Sustainable Energy Development: Iceland as a Case Study

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ABSTRACT

Increasing energy prices, political unrest in the Middle East and climate change are only a few issues that have pushed planning for Sustainable energy development (SED) onto the political horizon. SED is broadly defined as 'the provision of adequate energy services at affordable cost in a secure and environmentally benign manner, in conformity with social and economic development needs'. Planning for SED implies that we need to consider the three dimensions of sustainable development, where such movement should not have negative consequences for the economy, the public (social dimension), nor the environment.

This paper presents the development of the Icelandic Energy System since the year 1900 in this context. Iceland has in the last 40 years gone from being mostly reliant on coal and oil, towards extracting 73% of its primary energy needs from renewable energy, and at the same time achieved impressive economic success. Only the transportation sector relies on fossil fuels, and various experiments are being conducted to significantly reduce the reliance on imported fossil fuels. Some of those experiments include planning for a hydrogen economy by 2050. A central question that is asked in this presentation is if Iceland's path is indeed sustainable, if it is unique and if other countries possibly can do the same.

Sustainable Development

Introduction

Since the publication of the Brundtland Report (WCED 1987), sustainable development (SD) has evolved from a vague concept into a somewhat coherent development framework. In the Brundland report sustainable development was defined as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The foundation of this framework is embodied in Agenda 21, which was adopted by the United Nations Conference on Environment and Development (UNCED) at the 1992 Earth Summit. Agenda 21 categorized the primary themes and goals of SD into three key dimensions: economic, social and environmental - theorizing that the challenge for future development is balancing economic development with social and environmental objectives (IEA/OECD 2001; WEC 2000).

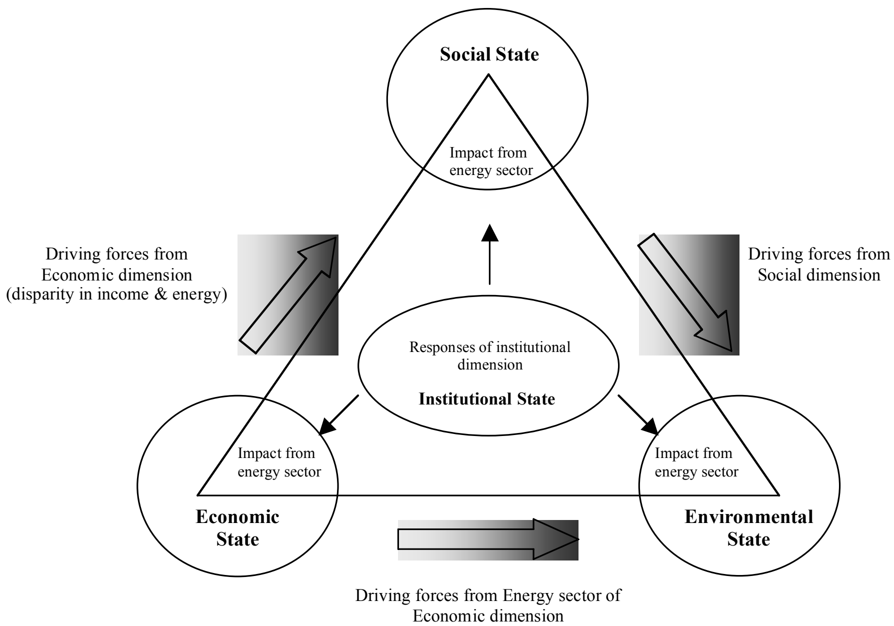
Energy and the Three Dimensions of Sustainable Development

Energy use is a vital component of economic and social development, but the use of energy also significantly contributes to environmental degradation. Energy is an important driver of economic and social development because it provides basic services such as heat, illumination, refrigeration, communication, and power for agricultural processes, industry and transportation, just to name a few (Smil 2003). Moreover, energy use is empirically linked to economic growth (Stern 2000), human welfare (Johansson and Goldemberg 2002, Reddy 2002) as well as local, regional and global environmental degradation (WEC 2000). As a result, energy use is central to all three dimensions of SD sometimes as a necessary prerequisite for SD in one dimension (e.g. social dimension) but the culprit for movements away from SD in others (e.g. environmental dimension). Consequently, the development of sustainable energy systems -has 'emerged as one of the priority issues in the move towards global sustainability' (Malkina-Pykh et al. 2002). Figure 1 depicts the relationship between the three dimensions of SD and energy as illustrated by IEA/IAEA (2001).

