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# How to measure national energy sustainability performance: An Icelandic case-study

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ABSTRACT

The development of sustainable energy systems is now firmly on the international agenda. Nations and their governments must strive to implement energy policies that facilitate sustainable development for society. Although Iceland is highly ranked by currently available energy indices, controversy has surrounded the development of previously undeveloped areas for power development and Iceland now finds itself at a crossroads regarding future energy developments. Well-designed indices for measuring the sustainability of energy systems can help policy-makers make the best choices for their national circumstances. However, often indicators and indices suffer from limitations and it may not be advisable to implement indicators designed for global comparisons at local, regional or even national scales. Nonetheless, indices such as those developed by the World Economic Council (WEC), World Economic Forum (WEF) for ranking countries and indicator sets such as the International Atomic Energy Agency's Energy (IAEA) Energy Indicators for Sustainable Development (EISD) may still be useful guides to decision-makers when designing their own national measurement tools provided the indicators fulfil certain criteria. Through interviews with key energy practitioners and decision-makers in energy development in Iceland and an extensive literature review, we identify the challenges faced in sustainable energy development in Iceland. We assess the suitability of indices proposed by organisations like the WEC, WEF and IAEA for reliably measuring the sustainability of energy development in individual countries like Iceland. We find that the indices and indicators evaluated suffer from commonly cited limitations including lack of methodological transparency, misalignment with sustainable development principles, inappropriate metrics, lack of clear targets, failure to capture socio-ecological impacts at different scales and failure to meet the interest of the target audience. Hence, they do not facilitate effective measurement of progress towards sustainable energy development for individual nations. Important issues relating to energy affordability and equity, environmental sustainability, efficiency, energy security and renewables are neglected by the indicators in all cases, although it should be said that the IAEA indicators are more comprehensive in their coverage of energy efficiency, renewables and environmental sustainability. In each case the indicators are at best only partially relevant to the Icelandic case, due to the country's unique energy mix, environment, economic structure and size and standard of living. By identifying their limitations and by examining them in light of criteria for good indicators as recommended by the Organisation for Economic Co-operation and Development (OECD) and International Institute for Sustainable Development (IISD), we contribute to the discussion on the value and validity of indicators, indices and frameworks. Knowing the potential pitfalls, we are in a better position to design a more effective measurement tool. We conclude that a more comprehensive, multi-level, context-specific measurement tool would be needed for measuring national energy sustainability in Iceland and would require methods that allow broad public participation.



## Introduction

In Iceland, living standards are among the highest in the world and the population enjoys access to energy in the form of geothermal space heating and electricity generated almost exclusively from renewable sources (geothermal energy and hydropower). However, energy development in Iceland has resulted in negative environmental and social impacts, and the country now has one of the highest ecological footprints in the world (Olafsson et al., 2014). The development of previously undeveloped areas for power development in Iceland remains a contentious topic. In an attempt to achieve consensus on Iceland's energy future, various stakeholders around the country took part in a decade-long process to develop a Master Plan, which was presented to the National Parliament in 2011. However, soon afterwards, various stakeholders demanded that it be amended, and the debate continues (Juliusdottir, 2015). Icelandic energy policy is not

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currently coordinated at the national level. A list of critical factors that planners and decision-makers should consider to ensure sustainable energy development will have value for Icelandic energy decision-making. Such a tool created with the input of high level decision-makers and the public, would be more likely to result in effective decision-making where energy is concerned.

Two new indices published by the international organisations the World Energy Council (WEC) and the World Economic Forum (WEF) aim to measure and rank the performance of countries regarding energy sustainability. Recently, the WEC has launched a new updated version of its World Energy Trilemma Index (ETI), which ranks the sustainability of countries' energy systems according to how they perform for certain indicators. One of the WEC's goals is to ensure that the ETI will be a benchmark for assessing good energy policy at country level and claims to be a country ranking system that measures country's ability to provide a stable, affordable, and environmentally sensitive energy system by showing the aggregate effect of energy policies applied over time in the context of each country (WEC, 2015). The WEF wishes to provide a tool that can "provide an additional set of data to help leaders benchmark the current performance of national energy systems, and inform decision-making in the context of the changes under way in the global energy landscape" (WEF, 2015) and have created the Energy Architecture Performance Index (EAPI). Another indicator framework that has existed for a longer time is known as Energy Indicators for Sustainable Development (EISD) from the International Atomic Energy Agency (IAEA, 2005). This is not intended to be used for ranking purpose, but instead to present a sample set of indicators for use or improvement, that the IAEA hopes countries will use the to assess their energy system and track their progress towards nationally defined sustainable development goals.

