DEVELOPING THE ICELANDIC GENUINE PROGRESS INDICATOR

– Accounting for the use of renewable energy sources when estimating Icelandic GPI

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Abstract

The Genuine Progress Indicator (GPI) is a tool for measuring the wellbeing of an economy. The question of how to include the use of renewable energy sources is important when estimating the GPI for an economy highly dependent on renewable energy like Iceland. An analysis of GPI estimations showed that the use of renewable energy sources is reflected by the subtraction of the use of non-renewable ones. Furthermore the study shows that the negative impacts of renewable energy production are somewhat included in the indicator, although further discussion is needed about the effects on terrestrial and aquatic ecosystem services. As for the financing of renewable energy projects it is important to subtract the investments that are based on foreign currency loans.

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1 Introduction

With a society striving to move towards a more sustainable future, the importance of monitoring this development increases. One of the foundations in changing the consumption patterns in a way that supports the well-being of future generations is changing the dependence on non-renewable resources. This shift away from non-renewable resources is a step towards reducing environmental impact of our consumption habits. The Genuine Progress Indicator (GPI) is a monitoring tool for evaluating if economic development has followed the principles of sustainable development and thereby ensured positive development of economic and social welfare. Thus, the GPI can function as a tool that can help decision-makers develop sustainable economic policies.

In the development of a GPI for Iceland it is very important to evaluate how to include the use of renewable energy sources, since the Icelandic energy sector relies on those. In this paper I hope to shed light on how and how well the methods most widely used for GPI reflect the use of renewable energy by analyzing previously published estimates of national GPI. The questions of how renewable energy has been included so far and how it can be included will be answered by defining methods used so far and by demonstrating how negative impacts of energy production are included. My hopes are that the study will promote further discussion of the subject in the development of methodology for the estimation of Icelandic GPI.

In order to answer these questions this paper will initially address the development and use of economic indicators as well as the development and use of indicators of economic welfare. Background information about the Icelandic energy sector will be presented to emphasize the importance of conducting this study and the negative effects of renewable energy production will be listed. In the analysis GPI-studies from other countries will be examined beginning with the methods for calculations of the use of non-renewable sources following the monetization of renewable resources such as forests and fisheries. How the negative effects of renewable energy production listed in the background are reflected in the indicator will then be examined. The analysis ends with a short investigation of the financing of renewable energy production in Iceland. Discussion and conclusions will then be built on the analysis.

2 Background

2.1 The development and use of Gross Domestic Production (GDP)

The Gross Domestic Production (GDP) is the most widely used economic indicator. The indicator measures *"... the market value of all final goods and services produced within a country in a given period of time"* (Mankiw and Taylor, 2006). GDP has been used since the late 1940's to reflect the economical progress of nations. The development was triggered by the unstable economical system, trade restrictions and high unemployment rate following the great depression and the 2nd World War. By monitoring the economic activity, governments were better equipped to develop trade-policies and make decisions to ensure that the economy was growing fast. A fast growing economy generated jobs and therefore increased the living-standard. In the following years, the GDP reflected welfare in a way, since increased employment meant that people could afford basic needs like food, housing and healthcare at the same time as taxes helped build up a stable economy. (Costanza et al. 2009)

Since the 1940's the GDP has therefore been treated by governments and media as an indicator of welfare, even though economists around the world have pointed out that the GDP is a specialized economic tool built to showcase the flow of money through the economy but does not reflect on national economic or social welfare nor sustainable development. (Costanza et al. 2009)

2.2 The development of the Index of Sustainable Welfare (ISEW) and the Genuine Progress Indicator (GPI)

The use of GDP as a welfare measure led economists to see the need for developing alternative indicators for measuring the sustainability of the economy or the national economic welfare. For the last 30 years several indicators of economic welfare that include the effects of production on the society and the environment have been developed, some as a complement (correction) to GDP and others as independent indicators (Costanza et al., 2009). This search for new measure of welfare started with Nordhaus and Tobin's Measure of Economic Welfare (MEW) where they subtracted factors that decrease welfare, such as sanitation services, from the GDP (Nordhaus and Tobin 1973). Their conclusions were however that there was a strong correlation between MEW and GDP so that GDP could be used as a welfare measure (Pulselli et al. 2011). The Index of Sustainable Economic Welfare

(ISEW) was then developed by Daily and Cobb in 1989 and later modified as the Genuine Progress Indicator (GPI) (Costanza et al. 2009).The estimations of national GPI have shown to differ from GDP so Nordhaus and Tobin's conclusion about GDP reflecting welfare does not hold. Studies have shown that the GPI and GDP tend to increase together up to a certain point where GPI either stagnates or decreases (Jackson and Stymne, 1996). This is known as the threshold-hypothesis and shows that when the economy of developed countries has grown up to a certain point, the pressure of production and consumption starts taking its toll on social and natural capital (Max-Neef, 1995). The estimations of the development of the ISEW for the 6 countries in Figure 1 display the hypothesis (Jackson and Stymne, 1996).

