. The project of highest profit was assigned the profit index 10 and other projects got an index based on their profit relative to the highest scorer. Similarily the working group assigned an index of rate of return to the projects.

4.5. Phase 1 - Summary of Results

Forty three potential power projects were evaluated during phase 1. These were 19 hydropower projects with a estimated total power capacity of 16.6 TWh/a and 24 geothermal projects with estimated capacity of 18 TWh/a. The Steering Committee analysed the results of the four working groups and decided to use three indices for ranking the project. These indices are (1) Index U of environmental value and impact that was based on the ranking of working group I and II, rating the ranking of group I double against the ranking of group II; (2) Index H for total profit over 50 years operation and (3) Index A for rate of return of initial capital cost. Both index H and A were defined by working group IV . The projects of small environmental impact got a low U-value but the project of maximum profit and rate of return got maximum index values. The index scoring was divided into five groups as shown in table 3.

TABLE 3: The indices and index groups to rank the power projects

Groups	Index (U) Environmental Impact	Index (H) Total profit	Index (A) Rate of return
a	0-0.9	10-5	10-5
b	1-2.4	4.9-1.15	4.9-4.0
c	2.5-3.9	1.14-0.9	3.9-3.4
d	4.0-7.9	0.8-0	3.3-2
e	>8	<0	<2

Table 3 formed the basis for the final ranking of the 43 power projects evaluated in phase 1 of the master plan. There was greatest interest in ranking the projects after the environmental impact index. The result was that nineteen of the project have relatively small environmental impact and fall into group a. Only four of these are hydropower projects and the rest are geothermal. In environmental group b are nine projects, 3 geothermal and 6 hydro. Four project were ranked in environmental group c, 7 in group d and 4 hydropower projects were ranked in environmental group e. The ranking of the power project shows clearly that geothermal power developments are considered to have much less environmental impact on Icelandic nature than hydro power developments.

5. THE MASTER PLAN -PHASE 2

The second phase of the master plan was launched in September 2004 when a new Steering Comittee was appointed. This time the committee consisted of 3 persons, the chairman of the Steering Committee of phase 1 and a representative from each of the two ministries. The commitee works closely with the institutions of the ministries, mainly Orkustofnun (the National Energy Authority) and the Icelandic Institute of Natural History. In phase 2 the focus is on the exploration of the active geothermal systems in the central highlands of Iceland and the methodology of geothermal reservoir assessment in order to compare the various geothermal reservoirs and then reevaluate all the geothermal project areas. The pioneering work on how to evaluate landscape that workgroup I started on during in phase 1 will continue in phase 2. Finally the potential in the general hydrological runoff for mini hydro's in Iceland will be evaluated (H. Aðalsteinsson, 2006).

The Steering Comittee has set up two consultancy groups. One to evaluate methods applied to assess the biological and geological nature of geothermal fields and the generating capacity of geothermal reservoirs, and the other to advise on how to improve the methodology in evaluating landscape with emphasis on the landscape characterizing the geothermal areas.

The consultancy groups have worked hard during the last two years and they have put forward several exploration and data collections programmes, some which are now being executed. The main worktasks that will be carried out in phase 2 are:

1. Exploration of the unexplored geothermal areas in the highlands. This includes geological mapping, geophysical exploration and sampling of fluids from hot springs and fumaroles in the area. The ultimate goal of the exploration is to develop a conceptual model of the geothermal system, estimate its size and reservoir temperatures.
2. Classification of geothermal manifestations and colorful altered grounds found in the geothermal areas. Evaluations of the protection value of these.
3. Mapping of the special vegitation found near the geothermal manifestations and the microbiota found.
4. Methods to evaluation Icelandic landscape and comparison to similar methods applied in Europe.
5. Mini hydros
6. Re-evaluation of modified hydro- and geothermal projects from phase 1, based on improved field data, and applying revised methodology. Evaluation of additional projects that have been prepared for evaluation since phase 1.

The second phase is expected to be completed in 2009.

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