All too often, however, indicator information fails to bridge the boundaries between science and policy, due to inadequate design or implementation within institutions (Cash et al., 2002a, 2002b; Moreno-Pires and Fidélis, 2012). Furthermore, indicators may be used to either delay the taking of action, propagate the business as usual agenda, or to justify an unsustainable action or lack of action, by providing a precise and simplified yet biased viewpoint (Molle and Mollinga, 2003; Russell and Thomson, 2009). For example, the Gross Domestic Product (GDP) indicator may be used as a sole measure of economic well-being, or government performance, despite its failure to take account of such things as environmental degradation or human rights violations (Talberth et al., 2007).

According to Pinter et al. (2005), aggregate indices such as the Human Development Index (HDI); Genuine Progress Indicator (GPI) have experienced a rise in popularity, but due to issues with measurement, weighting and indicator selection, many have not been deemed appropriate for actual decision-making. The design of indicators and indices of sustainable development is a problematic process and sustainability assessment tools have been criticised for various reasons. Limitations of sustainability indices or indicator frameworks have been recognised in relation to scalar mismatching, difficulties in defining or agreeing on definitions of sustainable development, lacking fine-grained spatial information or failing to take account of causal linkages or ecological aspects, neglecting national specificities, lacking broad public participation and failing to look to the future.

Regardless of the limitations of indices or frameworks, indicators found within such frameworks, may still hold some value for measuring national energy sustainability. The International Atomic Agency claims that their Energy Indicators for Sustainable Development indicators are intended to be used directly by national decision-makers in the way they see fit: "Policymakers need methods for measuring and assessing the current and future effects of energy use on human health, human society, air, soil and water. They need to determine whether current energy use is sustainable and, if not, how to change it so that it is" (IAEA, 2005). The aim of the organisations producing the indices, apart from ranking nations, is also to provide a guideline to nations regarding important factors required in order to maintain a sustainable energy system. Indeed, the WEF themselves state that "there is no universally applicable formula for energy reform; each country must develop and implement policies that address its own unique circumstances. Despite this, there are lessons to be learned from successes and failures of other countries to avoid some of the pitfalls of "learning by doing"" (WEF, 2015).

Little research has been carried out on the effectiveness of methods designed for assessing sustainable development at global or national scales but implemented at local or regional scales (Graymore et al., 2008). Whilst the aim of this paper is not to carry out an assessment of policy impact of the aforementioned indices, we wish to take the first step in designing the most suitable assessment method for national energy sustainability. Using Iceland as a case-study, we seek to identify important national challenges for sustainable energy development faced by key decision-makers in the energy sector. We also analyse the usefulness and suitability of chosen indices and frameworks for the purpose of measuring national energy sustainability.

## *Research objectives*

Taking Iceland as a case study, this paper will consider the following questions:

1. What are the country-specific energy challenges faced in Iceland that policy-makers must overcome to facilitate sustainable development?
2. How suitable are currently available energy indicators, indices or frameworks in terms of measuring sustainable energy development for an individual nation such as Iceland?

This paper is structured into sections as follows: we introduce the concept of sustainable energy development as it is presented in major policy texts, identifying its common themes. In the section Indices and indicator frameworks of sustainable energy development we introduce the concept of energy indices and frameworks, and their recognised limitations, followed by a description of two energy-focused indices and one energy framework that we will analyse for suitability. The section Evaluation method for suitability of indices describes the methods used to evaluate suitability: we describe the interview process and data triangulation methods. In the section Discussion: suitability of the selected indices for measuring national energy sustainability, we describe the key challenges for Icelandic energy development identified in the interviews. The indicators and results of the WEC and WEF energy sustainability indices as well as the IAEA energy indicator framework are examined to determine whether they are appropriate measures of energy sustainability in Iceland. Some of the most recent published data for the indicators relating to the Icelandic case is analysed. An in-depth discussion examines the indicators with particular regard to their suitability to the Icelandic case: this discussion is organised using cross-cutting themes of sustainable energy development.

