SUSTAINABLE GENERATION AND UTILISATION OF ENERGY THE CASE OF ICELAND.

PRODUCTION ET UTILISATION DE L'ÉNERGIE SOUTENABLE: LE CAS DE L'ISLANDE

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1. Introduction

Iceland is a country of somewhat less than 300,000 people located astride the North Atlantic Ridge. It is mountainous and volcanic, with much precipitation. These geographical peculiarities lead to a situation where geothermal and hydropower are abundant, while the small population lends itself to a large measure of renewable energy per capita.

During the course of the 20th century a remarkable transition has taken place in Iceland. From being among Europe´s poorest countries dependent upon peat and imported coal for its energy, Iceland now has practically all of its stationary energy and over 72 percent[A] of its primary energy from indigenous renewable sources, and has one of the highest standards of living in the world.

In this paper we will examine how and why this change came about. We will demonstrate the importance of economics on the success of renewables, and how public policy may be set to encourage their successful development. We will also address some of the technical and environmental issues encountered on the way, as well as looking at technology transfer and efforts to increase the share of renewables in the primary energy.

The lessons learned from Iceland´s evolution towards a renewables based energy system may be particularly interesting to developing nations with untapped renewable energy sources.

2. Energy Resources

Les sources de l'Énergie

We begin our study by looking at the magnitude of the two most important sources of renewable energy in Iceland – hydro and geothermal energy.

It has been estimated that the total potential energy of all precipitation that falls on Iceland is approximately 300 TWh/annum. Figure I shows the fate of this precipitation. Of the 64 TWh/annum that are technically harnessable, it is estimated that 37 TWh/annum would be economically viable, and some 25 TWh/annum once environmental concerns have been taken into consideration.[B]

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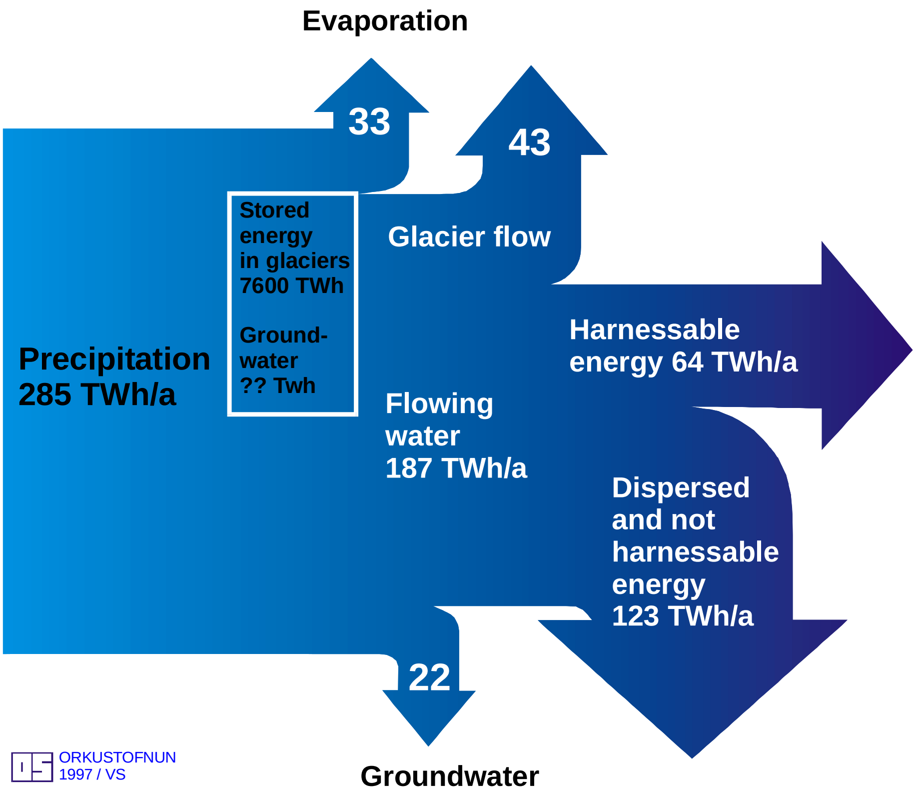

Figure 2: Hydro Energy Derived from Precipitation in Iceland.
L'énergie hydraulique dérivée de la précipitation en Islande.

It is more difficult to estimate the amount of energy that may be obtained from geothermal sources, but the most recent estimates for sustainable use of high temperature fields suggest that they could yield 26 TWh/annum for electrical generation once economic and environmental factors have been taken into account. Resources for heating are much higher.

Thus we may assume that approximately 50 TWh/annum of hydro and geothermal energy may be used for generation of electricity in a sustainable manner. Electrical production in 2003 amounted to 8.5 TWh.