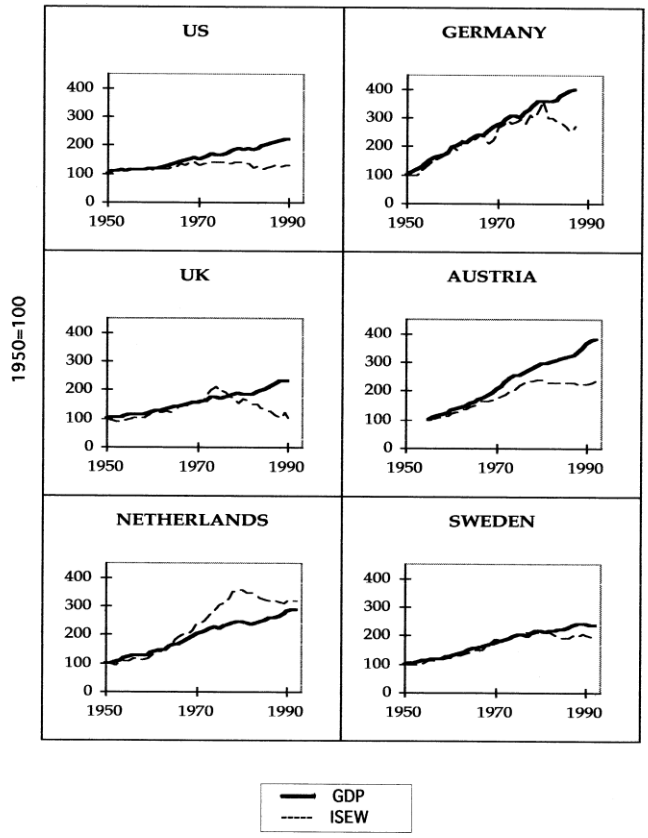

Figure 1: The development of the Index of Sustainable Economic Welfare (ISEW) for 6 countries (US, Germany, UK, Austria, Netherlands and Sweden) between 1950 and 1992 (from Jackson and Stymne, 1996)

The threshold-hypothesis showcases the need for economic welfare indicators like GPI that have the aim to better display national welfare and answer the question of sustainable economy: "*Can a nation's entire GDP be consumed without undermining its ability to produce and consume the same GDP in the future?*" (Hicks 1946).

2.2.1 The elements of GPI

The GPI adds and subtracts components according to the following formula (Bagstad 2009):

$$\mathbf{GPI = C_{adj} + G + W - D - S - E - N}$$

These calculations start with the personal consumption expenditure, but unlike the GNP the GPI accounts for income distribution by weighting the social effects of uneven distribution of income. By using indexes of income inequality the personal consumption expenditures are adjusted to reflect this uneven distribution and you get an adjusted consumption ($\mathbf{C_{adj}}$) (Jackson and Stymne, 1996). The following components (G, W, D, S, E and N) then add and subtract factors that affect the sustainability of the economy or the societal well-being.

The net capital investments are accounted for with the aim to assess changes in capital stocks and internet investments. This shows the development of capital and the change in international position (**G**). (Bagstad 2009).

A factor that is not counted for in the GNP is the value of non-monetary contribution (**W**). This component includes amongst others labour or services that are provided without producing a flow of money as well as the services of human capital.

As production increases, the society's cost for defensive measures increases. The expenditures needed to protect ourselves from unwanted side-effects of production and high consumption levels increase the GNP since it increases the flow of money through the economy. These expenditures have negative effects on well-being and decrease the sustainability of the economy and are therefore subtracted in the GPI (**D**).

The depletion of social capital is also accounted for with the subtraction of these losses (**S**). An example of loss in social capital is the loss of leisure time. This will have positive effects on the GNP since the loss leads to longer working hours that favour the production but at the same time decreases welfare.

The cost of environmental degradation (**E**) is also an important factor subtracting the societal cost of pollution amongst others.

The depletion of natural capital (**N**) is the last component. It addresses the change in the availability of resources in the form of habitat-loss or the depletion or restoration of important natural capital.

Each component consists of numerous indicators, which can depend on each country's development of indicators. Most studies however use the same or similar indicators to be able to compare different outcomes with other countries or areas. An example of indicators and if those are additive or subtractive can be seen in Table 1 which shows indicators used in a case study for the state of Vermont USA (Costanza et al., 2004).

Table 1: The main elements used to estimate the Genuine Progress Indicator for the state of Vermont (modified from Costanza et al., 2004)

GPI component	Indicators	(+ / -)
$\mathbf{C_{adj}}$	A: Personal consumption expenditure	+
	B: Income distribution	+ / -
	C: Personal consumption adjusted for income inequality	+
W	D: Value of household labour	+
	E: Value of volunteer work	+
	F: Service of household capital	+
	G: Service of highways and streets	+
	K: Cost of underemployment	-
	M: Cost of commuting	-
D	L: Cost of consumer durables	-
	N: Cost of household pollution abatement	-
S	H: Cost of crime	-
	I: Cost of family breakdown	-
	J: Loss of leisure time	-
	O: Cost of automobile accidents	
E	P: Cost of water pollution	-
	Q: Cost of air pollution	-
	R: Cost of noise pollution	-
	V: Long-term environmental damage	-
	W: Cost of ozone depletion	-
N	S: Loss of wetlands	+ / -
	T: Loss of farmland	+ / -
	U: Depletion of non-renewable resources	+ / -
	X: Loss of forest cover	+ / -
G	Y: Net capital investment	+ / -
	Z: Net foreign lending and borrowing	+ / -

Examples of other indicators are commercial sex work (Clarke and Islam, 2005) and the cost of urbanization (Pulselli et al., 2011). Countries with rich fish stocks, like Iceland, should probably take the depletion of fish stocks into account.