Sustainable Energy Development

Sustainable energy development (SED) is broadly defined as 'the provision of adequate energy services at affordable cost in a secure and environmentally benign manner, in conformity with social and economic development needs' (IAEA/IEA 2001).

Figure 1. Relationship between the Three Dimensions of SED (Davidsdottir et al 2007)



One of the more comprehensive definitions of SED set forth is "development that should involve: "improving access to reliable, affordable, economically viable, socially acceptable and environmentally sound energy services and resources, taking into account national specificities and circumstances through various means such as enhanced rural electrification and decentralized energy systems, increased use of renewable energy, cleaner liquid and gaseous fuels and enhanced energy efficiency" (Johannesburg declaration 2002).

Taken together with the IAEA/IEA definition given earlier there are four central goals/themes of SED that emerge:

1. Increase the technical and economic efficiency of energy use and production.
2. Improve energy security by diversifying the portfolio of energy supply, reducing reliance on imported energy, and securing the long-term availability of energy.

3. Reduce the environmental impact of energy use and production via the use of clean technologies and fuels to ensure that solid and gaseous waste generation and disposal does not exceed the Earth's assimilative capacity.
4. Expand and ensure reliable access to affordable and high quality energy services.

SED aims at coordinating those seemingly conflicting goals simultaneously into a cohesive development strategy. Every country or region shares these goals in the long run, but the means by which these goals are attained are and ought to be region specific.

By international comparison, energy use in Iceland is in a class by itself. Per capita energy consumption is practically the highest known or 517 Gigajoules per capita – for comparison, energy use per capita in the United States is approximately 350 Gigajoules per capita. Yet, Iceland is in a unique situation as 73% of its energy supply already is renewable, with 55% derived from geo-power, 18% from hydropower, and 99% of the electricity consumed in the country is derived from renewable sources. This high proportion of renewable energy in total primary energy supply (TPES) in Iceland however, was not always the case. In this paper I illustrate the development of the Icelandic energy system, with two questions in mind. First I will assess if this development has moved the system to increased sustainability and briefly assess what Icelanders need to – and intend to do to enhance the sustainability of their system. Second, I will speculate if the Icelandic case truly is unique and non-transferable, or if Iceland can contribute to SED and energy security worldwide.

Indicators for Sustainable Energy Development

In 1999, the International Atomic Energy Agency, in collaboration with the UN Committee on Sustainable Energy, the United Nations Work Programme on Indicators of Sustainable Development and other organizations initiated a program to develop energy system indicators. Davidsdottir et al (2007), used the report and indictors defined in this program to initiate the development of a multidimensional vector based index for SED – the SEE index. The index is broken to the three dimensions of SED, the economic, environmental and social dimensions – in which each includes defined sub-indicators (Davidsdottir et al. 2007).

a) <u>Economic dimension:</u> The goal of SED within the economic dimension is to increase the end-use and supply efficiency of the energy system, while enhancing energy security and ensuring continued economic growth. This indicates that a move towards SED occurs if the energy intensity of the economy declines, the share of domestically produced energy increases as a proportion of TPES (reduced import dependency), the proportional share of renewable energy in TPES increases and diversification of the energy system increases. Those factors thus constitute the indicators for SED when assessing the move towards SED within the economic dimension.
b) <u>Environmental dimension.</u> The goal within the environmental dimension is to minimize the environmental impact of energy production and consumption. Davidsdottir et al (2007) chose indicators that were internationally available, transparent and clearly could be linked to energy use. The indicators chosen were: energy related NOx emissions, energy related SO2 emissions, energy related CO2 emissions and the accumulation of spent nuclear fuel. Of course indicators such as land submerged as a result of hydropower development also could be included, but lack of data prevents such inclusion.