3. Economic background
Antécédents économiques

Towards the end of the 19th century, Iceland had begun its transition from a traditional agrarian economy with minimal foreign trade to a modern economy integrated with foreign markets. This was driven by education, technical advances and the introduction of more economic freedom and flexibility than had hitherto been available. Access to capital and labor led to substantial investments in the most lucrative economic sector –the fishing industry. The fishing industry became dominant in the economy, generating 85–90 percent of the export revenue – a fact that becomes even more compelling when one considers how much Iceland relied on foreign markets (export value was roughly 40 percent of the GDP in the interval 1900 – 1930).[C,D]

After getting home rule in 1918, the Icelandic government limited possibilities for foreign investment in Icelandic industries. This trend, which became ever stronger with the onset of the Great Depression and worldwide curtailing of free trade, was to have dire and longstanding consequences. Lack of capital was a constant obstacle towards diversification of an economy that was almost solely reliant on exporting fish.

The onset of the Second World War proved to be an economic boon for Iceland. Foreign (mainly British) fishing operations in Icelandic waters (which had been substantial) came to a halt and fish prices shot up. In addition the British, and later American, forces that occupied Iceland from early 1940, injected much needed capital into the country and many jobs were created building up the infrastructure needed for the foreign troops. The upshot of all this was that at the war´s end, the per capita income in Iceland was one of the highest in the world – in sharp contrast to what it had been just 10 years earlier. Unfortunately, a period of prodigal consumption and over-investment in the fishing industry, and lack of investment in a more diverse and stable economy, led to Iceland depleting its cash reserves in the space of a few years. The government´s response to this situation was to introduce ever more stringent regulations concerning economic activity which further hampered enterprise in the country.

After 1960, there was a change of tack in economic policy, leading to more liberalisation and opportunities for economic diversification.

The economic climate had a strong effect on the development of renewable energy resources and, in turn the use of those resources affected the society to a large degree.

4. Overview of energy production
Regard sur la production de l'Énergie

4.1 Early use of renewables
Premières utilisations des énergies renouvelables

At the beginning of the 20th century imported coal, and later oil, were the dominant sources of energy in Iceland. The first hydropower installation (amounting to 9 kW) was built in 1904 by a local entrepreneur, but the first large municipal hydropower plant was built in Reykjavík in 1921. This 1 MW plant quadrupled the national electrical power capacity and brought electrical lighting to homes in Reykjavík. For the next 30 years, increases in hydropower were gradual and geared towards satisfying the needs of general consumption.

The other development in the use of renewables was the introduction of district heating by geothermal energy. This development was begun in 1930 and became a large scale project in 1943. Nonetheless, oil still remained the primary source of energy for heating – something that would not change until the 1970s.

Let us now turn our attention to developments taking place after the beginning of the Second World War. Figure 2 shows the historical development of sources of primary energy in Iceland during the interval 1900–2002. From this figure one can sense the general tenor of development, but let us look at the use of hydropower and geothermal energy separately in some detail.

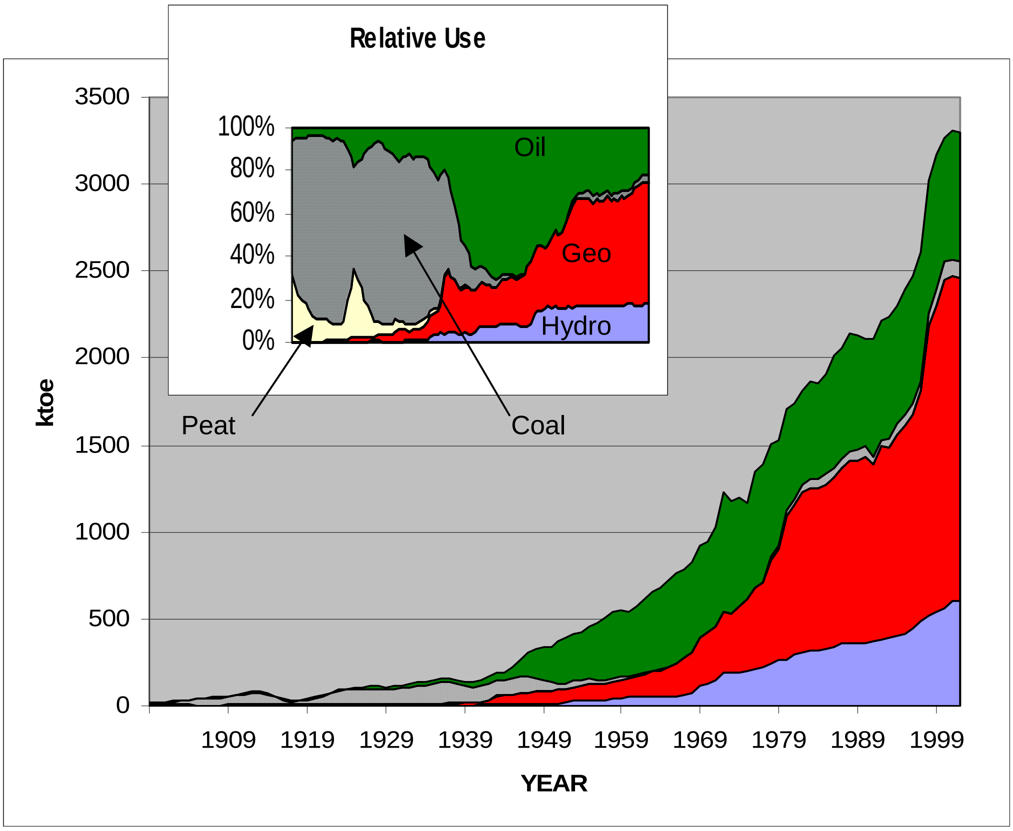

Figure 2: Sources of primary energy.
Les sources de l'énergie primaire.