2.3 The Icelandic Energy Sector

The composition of energy production in Iceland differs from most countries in the world because of the fraction of electricity produced by renewable energy sources and the use of geothermal power for house heating. According to the European Union statistical office close to 100% of Iceland's electricity production is derived from renewable energy resources (Eurostat, 2011), the only country with similar profile being Norway. The production is built entirely on the plentiful water and geothermal resources where hydropower stations make for 73% while geothermal power contributes 27% (Orkustofnun, 2011). This makes Iceland extremely interesting when estimating the GPI since the subtraction of the depletion of non-renewable energy-sources usually represents the largest cost included in the GPI account (Talberth 2006). The question of whether or how to account for the use of renewable sources is therefore crucial for the development of methods for calculating national GPI.

2.4 The effects of renewable energy sources

Energy is the foundation for social and economic development and is vital to sustain the living standard of the developed world. With increased energy demand, global resources of non-renewable energy are being depleted at a fast rate at the same time as the use of fossil fuels is the biggest emission source of greenhouse gases. Building a society on renewable energy therefore has its obvious advantages, making it possible to build a society on sustainable resources with minimum effect on the global climate (Banos et al., 2011). The advantages are enormous but there are some disadvantages to consider.

2.4.1 Hydropower

In Iceland 12.3 GWh of electricity are produced annually in hydropower stations around the country (Orkustofnun 2011). In the Report of the World Commission on Dams the negative environmental impacts of hydropower production have been stated as following (UNEP Dams, 2000):

Impacts of reservoirs on terrestrial ecosystems and biodiversity;

With flooded land many species will lose their habitat and face extinction or be forced to migrate to other areas. The reservoir will kill terrestrial flora and fauna and can affect populations of endangered species and unique wildlife habitats.

Emission of GHG's associated with large dam projects and their reservoirs;

The building of infrastructure, the transportation of material and labour and the daily operation of power plants causes some emissions of greenhouse gases. However the reservoirs themselves are the most substantial source of greenhouse gases. When vegetation is flooded, biological matter decomposes in an anaerobic environment leading to emissions of methane (CH_4) to the atmosphere (Barros *et al*. 2011). After being flooded the vegetation also loses its ability to act as a carbon sink. This effect however only appears during the first years of operation.

Impacts of altered downstream flows on aquatic ecosystems and biodiversity;

The changes in downstream flow and natural distribution of water downstream from the dam affects natural habitat by changing the composition of the water and river benches. The river's ability to transport nutrition and particles decreases and ecosystems can collapse or change dramatically. The river looses its natural variability when it's regulated and the temperature and chemistry of the water can also change.

Impacts of altering the natural flood cycle on downstream floodplains;

The decreased flow of suspended sediments downstream from the dam can lead to degradation and erosion of river benches, deltas and coastlines. The land around the reservoir may also erode when water levels are low and the land that otherwise is flooded with water blows away since there is no vegetation to hold it.

Impacts of dams on fisheries in the upstream, reservoir and downstream areas;

A dam interferes with the upstream/downstream migration of aquatic organisms and leads to extinction of freshwater species. The aquatic environment upstream from the dam changes since a flowing river changes to still water. The changed flow can even affect marine fish due to changed freshwater flow and the loss of spawning habitats in deltas and estuaries.

The magnitude of the impacts depends on the size of production, the infrastructure, reservoirs and the vulnerability of surrounding ecosystems. But in all cases there will be changes of habitats, land change, land erosion, change of particle flow, sedimentation of the reservoirs and changes of downstream ecosystems. (UNEP Dams, 2000)

2.4.2 Geothermal power

Today seven geothermal power plants in Iceland produce 4.5 GWh of electricity per annum (Orkustofnun 2011). There have been concerns of the sustainability of geothermal power since the production can be carried out at a rate that depletes the local water supply temporally. However the production can be maintained at a sustainable level by defining the maximum energy production for each geothermal system. This can however not be done until the production has been going on for a few years. (Ketilsson et al. 2011) The negative effects of geothermal energy production listed below are defined by the International Geothermal Association (Dickson and Fanelli, 2004) and the Icelandic National Planning Agency (Skipulagsstofnun. 2007):

Air quality pollution;

The geothermal fluids contain numerous gaseous pollutants such as hydrogen sulphide (H_2S), carbon dioxide (CO_2), ammonia (NH_3) and methane (CH_4) which contribute to global warming as well as acid rain.

Surface and underground water pollution;

The cooled geothermal fluids from geothermal stations contain traces of heavy metals and other dissolved chemicals which can affect the surrounding ecosystems by polluting the surface water. These include sodium chloride (NaCl), boron (B), arsenic (As) and mercury (Hg) some of which can be biomagnified in food webs.