c) Social dimension. The goal of SED within the social dimension is to ensure secure, reliable and affordable access to quality energy sources for all members of a given population (Davidsdottir et al 2007). Thus as access, reliability and affordability increases, the energy system moves towards SED. Two indicators are used to depict movement in the social dimension: (1) affordability that is measured as average private energy expenditures as a fraction of average disposable income and (2) access to high quality fuels is measured as electricity use per capita up to a threshold level. Ahlen (2004) shows that a close statistical relationship exists between human welfare and electricity consumption per capita. Reliability is not yet captured in a single metric.

In this paper we focus on the indicators of SED defined by Davidsdottir et al (2007) to frame our discussion of the sustainability of the Icelandic energy system.

Iceland – A Case Study

Iceland lies just below the Arctic Circle in the North Atlantic Ocean. At roughly 103,000 square kilometers, Iceland is slightly smaller than Kentucky. However with a population of only about 300,000 individuals it is very sparsely populated with approximately only 3 persons per square kilometer. The Icelandic economy has gone through a remarkable change in recent years, from being the poorest country in Europe at the turn of the century, to being one of the richest per capita, with a gross domestic product per capita in 2005 of $35,600 USD (Hagstofa Islands, www.hagstofa.is).

Temperatures are mild, yet glaciers cover 11 percent of the country. Only 1 percent of the country is forested, and roughly 25 percent is suitable for agricultural use. Iceland is relatively young geologically, and active. Approximately 200 volcanoes dot the landscape and some of then still active, which certainly is relevant for the use and availability of renewable energy.

Energy Resources[1]

Iceland's energy resources consist primarily of hydropower and geothermal power. Other energy resources are scarce with fossil fuel resources virtually non-existent (as far as we know). Currently Icelanders utilize approximately 17% of the domestic energy that today is economically efficient, technically and environmentally feasible to harness (Icelandic Energy Agency 2006 (in Icelandic)).

Geothermal power. Iceland is a young country geologically, and due to its location is one of the most tectonically active places on earth. This high activity manifests itself in a large number of volcanoes and hot springs. More than 200 volcanoes are located within what is called the active volcanic zone, and at least 30 of them have erupted since the country settled. The areas where geothermal power can be harnessed are divided to two types: High temperature areas (HTA) and low temperature areas (LTA). HTA's are directly linked to the active volcanic systems or are marginal to them. The high bedrock permeability in the country results in a deep groundwater table and thus the surface manifestation of the heat in those areas is generally steam vents which in many cases is used to produce electricity (Icelandic Energy Agency 2006,

[1] Data in this entire section is derived from the Icelandic Energy Agency (www.os.is)

Ragnarsson 2005). About 250 LTA's exist in the country that we currently know about with temperatures not exceeding 150 degrees Celsius. In addition about 600 known active hot springs (with temperature over 20 degrees C) have been located. Those low temperature areas are located outside of the volcanic zone and are scattered around the country. On the surface low temperature activity appears as hot or boiling springs, while some systems have no surface manifestation at all (Ragnarsson 2005). Heat from LTA's is mostly used for domestic use such as space heating and washing. It is however possible to use this resource to produce electricity cost-effectively using new technology (see e.g. experimental use of the Kalina technology – Mlcak et al. 2002). Rough estimates indicate that the total capacity using current technology (ecologically, technically and economically feasible) of geothermal power in Iceland is roughly 20 TWh, of which about 8% is currently used (Icelandic Energy Agency 2006, Ragnarsson 2005). Iceland however, is not unique in the abundance of this resource, and for example a recent study of this resource in the United States illustrates vast unutilized potential (Tester et al. 2006). What is unique is the proportional share of the resource in TPES.