4.2 Hydropower after 1940
Énergie hydraulique après 1940

In the 1950´s, funds from the Marshall Plan were used to build two hydropower plants in the Sog river; a 31 MW plant in 1953, and a 26.4 MW plant in 1959. These were the first power plants built with the view of supplying industrial needs (fertilizer and cement production for domestic use). These were also the first plants to be co-owned by the municipality of Reykjavík and the Icelandic government –a result of government guarantees for the loans needed, and a portent of things to come.

In 1965, the National Power Company, Landsvirkjun, was founded with the purpose of supplying southwest Iceland with electricity. The company was jointly owned by the Icelelandic government and the municpality of Reykjavík. In a departure from prior policy, the company would be a for-profit concern. Previously, electricity had been looked upon as a public good with investments paid for, directly or indirectly, out of the state treasury. The first big project of Landsvirkjun was the building of a 210 MW hydropower plant at Búrfell on the Þjórsá river (comissioned in 1969). This plant was built in conjunction with a 33,000 ton/year aluminum smelter owned by the company Alusuisse and the power was sold by a 'take-or-pay' long-term contract guaranteed by the parent company. The new powerplant could supply both the smelter and increased general demand.

The founding of Landsvirkjun, and the introduction of power intensive industry for export, proved to be an important point in the development of Icelandic renewable energy sources. First of all, the size of Landsvirkjun, and its policy of operating on a for-profit basis, ensured that it could receive favourable interest rates on loans – not least due to the fact that the World Bank now considered that Iceland fulfilled requirements for a loan, a status that would help with access to private capital later on. Second, the presence of a large-scale buyer in the form of an aluminium smelter made the building of a large hydropower plant feasible, thus allowing for associated economies of scale. The start of large-scale energy projects also provided an impetus for the development of domestic technological know-how – a point to be discussed later in this paper.

4.3 The role of power-intensive industry

Le rôle de l'industrie à haute consommation d´énergie

Since larger hydropower plants are generally more economical (and with less relative environmental impact)[E] than smaller ones, the emphasis has naturally been to build higher capacity installations. Due to the small size of the Icelandic energy market, introduction of a large hydropower plant manifests itself as a sizeable jump in the total energy output, and would be hard to make feasible if it were only to satisfy steady increases in general consumption. The general strategy in power production has therefore been to build large hydropower plants in tandem with stepwise increases in power-intensive industry. Figure 3 shows electrical power production along with a timeline of industrial developments.

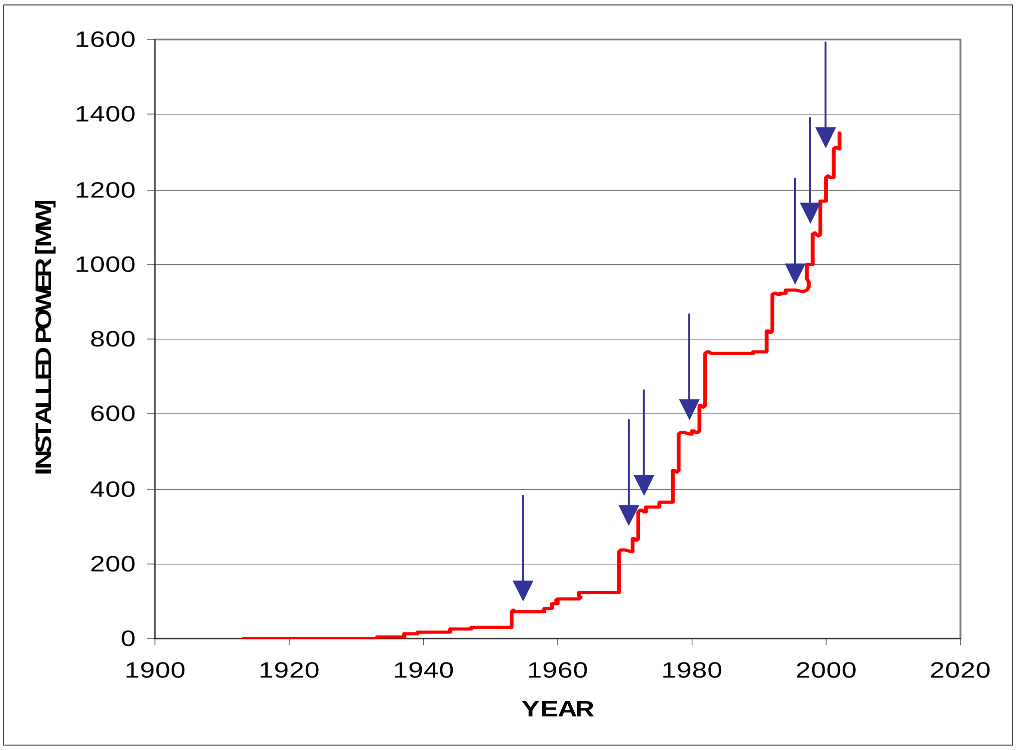

Figure 3: Electrical power production and industrial milestones (↓).
Capacité de production électrique et pics industriels.