Land subsidence;

When water from underground reservoirs is extracted there is a possibility of land subsidence. Because of the extraction the ground above the reservoir might start to slowly sink. The biggest effect of subsidence is that on infrastructure.

Effects on ecosystems in geothermal reservoirs;

The geothermal reservoirs, or geysers, have a special ecosystem consisting mainly of heat-seeking extremophile microorganisms. The reservoirs are defined as wetlands and have unusual conditions where organisms that can live under extreme conditions establish.

Direct effect on terrestrial ecosystems;

The building of geothermal power station will have direct effects on terrestrial ecosystems because of the land use. The flora and fauna in the area will be affected by increased traffic, the infrastructure and noise and air pollution. However areas of importance are often dry areas with limited numbers of organisms.

Chemical or thermal pollution;

When the warm water has been used a part is discharged to surface water. This leads to thermal pollution since the water temperature will increase. Increased temperature will have effects of present ecosystem and is likely to change the structure of the ecosystem by benefiting certain species and be a disadvantage to others.

Visual pollution, effects on tourism and outdoors activities;

Geothermal power stations are not easy on the eye. The stations are built in areas which have seismic activity which usually are rural. Areas with seismic activity are a natural tourist attraction due to geysers, lava-fields, hot springs and volcanoes. The pipelines and other infrastructure draw attention since these are likely to be the only constructions in an otherwise naked wilderness. Power stations can therefore affect the tourist industry in the area as well as outdoors activities.

High noise levels;

Noise pollution is an unavoidable effect from producing energy with geothermal power. There is a high-pitched noise when steam travels trough pipelines and the power plants have cooling towers and steam ejectors that make noise.

Conflicts with cultural and archaeological features;

The land used to build up plants can be of cultural or archaeological importance and the construction might raise voices of criticism concerning the value of the land to the society.

Negative effects of geothermal power stations can be minimized by increasing the percentages of water that is re-injected to the underground reservoir and with making the end-of-pipe cleaning mechanisms more effective. However, recent events in Iceland have raised concerns about re-injection to deep underwater reservoirs in certain areas as a trigger for earthquakes (Ketilsson et al. 2011).

2.4.3 Summarised negative effects

The negative effects of hydropower and geothermal power overlap significantly. To simplify and sum up the negative effects listed in the last two chapters, more general factors were developed that include all the effects listed above. These can be found in the following table along with how they include indicators listed above (Table 2). The table shows that the World Commission on Dams does not include social aspects of hydropower plants. The more general factors defined in the first column will be used for further analysis.

Table 2: Stated negative effects of renewable energy production

Environmental Impacts	*Hydropower*	*Geothermal power*
Terrestrial Ecosystems	- Impacts of reservoirs on terrestrial ecosystems and biodiversity	- Direct effects on terrestrial ecosystems - Chemical or thermal pollution
Aquatic Ecosystems	- Impacts of altered downstream flows on aquatic ecosystems and biodiversity - Impacts of dams on fisheries in the upstream, reservoir and downstream areas	- Effects on ecosystems in geothermal reservoirs - Chemical or thermal pollution
Air Quality	- Emissions of GHG's associated with large dam projects and reservoirs	- Air quality pollution
Water Quality		- Surface and underground water pollution
Geological Features	- Impacts of altering the natural flood cycle on downstream floodplains	- Land subsidence
Social Impacts	*Hydropower*	*Geothermal power*
Visual Pollution		- Visual pollution, effects on tourism and outdoor activities
Noise Pollution		- High noise level
Cultural and Archaeological Features		- Conflicts with cultural and archaeological features

The negative effects defined in the table are the effects on terrestrial ecosystems; aquatic ecosystems; air quality; water quality; geological features; visual pollution; noise pollution; cultural and archaeological features.

3 Methods

This study is a meta-study based on comparison of methods of national GPI studies. The study is a small part of a research project which aim is to develop methods for estimating Genuine Progress in Iceland. The project is directed by Dr. Brynhildur Davíðsdóttir, the director of the Program for Environment and Natural Resources at the University of Iceland. The questions addressed in this study are whether the methods used to estimate GPI reflect the use of renewable energy and how those can be improved to better reflect this use.

4 Analysis

4.1 Resources in national GPI studies

In the development of GPI, an indicator for the value of renewable resources has not been included per se. It seems to be accepted that subtracting the replacement cost of non-renewable sources accounts for the use of renewable ones, since countries with high fraction of renewable sources will minimize the subtraction for that indicator. In national GPI studies the question of renewable energy-sources is usually not even discussed but in some cases the effect of renewable energy is presented by showing the GPI if the economy was built exclusively on non-renewable sources (Jackson and Stymne 1996). An example of this kind of presentation can be seen in Figure 2 which shows the different results of GPI (ISEW) based on the actual energy production in Sweden on the one hand and how it would look if Sweden would not have resources to produce energy with hydropower on the other hand (Jackson and Stymne, 1996). The figure shows that the GPI reflects the use of renewable energy since the GPI is substantially lower when the economy is based solely on non-renewable energy. In Sweden around 45% of the gross final energy consumption is produced by renewable energy (biomass, hydropower, geothermal energy, wind- and solar-power) where hydropower counts for by far the biggest part (Eurostat 2011). With this fraction in mind it is clear that even with a smaller fraction of renewable energy the GPI would be substantially lower without it.