Hydropower. Iceland's hydrological resources are mostly stored in icecaps and groundwater. Much precipitation occurs over the icecaps and over half of all precipitation is widely distributed and thus not useable as a source of energy. Yet, about one fourth of precipitation and ultimate runoff is usable, and according to the Icelandic Energy Agency, the total capacity of the hydrological resource in Iceland that can be harnessed (and is ecologically, economically and technically feasible) is approximately 30TWh. Currently 27% of that potential is utilized. It must however be mentioned that it is unlikely that a total of 30TWh are indeed ecologically and economically feasible, mostly due to large environmental costs (Icelandic Energy Agency 2006).

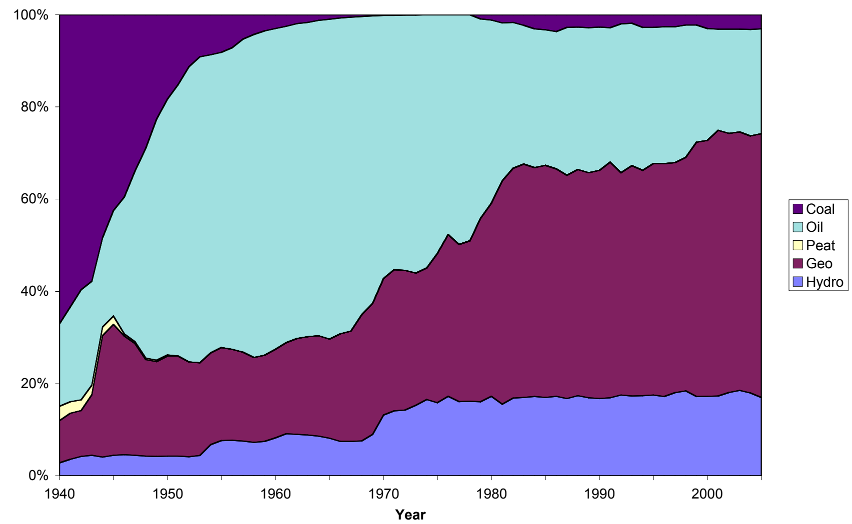
Energy Use in Iceland

Until the mid 20th century, peat and dried sheep dung were the most widely used fuels in Iceland – used for cooking and heating. Horses provided transport, and natural hot springs were used for bathing and washing. It wasn't until the mid 20th century that the age of mechanization took off in Iceland, with the first automobile arriving in 1904, and steam trawlers and motor powered boats arrived around that same time. Electricity was first produced in 1899 using a kerosene fuelled power-station.

Use of hydropower and geothermal power. The use of geothermal steam to heat houses was first tried in 1908, and successfully executed in 1911. The first hydropower turbine began operating 1904, but widespread electrification of the country did not occur until after the 1940's. Similarly, geothermal power did not become a significant source of energy until after the 1940s, and in 1944 electricity was produced for the first time using geothermal power. Yet, as other countries Iceland needed high quality energy to develop, and as a result fossil fuels were imported that mostly consisted of coal and petroleum products. At the end of WWII geothermal and hydropower provided only about 16% of the country's energy requirements, the remainder fulfilled mostly by coal (see Figure 2).

As Figure 2 illustrates investment in renewable energy sources increased drastically in the late 1960's and continued to increase until the early 1980's. This increase was mostly due to a concerted effort by the Icelandic government to provide financial incentives to municipalities and individuals to replace coal and later oil with geothermal power as a heating source and a source of electricity (Icelandic Energy Agency 2006) and thereby launching Iceland to a technology development trajectory away from fossil fuels towards renewable energy. In the late 1940's a similar push had occurred but at a much smaller scale – and a company was founded that today is called Reykjavik Energy[2]. Today, geothermal power provides over 55% of the country's energy needs, hydropower over 18%, and coal and petroleum products provide together around 27%.

Figure 2. Primary Energy Consumption in Iceland by Type 1940 – 2005 (Source Icelandic Energy Agency 2006)



Corollary to the increased share of domestic renewable fuels as a proportion of TPES in Iceland, the reliance on imported fuels declined significantly, and thus import dependency declined[3]. The diversification of the energy system however remained relatively constant since 1980, and only slightly increased since 1940 (see Figure 2, and Table 1)[4]. Yet, the shifts between various fuel components in the system have been favorable, as Icelanders have shifted towards using renewable domestic energy – and thereby enhancing the security of their system.