It has been estimated that power intensive industries have contributed, beyond opportunity costs, 0.5 percent of the annual GDP, on average, over the period 1969 to 1997.

4.4 Geothermal energy
Énergie géothermale

Although the use of geothermal energy for district heating in Reykjavík had already begun on a small scale in 1930, it did not take off until in 1943. From that period there was a gradual increase in the use of geothermal energy for heating until the the first oil crisis in 1973. In response to the increased price of oil there was a spurt of activity in geothermal district heating. The contribution of geothermal energy to space heating rose from 43 percent in 1970 to 87 percent in 2002, most of the remainder being heated with electricity from hydro or geothermal. In fact, only 1.5 percent of energy used for space heating in 2001 came from non-renewable sources. Figure 4 illustrates this development and the effects of the oil crisis on energy soure selection for heating quite well.

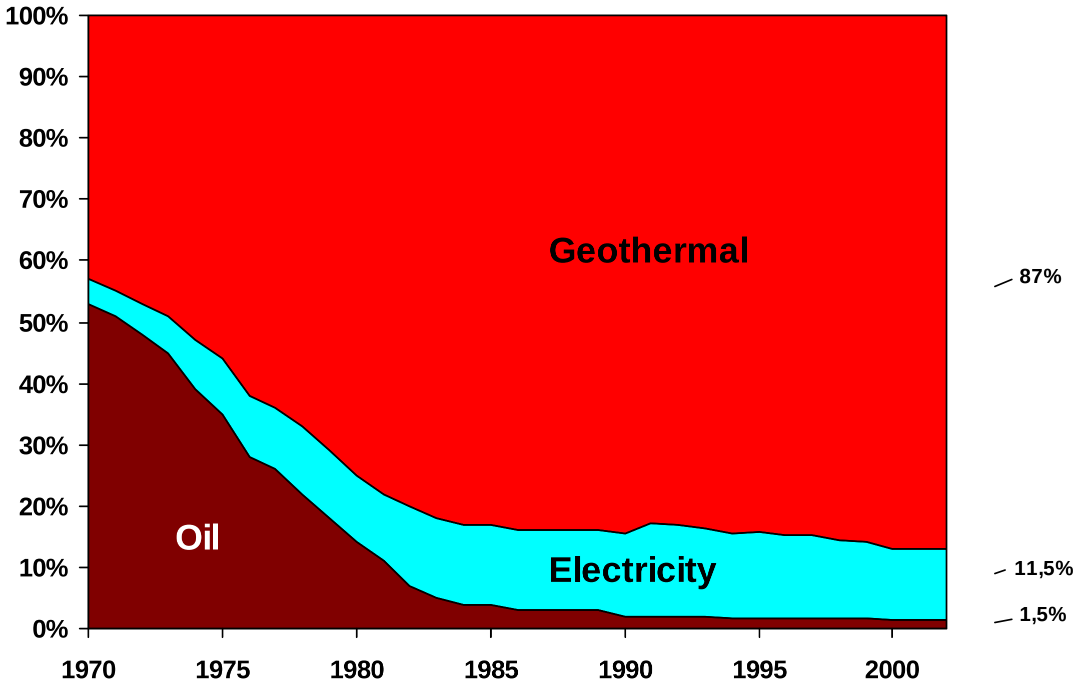

Figure 4: Energy sources for space heating.
Des sources d'énergie pour réchauffement des résidences et bureaux.

Geothermal energy has several advantages for generating electricity. First of all, the source is not affected by seasonal variations. Second, powerplants can be built economically in smaller steps than is the case for hydropower plants. Nevertheless, use of geothermal energy for production of electricity came about relatively late in Iceland. The first geothermal powerplant was installed in 1969 but, as can be seen from Figure 4, generation of electricity with geothermal really took off during the mid-1990s. The reasons for this delay are probably twofold. Greater familiarity with hydropower was probably a deciding factor, as well as the fact that hydropower was less expensive for the mini-powerplants that characterised early development (this is only true for very small capacity hydropower plants). During the 1970s, when Icelanders had become more knowledgeable about geothermal energy through long experience, a decision was made to build a large geothermal powerplant at Krafla in northeast Iceland. Unfortunately, due to political reasons, the construction effort suffered from a lack of professional decision-making and became overly expensive. Also, volcanic activity nearby had extremely detrimental effects on the longevity of the boreholes. These factors resulted in a wariness concerning geothermal powerplants among the public. Combined with stagnation in the growth of power-intensive industries, this led to a lull in the expansion of geothermal power capacity. However, the Krafla powerplant continued operation and, with the experience from a successful cogeneration plant in Svartsengi, the stage was set for dramatic growth in electrical power generation in the 1990s under the guidance of the power companies.