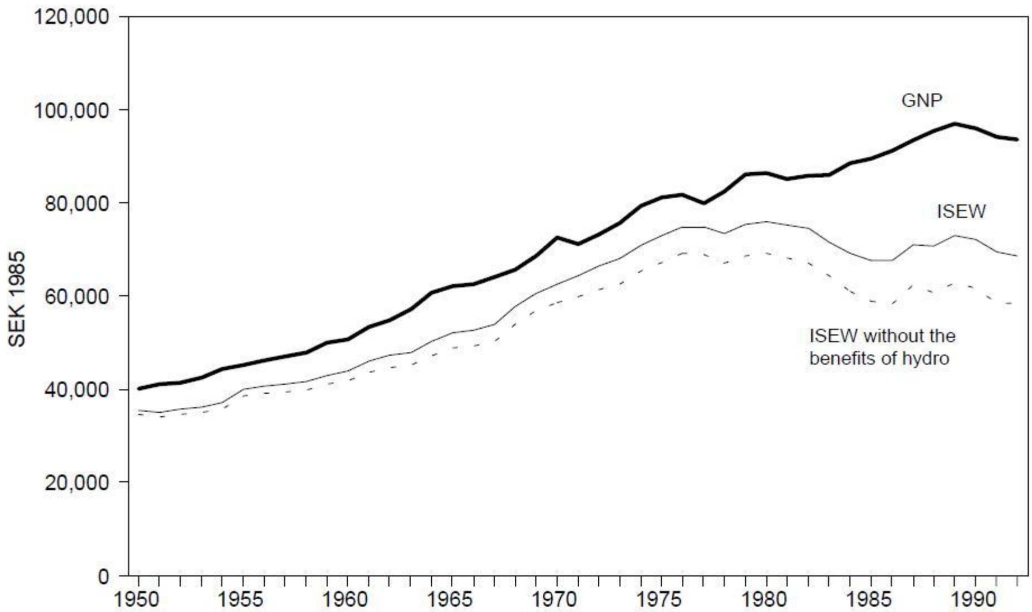

Figure 2: The Swedish Gross National Production (GNP), Index of Sustainable Economic Welfare (ISEW) and the ISEW without the benefits of hydropower (from Jackson and Stymne, 1996)

Since only a few studies address the question of how to handle renewable energy sources directly it is important to explore how non-renewable energy sources and renewable resources other than energy-sources are handled in the GPI and a) whether the methods used for those indicators are applicable on renewable energy sources and b) whether those indicators reflect the use of renewable energy.

4.1.1 The monetization of non-renewable energy sources

Several different methods have been defined to estimate the value of non-renewable resources. Only a few of those have been used in GPI studies since many are estimations of stock value, but flow value has to be used in GPI calculations. Some of those estimate only non-renewable energy production but other attempt to include the depletion of all non-renewable sources. Because of the many methods available this indicator reflects one of the critics directed at GPI, namely lack of consistency in the methodology (Lawn and Clark 2008). There have been discussions regarding which method is the best and which one should become standard for common usage, but at this point the replacement cost method is the most popular one (Cobb et al. 1995). Other methods such as the El-Serafy method (El-Serafy, 2002) and the net price method (Wen et al., 2007) have also been used. Following is a short description of these three methods found in analyzed articles:

The replacement cost method is probably the most widely used in GPI studies. The subtracted value of the use of non-renewable energy sources is estimated by converting all non-renewable energy produced into oil barrel equivalents and then by multiplying these by the cost of replacing this production with a renewable one. Most studies use the same value per barrel, \$75 (Cobb et al. 1995), which is the cost of producing “gasohol” from biomass (Hamilton 1999; Castaneda 1999; Jackson and Stymne 1996; Jackson et al. 1997; Talberth et al. 2007; Costanza et al. 2004). This figure is based on 1988 prices and in addition, the figure rises annually with 3%. When the value is derived this way, all resources in all areas/countries are assumed to have the same replacement cost.

In the Netherlands, a Sustainable National Income (SNI) is calculated on a yearly basis by the Environmental Statistics, which is a department within Statistic Netherlands. They apply the replacement cost by statistically estimating the cost of the replacement on an annual basis. The replacement cost is then used along with the life expectancy of the resource at the current extraction rate. The advantage of the method used in the Netherlands is that if the percentage of energy produced with renewable sources doesn't change between years, the cost of non-renewable resources will increase. This is due to the fact that the stock decreases between years. The cost will be held stable if non-renewable sources are replaced with renewable at the same rate as the non-renewable sources are extracted. (Hueting and de Boer, 2001)

The El Serafy method was developed in the 1980's to illustrate that developing countries, which income is mainly based on primary production, overestimated their national income by calculating the revenue of non-renewable resources without taking into account the expenses of the depletion. Using a non-renewable resource is like selling an asset, which can not be seen as income as the value of the resource is declining as more is sold. By basing the estimated income on these values the countries get an incorrect picture of the state of the economy and higher consumption is encouraged. (El Serafy, 2002)

The formula shows the proportion of the revenue which can be estimated to be "true income" or "sustainable income". This proportion is calculated with the size, the extraction rate and thus, the life expectancy of a resource according to the following formula:

$$\mathbf{X = R\ (1 - (1 / (1 + r)^{\,n+1})}$$

Where X is the true income, R is the revenue, r is the interest rate which points to the income that can be earned by the extracting agent if he invested part of the revenue in other assets in order to generate future income, and n is the life expectancy.