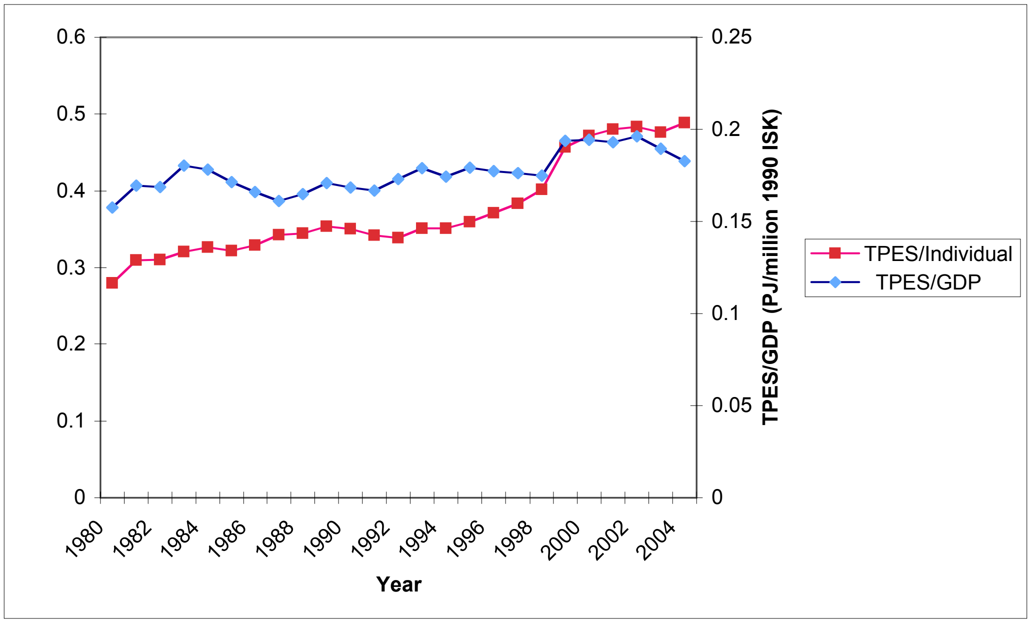
End-use of energy. Energy consumption per capita in Iceland is among the highest in the world or 517 Gigajoules per capita. It has increased significantly since 1940, as in other countries, where energy consumption in 1940 per capita was only 9% of what it is today (Icelandic Energy Agency 2006). Since 1980, energy consumption per capita has increased approximately 80% (Figure 3). At the same time energy use per GDP, or the energy intensity of the Icelandic economy has been relatively stable, but overall increased 12%.

[2] Reykjavik Energy provides over 2/3 of the Icelandic population with heat for their houses – and operates that largest district heat system in the world (Fridleifsson 2005).

[3] Only fossil fuels are imported – and since no fossil fuel resources exist in the country a decline in fossil fuel dependency indicates (measured as a proportion of TPES) a reduction in import dependency.

[4] According to the Sterling Index, diversification in 1940, 1980 and 2005 was 0.436, 0.471, 0.462, respectively. An increase in the Sterling index signifies an increase in diversification (see Davidsdottir et al 2007).

Figure 3. Primary Energy Use per Capita and Primary Energy Use per GDP in Iceland (Icelandic Energy Agency 2006)



Geothermal and hydropower. Today, space-heating accounts for over half of the use of geothermal power or about 57.4% with over 89% of all houses in 2005 heated with geothermal power. The remainder is heated with electricity (10%) and oil (1%). Over 16% of geothermal power is used to generate electricity. Other uses of geothermal power such as fish farming, swimming pools, greenhouses, industry and other uses count for less (Icelandic Energy Agency 2006). As expected 100% of utilized hydropower in the country is used to produce electricity.