The main factor for the success of district heating in Iceland has been its profitability, both for the utilities and for the consumers. It has been estimated that in the period from 1970 to 2000, consumers saved an estimated 3.5 billion dollars in heating costs. [7] This should be qualified by noting that oil heating might not have been the most economical approach if geothermal energy had not been used, and that consumers would probably have been more efficient in their energy use had they not had access to such inexpensive heating. Nonetheless, savings from using geothermal heating have been substantial. Geothermal space heating has not only brought savings, but also improved the quality of life. Besides improved air quality due to reduced emissions there are other benefits such as a plethora of geothermally heated swimming pools and the use of runoff heating water for melting of snow and ice (roughly 740,000 square metres of snow melting grids were in place by 2002). Figure 5 shows the breakdown of uses of geothermal energy in 2002.

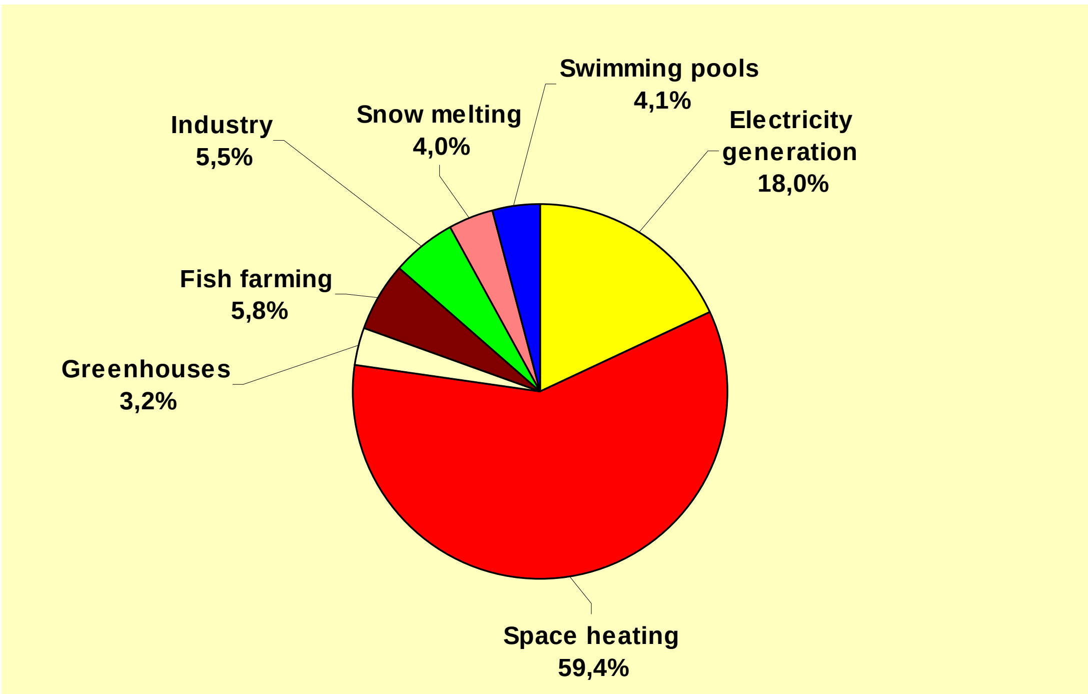

Figure 5: Uses of geothermal energy in 2002.
L'utilisation de l'énergie géothermale en 2002.

4.5 The role of government
Le rôle du gouvernement

Although some of the effects of government economic policy and public ownership of powerplants has been discussed, it should be noted that government involvement was much broader than that. For decades, harnessing of the domestic energy resources has been a cornerstone in the Icelandic energy policy. The government and its agencies have played a big role in implementing this policy. The government put emphasis on the exploration studies for the use of hydro and geothermal energy which resulted in extensive technological knowledge of the resources, creating grounds for sucessful development of the energy resources. Governmental funds were also established to enhance the use of these resources and, in the case of geothermal, to share the risk with developers in the relatively expensive drilling for geothermal water.[F] This policy has been an important factor in creating fruitful grounds for successful utilisation of the energy resources.

5. Environmental concerns
Issues environnementales

5.1 Localised environmental problems
Problèmes environnementaux locaux

The environmental problems posed by geothermal and hydropower projects are local in general, although international considerations may come into play concerning water rights. The main objections concerning hydropower plants are the following: large-scale flooding of land due to reservoirs, altered flow and effects on aquatic biology, and aesthetic concerns such as disappearance of waterfalls and presence of dams and other structures. Objections concerning geothermal power are associated with changes in geothermal water levels (e.g. disappearance of hot springs, and possible land subsidence) in the development area, contamination of freshwater, noise from and unsightliness of powerplants, as well as some problems with air quality (e.g., H_2S emission) and mineral deposits. There is also some limited CO_2 emission associated with geothermal electric power plants (minimal compared to fossil fuel plants). The gas content of low-temperature water used for space heating in Iceland is, however, in many cases minute, as in Reykjavik, where the CO_2 content is lower than that of the cold groundwater.