The method has been used in several national GPI-studies, especially where the depletion of mines is included (Stockhammer et al. 1997; Guenno and Tiezzi 1998; Pulselli et al. 2011). However it was not developed to be a part of the GPI and furthermore it was not developed as a tool for environmental preservation but as an instrument for developing countries to reflect their actual economic state.

The net price is the market price of a production unit minus the average cost per unit (Perloff 2009). The net price (the rent) from the depleted resource is required to reinvest making the rent equal to the depletion cost. Using the net price method is relatively simple in theory but to include all non-renewable sources, information has to be collected about the market price of all non-renewable raw materials and the average production cost. In a GPI case study in four cities in China this method was applied using the international market value, production volume and average production cost of coal, crude oil, natural gases, copper, iron and zinc (Wen et al., 2007). The method does however not reflect the advantages of renewable energy and does not resolve the problem of non-renewable sources been accounted for as assets.

4.1.2 The monetization of renewable resources other than energy

A study carried out by Castañeda on the ISEW in Chile is the only research reviewed that defined an indicator for renewable resources (Castañeda 1999), while other studies included indicators that measured a specific renewable resource like forest cover (Jackson and Stymne 1996; Costanza et al., 2004). In the Chilean study however the indicator named depletion of renewable resources only applies to forestry. What makes the methodology different from other studies when estimating the loss of forest cover is that the value of the resource service is estimated by using Hotelling rent (Castaneda, 1999). Hotelling rent, or scarcity rent, is the income the owner of a resource will receive merely due to the fact that the resource is scarce.

In a perfectly competitive market the cost of producing one more unit of a good (the marginal cost) is equal to the market price of the good. Even if there is competition in a market with a scarce resource the market price will exceed the marginal cost leading to a profit for the owner of the resource. This profit, which would not exist with an abundant resource, is the Hotelling rent or the scarcity rent of the resource. (Perloff, 2009)

When this method is applied the extra rent originated from the resource being scarce is subtracted from the GPI since this part of the money inflow is based only on the depletion of resources.

4.2 Does the GPI cover the effects of renewable energy production?

The positive effects on building an economy on renewable energy sources are not reflected directly in any of the additive indicators of the GPI. The building and daily operation of these power stations however has a positive effect on household income which is reflected in the personal consumption. Additionally large project have a positive effect on the net capital investment.

The negative effects of renewable energy production can not be reflected in one indicator but are reflected in a few indicators. In the following sections, the negative effects of hydro- and geothermal power will be discussed according to the factors defined in Table 2.

Effects on terrestrial ecosystems

The GPI does not include any indicator that reflects the impacts on terrestrial ecosystems nor biodiversity. The loss of habitats, changes in ecosystems and loss of biodiversity due to the building and drift of power stations is only indirectly reflected in the GPI if the land used for infrastructure can be defined as farmland, wetland or a forest. However these indicators ("Loss of wetlands", "Loss of farmland" and "Loss of forest cover") do not account for the effects the land loss can have on the ecosystems services in the area as they only measure the net change of area (Jackson and Stymne 1996; Clarke and Islam 2005; Wen et al. 2007)

Effects on aquatic ecosystem

As with the terrestrial ecosystems the GPI does not count for any effects on aquatic ecosystems. As both hydropower and geothermal power are based on water resources those will affect multiple aquatic ecosystems. By adding an indicator for measuring changes in fish stocks affected ecosystems will be partly covered.

Air quality

Air quality is addressed in two different indicators in the GPI. Greenhouse gas emissions are tackled in the indicator "Long-term environmental damage" and other air pollutants in "Cost of air pollution". The estimation of long-term environmental damage is based on greenhouse gas emission numbers from the System of National Account (SNA). In Iceland this information will be derived from the Environmental Agency's GHG inventory. The inventory covers the emission of CO_2 from the daily drift of both hydropower and geothermal power stations. The emission of CH_4 due to flooded vegetation and the lost ability of flooded vegetation to uptake CO_2 is estimated by the Environmental Agency and included in the inventory (Hallsdóttir, 2011). The SNA even includes the emission of H_2S from geothermal power plants.

In the Swedish ISEW study (Jackson and Stymne 1996), the indicator for air pollution includes sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter (PM). Most studies base their measurements of air-pollution on to the Pollution Standard Index (PSI) value (Costanza et al. 2004). The PSI-index normally includes carbon monoxide (CO), ozone

(O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and PM (Airnow 2011). None of those are present in the case of hydro- or geothermal power. These measurements leave out NH_3 and CH_4 from geothermal power, which are however estimated to be negligible (Hallsdóttir, 2011).