Fossil fuels. The use of oil has steadily increased since the 1940's, whereas coal use has not increased significantly since the mid 1970's. Currently coal accounts for 13% of all fossil fuel consumption in Iceland and petroleum products account for 87%. Imported coal is primarily used as feed in industry, and over 86% of all petroleum is used in the transportation sector. In total, fossil fuels account for 27% of all primary energy consumed.

Electricity production and end-use. Electric utilities consume approximately 27% of total primary energy in the country – of this 80% is derived from hydropower and 20% from geothermal power. The aluminum industry consumes a whopping 51% of all electricity produced in the country, and a ferrous silicon plant consumes 13%. Other sectors consume much less, with residential consumption accounting for 9%, the commercial sector for 6% and agriculture and the food industry approximately a total of 5%.

Energy and the Environment

The environmental impact of energy utilization and consumption in Iceland is best measured through emissions data and changes in hectares of land occupied by reservoirs and transmission lines.

Total carbon emissions doubled between 1980 and 2004[5], and increased gradually every year. Yet carbon intensity of the economy has not increased significantly due to high economic growth rates (Icelandic Energy Agency 2006). Sulfur dioxide emissions declined by 68% between 1980 and 2004, and NOx emissions increased by 27% between 1980 and 2004 (Icelandic Energy Agency 2006). Unfortunately at the writing of this paper, data on land use by the power sector is unavailable. What is known, however, is that the environmental impact from the hydropower sector certainly is significant.

Other environmental impacts are for example, potential thermal pollution due to the use of geothermal resources, such as sulfur. This sulfur e.g. is deposited around the vents or transformed into sulphuric acid, which leads to acid waters altering the soil and bedrock. Neither thermal pollution nor sulfur or other pollution released from geothermal steam has sufficiently been researched in Iceland to conclude on the actual impact.

Sustainable Energy Development?

The Past

As described in this short account of energy development in Iceland, it may seem that Iceland's experience may be a prototype for sustainable energy development elsewhere. But has the Icelandic energy system moved closer to sustainability? To analyze this question, I estimated the indicators presented in section 2 of this paper. At this time I only present the indicators separately and do not illustrate them in the context of the multidimensional vector-based index as done by Davidsdottir et al (2007). Table 1 illustrates the results.

Table 1. Indicators for SED in Iceland

Dimension and sub-indicators	Change 1940–2005 (%)	Change 1980–2005 (%)	Towards SED?
Economic Dimension			
TPES per GDP	N/A	-12.2	No
Renewable energy per TPES	390	25	Yes
Import dependency	70	37	Yes
Diversification	6	-1.8	Yes since 1940, No since 1980
Environmental Dimension			
CO2 emissions	NA	96	No
NOx emissions	NA	27	No
SO2 emissions	NA	-69	Yes
Land Use	NA	NA	NA
Social Dimension			
Access	100%	100%	Constant
Affordability	NA	NA	NA

[5] Unfortunately data series on emissions begin in 1980 and end in 2004.

When assessing if the development of the Icelandic energy system has been sustainable, Table 1 demonstrates that the movement consists of negative and positive movements. Import dependency has declined, the share of renewable energy has increased, yet diversification since 1980 has slightly declined and energy intensity of the economy has increased. Sulfur emissions have declined, but carbon emissions and NOx emissions have increased and so has land use due to the activities of the power sector. Secure and reliable access to high quality energy is universal in the country, and energy is affordable to all. Clearly the movement to renewable energy and reduced import dependency is a movement towards SED, but does this constitute a movement overall towards SED given other movements that move the system away from SED? This question, cannot be answered empirically until the system has been assessed in a multidimensional framework, - but overall my personal judgment is that the Icelandic energy system has moved towards increased sustainability[6] since 1940 due to the shift to renewable fuels. Yet since near saturation has been reached in the use of renewables in house heating and electricity generation, Icelanders will have to focus on other components of SED, to ensure continued movement towards sustainable energy development.

The Three Transitions and the Future

What should be clear from this short overview is that both the structure of energy supply and the level of energy consumption per capita in Iceland somewhat is unique, with Icelanders consuming more energy per capita than most other countries in the world, yet the supply is over 73% derived from renewable energy sources. The resource base however is not unique, simply the structure of utilization and the chosen infrastructure technology trajectory towards renewable energy.