## *Sustainable energy development: common themes*

Since the Brundtland et al. (1987) and the adoption of Agenda 21 at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, which noted energy's importance to sustainable development, the concept of sustainable energy has come up in a number of high level international policy fora and associated documents. The first World Energy Assessment (WEA) was undertaken in 2000, to build consensus on how to effectively use energy as a tool for sustainable development and to emphasise the need to create energy systems that lead to a more equitable, environmentally sound, and economically viable world (United Nations Development Programme, 2000). The purpose of energy is to enhance wellbeing, according to the report, which states: "Energy produced and used in ways that support human development over the long term, in all its social, economic, and environmental dimensions, is what is meant in this report by the term sustainable energy. In other words, this term does not refer simply to a continuing supply of energy, but to the production and use of energy resources in ways that promote—or at least are compatible with— long-term human well-being and ecological balance. Many current energy practices do not fit this definition." Likewise, the IAEA (2005) emphasises the main outcome of energy development as improved wellbeing: "Energy is central to improved social and economic well-being, and is indispensable to most industrial and commercial wealth generation. It is key for relieving poverty, improving human welfare and raising living standards."

The need for a shift to a new energy paradigm is stressed by the World Energy Assessment (WEA) and the WEA 2000 report compares the characteristics of a traditional energy paradigm to an emerging paradigm that will promote sustainable energy development (United Nations Development Programme, 2000). Table 1, taken from the aforementioned WEA report, outlines some of opportunities for the energy sector in moving into the new energy paradigm. For instance, the emerging paradigm is said to involve "greater consideration" of all possible impacts of energy use, and finding ways to address the negative "externalities" or impacts at all scales. These statements underscore the need to take account of not only the benefits increased energy production can bring but also the multidimensional, multi-scalar impacts of energy developments. The report concludes that further measures will need to be taken by individual countries: "because market forces alone are unlikely to meet the energy needs of poor people, or to adequately protect the environment, sustainable development demands frameworks (including consistent policy measures and transparent regulatory regimes) to address these issue." (United Nations Development Programme, 2000).

The importance of taking account of national circumstances when developing sustainable energy systems was stressed again in the Johannesburg declaration arising from the World Summit on Sustainable Development in 2002. The declaration reiterated access to energy as critical for the Millennium Development Goal of halving the proportion of people living in poverty by 2015. The Summit also called for changes to unsustainable patterns of energy production and use, calling participants to: "Improve access to reliable, affordable, economically viable, socially acceptable and environmentally sound energy services and resources, taking into account national specificities and circumstances" (World Summit on Sustainable Development, 2002).

Later reports such as *Energy Services for the Millennium Development Goals* (Modi et al., 2006) recognised that adequate and affordable energy supplies are central to improved social wellbeing and economic prosperity, due to its ability to relieve poverty and raise living standards. Modi et al. (2006), like the World Energy Assessment report (2000), note the urgency of social problems in poorer countries and argue that economic growth should take precedence over trying to 'leapfrog' to the cleanest possible technology for some countries: "Consideration of the positive environmental aspects of renewable energy sources must be balanced against meeting practically, quickly and efficiently the immediate energy needs of the poor with whatever energy services are accessible," …(**since)**…"the technology choices made in meeting the immediate energy needs of the poor need not be permanent". Hence the advantages and disadvantages of fossil fuels, particularly the environmental impacts, need to be weighed in a broader context of need (p 75).