Water quality

The question of water quality is more important in the case of geothermal power since dams don't emit any significant amount of material to the water. The pollution of surface and underground water from geothermal power plants is included in GPI in certain methodologies. In the Australian study cost of water pollution is estimated using the control cost of improving water quality (Hamilton, 1999). When building geothermal power station, money will be spent on minimizing the trace metals in the water before they get out in the environment. Money spent on cleaning the geothermal fluids before those are disposed of should be included in the cost of improving water quality. If other methods are used, like calculating the percentage of impaired waters (Costanza et al. 2004) or measuring levels of nutrients in the water (Jackson and Stymne 1996) the water pollution of geothermal energy production is not fully reflected in the GPI.

Geological features

The downstream land degradation and erosion following the altered flow of suspended sediments due to dams is not included in the GPI unless the areas degraded are defined as farmland, wetland or forests. The indirect effects of the loss of river benches, deltas and coastline might be reflected in other indicators such as "Cost of air pollution" since the loss of land can lead to an increased concentration of particle matter (PM) which is reflected in that indicator. The measurement of PM does not reflect the effects that the land degradation has in a bigger context, like on ecosystems and livelihood of people.

The slow gradual sinking of land due to geothermal water extraction is hard to translate into monetary terms since it is more of a risk factor, not necessarily leading to a negative effect.

Visual pollution

Visual pollution, the effects on tourism and the effects on outdoor activities are hard to measure. If visual pollution was to be included an indicator to evaluate the service of wilderness would have to be included. As with tourism the effects could be that tourists choose not to travel to the area because of the power plants or they on the contrary choose to travel to the area because of the power plants since this type of production is not carried out in all countries (UNEP Dams 2000). The change in tourism in the area should be reflected partly in the income since more traffic generates increased income in the area.

Noise pollution

The question of noise pollution is especially important when considering the negative effects of geothermal stations. However the problem of noise pollution does not become a problem until people are affected by the noise. By using the method of estimated cost of noise per person exposed to the noise pollution the noise indicator includes geothermal power production (Jackson and Stymne 1996). Production of geothermal power is unlikely to make a big change since power plants are usually built in rural areas where few people live.

Cultural and archaeological features

The land-use change can raise conflicts due to the cultural or archaeological value of the land. On an economic ground the building of power plants increases the value of the land since it increases the employment rate and the flow of money into the local economy. The conflicts can be seen as sentimental values which are not included in the GPI.

4.3 The financial implications of renewable energy production

An economy built on loans from other countries cannot be seen as sustainable since the loans must be paid back eventually. The increased welfare derived from those loans is only short-term welfare. In the development of GPI an indicator has been added to reflect the international position or the net lending and borrowing (Daly and Cobb 1989). In small economies, like Iceland, expensive projects are dependent on foreign currency loans. When considering the sustainability of renewable energy production this factor must be considered since hydropower projects are often funded mostly through loans in foreign currencies (Landsvirkjun 2010). The indicator for net lending and borrowing will fully reflect these loans by subtracting the negative net balance based on the Icelandic SNA.

5 Discussion

5.1 Possible methods for including renewable resources in GPI estimations

Four methods are mentioned in the study concerning how to include resources in GPI estimations. Those are the replacement cost method, the El Serafy method, the net price method and Hotelling rent. Even though Hotelling rent was applied to renewable source in this case all those methods are designed to monetize the use of non-renewable resources.

It doesn't seem like the replacement cost method can be applied directly to renewable resources since it's based on the cost of replacing non-renewable resources with renewable resources. However production of renewable energy in Iceland is not all being carried out in a sustainable way. Energy production in geothermal power plants is in many cases held out at a rate that depletes local water supplies. While production of geothermal power is maintained above sustainable yield the replacement cost method can be applied to the fraction of the production that cannot be seen as sustainable (the production that exceeds the sustainable yield). However the way the method has been used is not based on the actual depletion of a resource since it does not include any calculations of the actual properties of a resource. By applying the same cost on all resources, regardless of the country, local conditions, type of resource or the scarcity, the only advantage of using the methods seems to be the fact that it's easy to apply. By giving all non-renewable energy sources the same qualities many important factors are discarded. Stating for example that the costs of replacing a unit of oil is equal to the cost of replacing a unit of nuclear energy discards the cost of storage of nuclear waste that will fall on future generations. Furthermore the price of producing "gasohol" from biomass depends on local conditions such as the actual availability of biomass. The production of "gasohol" might not be the best or the cheapest replacement for a country that has abundant water resources or great wind- or solar-power opportunities. To make the replacement cost method more reliable it needs to include the actual profile of energy production in the country or area and use the price of producing the same amount with a renewable source that is actually available in the country.