The Icelandic experience with renewables has not been exempt from these objections. As early as 1907 the possible use of hydropower for fertiliser production was objected to on the grounds of the destruction of waterfalls among other reasons. Recent objections have mainly been due to the loss of land to reservoirs. Since the reservoirs are almost exclusively in glacial rivers in uninhabitable areas, these protests are not based on human activity but mostly on aesthetic objections to altering the landscape and because of worries of limiting the habitat of several animal species. Another aspect is protests the end use of the electrical energy for power intensive industry. Public acceptance of geothermal energy has, thus far, been much more widespread than that of hydropower.

Responses to environmental concerns have ranged from site-specific to wide-reaching programs. Systematic studies on the environmental impact of the use of hydro started already in the early 1970’s. As of 1993, individual hydro and geothermal projects have had to undergo environmental impact assessments and must meet certain standards. Recently, a systematic survey of all known potential sites for powerplants was undertaken to evaluate their economic and environmental viability.[G] The results were used to construct a framework to be used as an overall guide for the setting of policy, taking into account environmental and economic considerations, as well as concerns of the travel industry, and use of land for recreation, and farming and other economic activities.

As a result of modern communications, it is not only necessary to address the concerns of the local population to local problems, but it now happens that outside parties that do not benefit directly from power projects protest them, and may potentially try to inflict some sort of economic punishment upon those who carry out the projects. This novel problem has been encountered during the building of the hydropower plant, Kárahnjúkavirkjun, where environmental activists abroad have painted an unflattering picture of the enterprise. It is therefore possibly important to inform a much wider audience than the local populace of the benefits and drawbacks of various types of renewable energy generation.

5.2 Climate change

Changement climatique

Although the effects of anthropogenic greenhouse gas on the global climate are not fully understood, there is a general consensus for limiting their emission worldwide as a precautionary measure. How this is to be done in an economically sound and equitable manner is a matter of some contention. One approach is that set forth by the Kyoto Protocol which commits the so-called Annex I participating nations (the OECD countries and countries in Central and Eastern Europe) to legally binding targets to limit their greenhouse gas emissions in the years 2008–2012. Those commitments add up to a cut of at least five percent from 1990 emissions.

In 2001 Icelandic greenhouse gas emissions were equivalent to 3.1 million tons of CO_2. The origins of these emissions are shown in Figure 6.

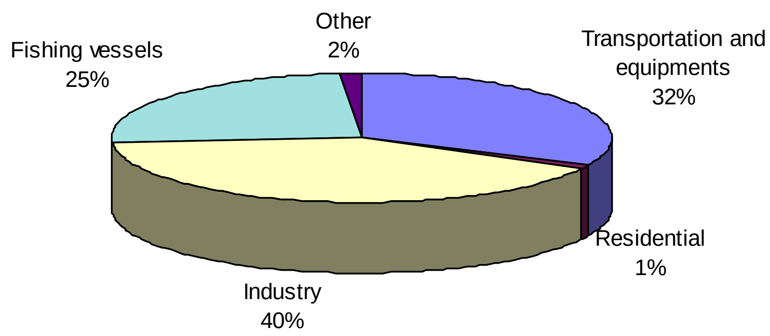

Figure 6: Origins of greenhouse gas emissions.
origines des émissions du CO_2

A feature of the figure that may be surprising, when one considers that almost all stationary energy comes from renewable sources, is the large part of industry in emissions. The main contributor to industrial process emissions is the power intensive industry, comprised of aluminum smelting and ferro-silicate production, which is an unusually large sector in per capita terms. These operations account for over 75 percent of industrial emissions of CO_2, the rest coming mainly from fishmeal production.

The Icelandic government wished to ratify the Kyoto Protocol but was presented with a twofold quandary. First of all, Iceland’s transition from fossil fuels to renewables for stationary power generation and heat production had taken place well before 1990, resulting in very limited opportunities for cutting back on greenhouse emissions from the energy sector after 1990. Secondly, worries arose about the effects on the power intensive industry. The first concern was allayed by setting the base value of emissions for Iceland to 110 percent of the 1990 level.[H] The second concern was addressed in decision 14/CP.7 of the Framework Convention on Climate Change[I]. The processes involved in aluminum smelting and ferro-silicate production inherently produce CO_2. However, when one considers total emissions from such processes, taking into consideration the sources of electricity, it becomes evident that it is much preferable to locate these power-intensive industries in places where they use electricity generated from sources with limited, or no greenhouse gas emission, such as hydropower. This is taken into account and, under specific conditions, CO_2 process emissions that can not be avoided using best available technology and best environmental practices, are not counted toward total emissions. In negotiations on commitments for the period after 2012, a new approach will be needed, possibly making use of benchmarks for different sectors and thereby taking into account the different situations and possibilities of the participating countries of the Climate Convention. The method described above could perhaps serve as a precedent.

6. The role of renewables in technological expertise

Rôle des énergies renouvelables dans les expertises technologiques

The question arises how exploitation of domestic renewable energy sources has affected the technology sector. The answer differs somewhat for hydropower and geothermal energy. Let us examine how.