Since the 1900's the Icelandic Energy System has gone through three transitions. First, the transition from peat to coal occurred from 1905 to 1920's. The second transition was the transition from coal to oil, which occurred in a relatively short period of time between 1945 and 1950 and was driven by an increase in car ownership in Iceland, increased electrification, and the mechanization of the fishing fleet, in addition to an increase in the use of oil as a heating fuel. The third transition was the transition from fossil fuels as a main source of electricity and heat, to renewable fuels. A precursor of this transition began in 1945, but it really took of between 1965 and lasted until 1980. This transition was driven by an increase in energy prices, and government incentives to shift the energy infrastructure towards the use of renewable energy.

Today, only the transportation sector uses significant quantities of non-renewable fossil energy, and is almost solely the culprit for continued import dependency and fossil fuel derived emissions of carbon dioxide. Since the Icelandic government intends to increase further the sustainability of the energy system, the logical move would be to facilitate the fourth transition. A transition away from the use of fossil fuels in the fishing and the vehicle fleet over to the use of renewable fuels or energy carriers derived from domestic renewable energy. Currently several simultaneous technical strategies are being considered by the Icelandic government (e.g. use of methane, hydrogen, biodiesel, electricity) – in addition to experiments in carbon sequestration from industry into the porous Icelandic bedrock. The government is considering the best way to facilitate those strategies, both through research support, and through the use of market-based

[6] An issue not addressed here is the lack of diversification in the **use** of renewable energy – but that is not an issue of the power sector but an issue of economic planning in general.

methods, such as tax credits and alleviation of import duties for more environmentally friendly vehicles. Standards, such as the CAFE standards are not being considered.

Methane. The collection of methane from the largest waste yard in the country began in 1997. In the year 2000 the production of vehicle fuel from the refining of methane began. The fuel created currently is used to power about 46 small flexible use vehicles, 2 heavy duty vehicles and 2 public buses. This of course is a small quantity, but the total potential from this particular plant is sufficient to operate about 3000-4000 vehicles (SORPA personal communication).

Hydrogen. Hydrogen has been on the research agenda at the University of Iceland for several decades – but a Government based directive was set in 1998, that aimed at creating a hydrogen economy by 2050 (see e.g. http://physicsweb.org/articles/world/15/7/10). In this directive, which recently was reaffirmed, hydrogen was envisioned as the energy carrier of the future, and produced from domestic renewable sources using electrolysis.

Various shareholders created a company called Iceland New Energy in 1999, which was to help realize this progressive vision. Shareholders in Iceland New Energy include the Icelandic government, key energy companies, academic institutions, and international players in hydrogen technology such as Norsk Hydro (who provided hydrogen station), DaimlerChrysler (provides hydrogen - fuel cell busses) and Shell Hydrogen (who provided the site for a hydrogen fuel station) (Icelandic New Energy, personal communication).

The transition to a hydrogen economy is still in its experimental phase, and of course has encountered numerous show-stoppers such as high cost of producing hydrogen, low energy density, difficulty in storing the energy carrier and high cost of fuel cells. Yet Iceland New Energy already operates three pollution-free fuel cell driven hydrogen buses in the capital area of Reykjavik as part of the city's public transportation system. The company also oversees the world's first hydrogen refueling station located on the site of a conventional filling station and which is open to the general public. In the summer of 2007, 30 fuel cell driven hydrogen passenger vehicles will be launched to the streets of Reykjavik, and experiments will begin on using hydrogen-fuelled fuel cells at sea (Icelandic New Energy, personal communication).

Carbon sequestration – by chemical weathering. One possible technology that has been proposed to increase sustainability of the energy system is to sequester carbon emissions using mineral carbonation (or briefly: mineral CO2 sequestration). In essence the idea is to mix water and CO2 derived from heavy industry such as aluminum smelters. Let the carbon dissolve under high pressure (ca 30 bars), and then pump the solution underground on site of the heavy industry and let natural weathering occur, where the carbon may go into a solid carbonic state. What will happen is that the permeable basalt in Iceland will fill with mineral carbonates – which are known to be stable for millions of years. Currently experiments are being conducted in Iceland by researchers at the University of Iceland and Columbia University (Gislason et al. 2007).