Both the El Serafy method and the Hotelling rent could be applied to renewable resources in the same sense as the replacement cost method, that is to the fraction of the production that is carried out above sustainable yield. If the El Serafy method would be used, the life expectancy of the resource would have to be estimated to calculate which fraction of the income would be sustainable. As with the replacement cost the El Sarafy method only applies to geothermal power if the production is carried out above sustainable yield. When it comes to hydropower the resource cannot be depleted in the same way since it's not based on a stock-resource. The Hotelling rent of a renewable resource could be estimated, but in the case of such an abundant resource as water is in Iceland, the value would have only a considerably small effect on the GPI.

The net price method can easily be applied to renewable resources, however the method is not even considered as an option in the monetization of resources since it does not include any estimation on life expectancy, depletion rate or scarcity of the resource. It does not reflect the disadvantage of using non-renewable sources since renewable energy sources would give only a slightly lower results of the net price. The net price is therefore a poor indicator of the rate at which the depletion of resources is affecting the sustainability and future living standards.

5.2 How well are the effects of renewable energy production reflected in the GPI?

Dependency on renewable energy sources does not have any direct negative effect on welfare. However if the production exceeds the level of sustainable yield the cost of this over-exploitation should be included in the GPI calculation. The subtraction of this exploitation should rely on the same methods as used for non-renewable resources. When comparing the methods available for monetization of non-renewable resources it seems that the El Serafy method succeeds to include both the properties of a resource and the income it generates. By subtracting the unsustainable fraction of the income the method manages to subtract the income that has negative effects on sustainable economical welfare. Subtracting the use of non-renewable energy sources or renewable energy sources that are overexploited fully reflects the positive effects of having an economy dependent on renewable energy. The fact that the use of non-renewable sources is by far the biggest subtraction factor supports my conclusions, since even a small fraction of renewable energy in the national energy mix will be reflected in higher GPI due to less subtraction for that indicator.

The study showed that the positive effect of relying on renewable resources is not taken directly into account when estimating GPI. The advantages of using renewable sources are enormous which makes one wonder if those should be an additive indicator in the GPI. Keeping in mind that the aim of the GPI is to reflect welfare I do not see a reason for adding a value despite the wide use of renewable sources. Let’s imagine two countries, one where all energy is produced with non-renewable sources (A), one where all energy is produced with renewable sources (B). With the term welfare in mind it’s safe to say that country B should have the highest welfare since it is not depleting resources at the same time as it maintains a certain living standard. The design of GPI means that country B will have higher welfare than country A, since it is not dependent on non-renewable sources, has a higher employment rate and receives rent from the production of renewable energy. The positive effects of using renewable energy are in other words already reflected in the GPI and adding positive value will encourage production exceeding the national demand for energy.

5.3 Including the negative effects of renewable energy production

Analyzes of the methodology and calculation used in GPI studies showed that some of the defined negative effects of hydropower and geothermal power can be seen in the indicator. Impacts that the GPI fails to include are the effects on terrestrial and aquatic ecosystems, geological feature and cultural and archaeological features.

The biggest shortcoming for both energy sources is the exclusion of the effects on ecosystems. The conservation of ecosystems, biodiversity and natural habitat is an important part of ensuring continuing ecosystem services which present economic growth is dependent upon. To include the lost ecosystem services is tricky since methods to estimate these losses vary and are dependent on both the area in question, the person who does the estimation and many other factors. If the GPI is to be comparable between areas and countries, estimations of the value of natural resources are therefore not favourable.

If the effects on ecosystems should be included in the GPI the most straight forward way might be to adjust the income in a similar way as with the uneven income distribution. That is to estimate the more general effect all production has on ecosystems and the effects on the future services of ecosystems.

Impacts on geological features and cultural and archaeological sites are hard to estimate. Such estimations would undermine the credibility of the indicator. In a country like Iceland with a very low population density, cultural and archaeological impacts are a smaller problem than in more densely populated countries. The effects of land erosion and altered flow of sediments have turned out to be a big part of the negative effects of big hydropower projects in Iceland (Landsvirkjun 2010). Further discussion is needed on whether or not it is possible to estimate those.

5.4 Discussion of financial implications

The fact that big renewable energy projects in a country with a small economy like Iceland will be dependent on foreign investments has to be reckoned with. However the GPI should cover those completely by subtracting the negative net balance due to these investments. An economy based on foreign loans is in principle like an economy based on non-renewable sources since the income generated from those needs to be paid back eventually.

6 Conclusions

When estimating the Icelandic Genuine Progress Indicator a discussion of the importance of building an economy on renewable sources is very important. The fraction of renewable energy production that is carried out in a non-renewable manner should be subtracted from the GPI, preferably using the El-Serafy method. The negative effects of this production are somewhat included in the GPI but further development and discussion is needed on the negative effects of the production on ecosystem services. The use of renewable energy has several advantages for both the society in question and the global environment. However the advantages do not need to be added in GPI calculations since countries which depend on renewable energy resources will have a higher GPI anyway due to the fact that they do not have to subtract the use of non-renewable sources. Furthermore adding a positive value can encourage production that exceeds the national demand and with that increase consumption. As the world moves towards a more sustainable way of thinking, people are starting to realize that increased consumption does not necessarily increase welfare. Consumption patterns need to shift from focusing on an economy with a big throughput towards an economy with more circulation within the economy.

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