Although the University of Iceland was founded in 1911, it was not until the advent of the Second World War that science and engineering was taught there. Prior to that, Icelanders who wished to pursue those fields of study had to go abroad (mostly to Denmark and Germany). Since travel to the continent was out of the question during the war, a makeshift engineering program was established, but it only taught preparatory courses and did not grant degrees until 1970.

The first hydropower plants were designed and built by Icelanders, but these were all fairly small in capacity. Of all the hydropower plants built between 1904 and 1966, the largest capacity one of Icelandic design was 7.9 MW. The three largest plants built in that period (15–50 MW capacity) were designed by foreign parties. The 210 MW power plant commissioned in 1969 was solely designed by foreign consultants at the insistence of the World Bank which wanted proven experts to be in charge of the project. However, design of the next two large hydropower plants (150 MW and 210 MW) was a joint effort of Icelandic and foreign engineers. Subsequent projects have been mostly of Icelandic design. Icelandic firms (power companies, consultants, banks and contractors) now have the know-how and resources to design, finance and build hydropower projects in Iceland and market this expertise internationally. One example is a small hydropower plant in Greenland designed by Icelandic consultants and built jointly by Icelandic and Danish firms. Other possibilities are in sight in countries in Eastern Europe and in the Balkans.

In harnessing geothermal energy, matters developed in a different fashion. Iceland was at the forefront of geothermal energy use, and thus much of the technical development was homegrown. Icelandic engineers and scientists furthermore cooperated with their counterparts in other pioneering countries in geothermal energy, such as Italy, New Zealand, and the US. For decades, geothermal resources have been used in Iceland for space heating, swimming pools, greenhouses, industry, fish farming, and snow melting, as well as for the production of electricity. Iceland is the leading country in the world in the cogeneration of electricity and hot water for space heating. With over 50 percent of the primary energy production of the country being obtained from geothermal resources, a highly specialised workforce has been built up in geothermal exploration, development, production, and operations. Icelandic geothermal experts have worked as consultants in a large number of countries in all continents. The energy companies and consulting firms have now formed a consortium to market their technical expertise overseas.[J]

Since 1979, a part of the official development aid of Iceland has been to operate an international geothermal graduate school under the auspices of the United Nations

University (UNU).[K,L] The UNU Geothermal Training Programme (UNU-GTP) has held annual six-month courses for professionals from developing and transitional countries. Specialised training is offered in geological exploration, borehole geology, geophysical exploration, borehole geophysics, reservoir engineering, chemistry of thermal fluids, environmental studies, geothermal utilisation, and drilling technology. The trademark of the UNU-GTP is to give university graduates engaged in geothermal work intensive on-the-job training in their chosen fields of specialisation. The aim is to assist developing countries with significant geothermal potential in building up groups of specialists that cover most aspects of geothermal exploration and development. During 1979–2003, 300 scientists and engineers from 39 countries have completed the six-month courses. Of these, 43 percent have come from countries in Asia, 25 percent from Africa, 15 percent from Latin America, and 17 percent from Central and Eastern Europe. In many countries in these continents, UNU-GTP graduates are among the leading specialists in geothermal research and development. They have been very successful, and have contributed significantly to energy development in their parts of the world.

Since 1998, a second graduate school, the UNU Fisheries Training Programme (UNU-FTP),[M] has been operated in Iceland. It is no coincidence that the two UNU programmes, UNU-GTP and UNU-FTP, are hosted in Iceland. Both of these specialities are of national importance, since approximately 60 percent of the export earnings of Iceland come from fish products, and over 50 percent of the total primary energy is provided by geothermal energy. The technically highly developed and sustainable use of the fisheries resources, and the renewable energy resources (geothermal and hydropower) have been instrumental in bringing Iceland from the category of developing countries in the early 1960s, to the ranks of the ten countries with the highest BNP/capita since the 1980s. Iceland wants to share its experience with the developing and transitional countries. For this purpose, the Government of Iceland contributes a higher amount annually to the UNU than any other institution within the UN system. The feedback from the cooperating countries has been very favourable.

7. Possible developments in renewables

Développements possibles des énergies renouvelables

Currently, geothermal and hydropower remain the only cost-effective renewable energy sources in Iceland. Since the potential capacity of these sources has been exploited only to a small degree, it seems that they will remain the energy sources of choice for the medium-term future. However, preparations are being made to utilise other sources of energy if feasible.

There is also work being done on different ways to harness renewables. The most ambitious of these is an international deep drilling project in Iceland.[N] A consortium of Icelandic energy companies is leading the preparations for the drilling of four to five kilometre deep drillholes into high-temperature hydrothermal systems to reach 400–600°C hot supercritical hydrous fluid for production. The main purpose of the project is to find out if it is economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions. To study the supercritical hydrous fluid, an advanced drilling technology needs to be applied and a novel fluid handling and evaluation system designed. A positive result of this project might increase the geothermal potential of Iceland and other volcanic countries by an order of magnitude and reduce significantly the size of land needed for production fields.

There is also considerable interest in decreasing the share of fossil fuels in primary energy. Since practically all stationary energy comes from renewables, the focus is on the transport and fishing sectors. Aside from encouraging further fuel efficiency, there is a desire to use renewables to produce synthetic fuels, such as hydrogen, if feasible.