Recently, a set of goals that have been drawn up by the UN to stimulate actions towards sustainable development in countries adopting the 2030 Agenda for Sustainable Development. Goal 7 specifies that countries must "Ensure access to affordable, reliable, sustainable and modern energy for all". Along with the other sustainability goals, the provision of sustainable energy is seen as instrumental in the attainment of sustainable development. The UN's "Sustainable Energy for All (SE4ALL)" initiative has also recently manifested, with three key development objectives for the energy sector by 2030: "ensuring universal access to electricity and modern cooking solutions, doubling the rate of improvement of energy efficiency, and doubling the share of renewable energy in the global energy mix." The initiative calls for the monitoring of progress of action on sustainable energy, and itself uses a global tracking framework with global indicators across what it calls the "dimensions of sustainable energy for all", namely, access, efficiency and renewables. In 2015 in the EU, The Energy Union Strategy (a project of the European Commission) was also launched, with the aim of coordinating the transformation of European energy supply to one that provides secure, sustainable, competitive, affordable energy (European Commission, 2015). Reports on the state of the Energy Union are published annually and include a set of indicators that monitor progress towards clearly specified Energy Union policy objectives within the member states.

Some common themes may therefore be identified from the international policy literature, namely those of accessibility, affordability, security, efficiency, renewability, economic efficiency, environmental sustainability and contribution to human wellbeing. We propose that these themes, summarised in Table 2, can be used as a broad frame with which to envision the end goal of an ideal sustainable energy system. We use these themes to structure our discussion (Discussion: suitability of the selected indices for measuring national energy sustainability section) of the suitability of the three selected energy indices for the case of Iceland. It must be acknowledged, however, that

**Table 1**
Opportunities for energy in the new energy paradigm.

| Traditional paradigm | Emerging paradigm |
|---|---|
| Energy considered primarily as a sectoral issue | Greater consideration of social, economic, and environmental impacts of energy use |
| Limitations on fossil fuels | Limitations on the assimilative capacity of the Earth and its atmosphere |
| Emphasis on expanding supplies of fossil fuels | Emphasis on developing a wider portfolio of energy resources, and on cleaner energy technologies |
| External social and environmental costs of energy use largely ignored | Finding ways to address the negative externalities associated with energy use |
| Economic growth accorded highest priority (even in prosperous countries) | Understanding of the links between economy and ecology, and of the cost-effectiveness of addressing environment impacts early on |
| Tendency to focus on local pollution | Recognition of the need to address environmental impacts of all kinds and at all scales (local to global) |
| Emphasis on increasing energy supply | Emphasis on expanding energy services, widening access, and increasing efficiency |
| Concern with ourselves and our present needs | Recognition of our common future and the welfare of future generations |

**Table 2**
Themes within Sustainable Energy Development Paradigm – Summary Table.

| Theme | Explanation/rationale |
|---|---|
| Access & electrification | All members of society have access to readily available modern, high quality energy sources. |
| Affordability and equity | Energy is equitably affordable for all members of society. |
| Security | Energy supplied is reliable, effective and secure. Energy systems are stable, resilient and adaptive. |
| Efficiency | Energy is efficiently generated, supplied and used. |
| Renewables | Energy sources are kept available for future generations. |
| Economic or cost-efficiency | Energy production is economically and financially viable. |
| Environmentally benign and clean | Energy production avoids or mitigates negative environmental impacts in whichever form they occur. Impacts in all domains: air, water, land, forests, oceans, biodiversity, etc. should be considered on all scales. |
| Contributes to well-being | Energy is fundamentally a means to the end of enhancing intergenerational human wellbeing and prosperity within the capacity of the biosphere. Energy production should be socially acceptable and free from negative health impacts. |

certain issues such as increasing energy access or affordability for the poor are much more urgent in some countries, whilst in countries having universal access, the priority may move towards environmental sustainability or increasing the share of renewables, for example.

## Indices and indicator frameworks of sustainable energy development

Two composite indices and one set of non-composite indicators are analysed in this paper. The two composite indices were the World Economic Forum's Energy Architecture Performance Index (WEF-EAPI) and the World Energy Council's Energy Trilemma Index (WEC-ETI). The International Atomic Agency's Energy Indicators of Sustainable Development (IAEA-EISD) is a non-composite multidimensional indicator set.