Can Iceland Contribute to SED Worldwide?

It can safely be assumed that the Icelandic energy system is closer to sustainability than the system in most other countries. Over 73% of the energy consumed is renewable and the energy intensity of the economy and import dependency is rather low compared to other countries. In addition, as Iceland has moved away from using fossil fuels and towards increased use of domestic renewable energy it has enjoyed remarkable prosperity. Icelandic companies and consumers currently enjoy the luxury of being able to conduct their business and heat and operate their households mostly without being seriously affected by movements in the global energy market. The only remaining dependency on fossil fuels is in the transportation sector. The question that remains is the following: is the Icelandic case unique, or can Iceland somehow contribute to SED worldwide?

It must be stated outright, that the total potential Icelandic energy supply only amounts to 0.04% of the world total, and thus actual consumption or use of the Icelandic energy resource base (albeit mostly of renewable fuels) really does not significantly enhance sustainability worldwide. However any small contribution should not be discounted.

I argue that it is primarily through three pathways in which Iceland can contribute to the move towards SED. Those pathways or venues are:

1. Through our experience and unique development path towards renewable fuels, creating an inspirational and a practical story.
2. Through research and exported practical experience.
3. Through education.

Inspirational and Practical Story

As has been illustrated in this paper, Iceland's move towards SED is the story of a rather backwards poor country that became advanced and affluent while switching to renewable energy. Given the Icelandic experience, and given the tremendous untapped potential of renewable energy worldwide (such as wind, solar and geothermal[7]) – our story possibly could serve as an inspirational and a practical story to others that demonstrates that a move towards the use of alternative energy is indeed possible without paralyzing the economy. Iceland is not unique when it comes to the availability of geothermal energy, and its low population density is not the reason why Icelanders can use this abundant resource as it can be and is utilized in high population densities.

Research and Exported Practical Experience

Icelandic researchers and consultants have accumulated significant experience when it comes to assessing the energy-capacity potential of both high- and low-temperature geothermal fields, in exploration and drilling techniques, as well as in all other aspects of geothermal energy utilization (see e.g. www.enex.is , www.isor.is and www.jardboranir.is). In addition, various experiments are currently being conducted that aim at increasing the efficiency of using geothermal power. For example, in the year 2000 the Icelandic deep drilling project (IDDP), an Icelandic energy consortium was established (see www.IDDP.org). The purpose of the project is to study economic feasibility of extracting energy and chemicals from hydrothermal systems at supercritical conditions. Other interesting experiments such as the hydrogen economy and carbon sequestration by chemical weathering have already been discussed. Dissemination of this knowledge, research and experience should contribute to a move towards SED worldwide.

[7] Both using heat pumps and high and low temps areas (Fridleifsson 2005)

Education

In addition to the various research e.g. performed at the University of Iceland – Icelanders run the United Nations Geothermal Training Programme (Fridleifsson 2005). This program was founded in 1973 with the aim to assist developing countries with significant geothermal potential to build up or strengthen groups of specialists that cover most aspects of geothermal exploration and development. The effectiveness of this program has already been noted, as countries such as Kenya and El Salvador that have had high rates of participation in the program have significantly higher rates of geothermal utilization, when compared to other countries (Fridleifsson 2005).

Conclusion

It is inevitable that the world eventually will run out of economically extractable reserves of fossil fuels. However, if we want to move towards sustainable development, sustainable energy development is a central component of that transition as energy transcends every aspect of modern society.

What Iceland has to offer is renewable, virtually carbon free energy sources and accumulated knowledge on the use of those resources. Our story from use of peat to coal to oil and then to the use of renewable energy, illustrates that such transitions can benefit consumers and industries tremendously and can occur without damage to the economy. Our story and experience should offer more than hope but also practical illustration that other countries could do the same.

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