8. Discussion

The 20th century saw the Icelandic energy sector change from being completely dependent on fossil fuels at the beginning of the century to having 70 percent of its primary energy and over 99 percent of its stationary energy derived from renewable sources. During this period, energy use per capita increased fifty-fold, and GNP per capita increased thirteen-fold.

This transition had several drivers. Hydropower came about because of a desire for electrification and the hope of diversifying an economy dependent upon export of fish products. Use of geothermal energy was mostly due to the need to reduce the dependence on imported oil and to cut down on heating costs. Electrification was expensive and was, for the first half of the 20th century, hindered by a lack of capital. This was due mostly to lack of domestic capital as a result of imprudent fiscal policy, and later due to the fact that the World Bank would not consider making loans for government electrification projects that were not based on profitability. This changed when the publicly owned company Landsvirkjun was formed in 1965. It was to operate on a profit-making basis, and was large enough to secure favourable loans. In addition, the decision to attract power-intensive industry to Iceland afforded the opportunity to build relatively large hydropower plants and enjoy economies of scale that had hitherto not been available.

Since the use of geothermal energy was not subject to the same economies of scale, capital costs were not as prohibitive and use of geothermal energy grew steadily. The oil crises of the seventies and early eighties gave added incentive for the use of geothermal energy and it went from being the source of 40 percent of the energy for space heating in 1970 to 80 percent in 1985. Currently 87 percent of the energy for space heating comes from geothermal district heating, and about 11.5 percent from electrical heating (from renewable sources). Electrical generation from geothermal energy was late in coming and only took off in the early 1990s. The fraction of energy from geothermal rose from zero in 1970 to 17 percent in 2002 with most of the increase taking place after 1995.

A prime feature of the story of renewable energy in Iceland is that *success in harnessing renewables has been completely dependent on profitability and a favorable economic climate*. During periods when access to capital was limited, foreign investments discouraged, and energy costs were subsidised, progress in renewable energy production was slow, but was more rapid when these constraints were absent. Benefits, such as a cleaner environment and quality of life, followed, but were not driving factors. Ideally, societal costs and benefits should be factored into the price of all energy sources and thus serve as an economic spur to the development of optimal sources.

Another benefit of the development of domestic renewables is the strengthening of a foundation for a community of scientific and technological professionals. This has been important in the development of a more vibrant and modern economy. Expertise gained through the Icelandic experience has also been valuable outside its borders and has been the basis for export of knowledge both commercially and as a part of Iceland’s developmental aid program.

In general, the public perception of the environmental effects of Iceland´s renewable energy sources has been favorable. Large hydropower projects have faced some protests, due to the fact that large areas of land have been submerged under reservoirs. Another reason is that the large hydropower plants have always been tied in with foreign investment in power intensive industries which some of the political parties were against. Furthermore, some people have worried about the environmental impact of the factories. Environmental impact of all the larger hydropower plants was assessed before a decision to build was taken, and efforts made to mitigate that impact. This has resulted in plants within acceptable bounds with much less impact than stated by fervent opponents of the projects.

With regard to the emission of greenhouse gases, Iceland decided to ratify the Kyoto Protocol once consideration was given to the following: Iceland had already prior to 1990, dramatically cut down on the use of fossil fuels by using renewables for stationary power generation; although power intensive industries account for a large proportion of CO_2 emissions inherently due to their manufacturing process, they would emit much more CO_2 if they were operated elsewhere using energy derived from fossil fuels. To cut down on emissions from non-stationary sources, and to decrease dependence on imported fossil fuels, the Icelandic government is investigating means of increasing fuel efficiency and of converting to low- or non-emission synthetic fuels such as hydrogen, if and when that becomes feasible.

The question is whether Iceland is an aberration, or whether the lessons learned could be applied in other places. It is our belief that the importance of economic feasibility applies in general, but the Icelandic case might be most illuminating to countries with developing economies and abundant renewable resources, such as Tajikistan, Costa Rica and Kenya, to name but a few. Some of these countries will, however, have different advantages and obstacles to deal with. For instance in the tropics, geothermal energy cannot be utilised as efficiently as in cold climate countries since one cannot obtain as great a source to sink temperature differential from space heating etc. However, other countries may have the advantage of the possibility of exporting electricity to a large neighbor. Nonetheless, the possibilities of using renewable energy sources as a means of invigorating and broadening the economy are at hand, if care is taken to use a sound economic approach to the problem.

9. Conclusions

Icelandic efforts in utilising renewable energy resources in a sustainable fashion have resulted in those sources accounting for 72 percent of all primary energy, and virtually all electricity used in Iceland. This achievement was strongly influenced by government policy. The use of renewables only gained significant momentum after the establishment of large public companies that operated on a profitability basis came about and could secure capital for the projects at favorable rates. The policy of encouraging foreign investments in power-intensive industry was also important in securing income for the power companies. Other important features of energy policy were large-scale efforts in fundamental research and surveying related to renewable energy sources, and the government's establishment of a fund for risk-sharing with smaller geothermal energy companies.

10. References

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