The World Economic Forum's Energy Architecture Performance Index (WEF-EAPI) was developed in collaboration with a group of energy experts from across the value chain. The EAPI tool builds on the first edition of the index, published in the Global Energy Architecture Performance Report 2013 (World Economic Forum, 2012) and is described as a tool that can "provide an additional set of data to help leaders benchmark the current performance of national energy systems, and inform decision-making in the context of the changes under way in the global energy landscape" (WEF, 2015). The EAPI currently ranks 126 countries using the same set of 18 indicators grouped into three dimensions: economic growth and development environmental sustainability and energy access and security (Fig. 1). In 2016, the top performing country was Switzerland. Within the WEF-EAPI framework, Iceland achieved an overall ranking of 26 in 2016. Iceland was ranked 43rd in 2013 when the index was first published.

The World Energy Council's Energy Trilemma Index (WEC-ETI) is a country ranking system that aims to measure their ability to provide a stable, affordable, and environmentally sensitive energy system by showing the aggregate effect of energy policies applied over time in the context of each country. The ETI claims to highlight countries that are able to balance energy demands to deliver more sustainable energy systems for their citizens and secure long term competitive economies (WEC, 2015). One of the World Energy Council's goals is to ensure that the ETI will be seen as a benchmark for assessing good energy policy at country level. The ETI currently ranks 125 countries using the same set of indicators in three dimensions: energy security, energy equity, and environmental sustainability (Fig. 2). Another dimension "country context" was added in 2016 (World Energy Council, 2016). In 2016, the top performer was Denmark and Iceland achieved an overall ranking of 15. After six years of research, The WEC, in partnership with Oliver Wyman global management consultancy, carried out a review of the ETI in 2016 and produced a revised methodology, which it claims to have a broader scope and forward-looking view of energy systems.

In this study, we also examine the indicator set proposed by the International Atomic Energy Agency in 2005. Whilst this is not an index as such, we feel that this indicator set is also of interest, since it is intended to measure the sustainability of national energy systems. The purpose of Energy Indicators for Sustainable Development (EISD) from the International Atomic Energy Agency (IAEA, 2005) is to present a sample set of indicators for use or improvement, that the IAEA hopes countries will use the to assess their energy system and track their progress towards nationally defined sustainable development goals. According to the EISD, sustainable development is essentially about improving quality of life or wellbeing in a way that can be sustained, economically and environmentally over the long term supported by the institutional structure of the country. The indicators are divided into three dimensions: social, economic and environmental (Fig. 3) (IAEA, 2005). The EISD indicator set differs from the WEC and WEF frameworks, since it does not include a framework to aggregate these indicators together and it has not been used to rank countries. These

| Energy System Objective | Measure (of) | Indicator Name | Indicator Weight |
|---|---|---|---|
| Economic growth and development | Intensity | Energy intensity, GDP per unit of energy use (PPP $ per kg of oil equivalent) | 0.25 |
| | Supports / detracts from growth | Cost of energy imports (% GDP) | 0.125 |
| | | Value of energy exports | 0.125 |
| | Affordability | Degree of artificial distortion to gasoline pricing (index) | 0.125 |
| | | Degree of artificial distortion to diesel pricing (index) | 0.125 |
| | | Electricity prices for industry ($ per kWh) | 0.25 |
| Environmental Sustainability | Ratio of low – carbon fuel sources in the energy mix | Alternative and nuclear energy (% of total energy use, incl. biomass) | 0.2 |
| | Emissions impact | $CO_2$ emissions from electricity production, total $gCO_2$/kWh | 0.2 |
| | | Methane emissions in energy sector (metric tonnes of $CO_2$ equivalent / total population) | 0.1 |
| | | Nitrous oxide emissions in energy sector (metric tonnes of $CO_2$ equivalent / total population | 0.1 |
| | | PM2.5, country level (micrograms per cubic meter) | 0.2 |
| | | Average fuel economy for passenger cars (l/100km) | 0.2 |
| Energy access and security | Level and quality of access | Electrification rate (% of population) | 0.2 |
| | | Quality of electricity supply (1-7) | 0.2 |
| | | Percentage of population using solid fuels for cooking (%) | 0.2 |
| | Diversity of supply | Diversity of total primary energy supply (Herfindahl index) | 0.1/0.2 * |
| | Self-sufficiency | Import dependence (energy imports, net % of energy use) | 0.2 |
| | | Diversification of import counterparts (Herfindahl index) | 0.1/0 ** |

**Fig. 1.** WEF-EAPI index as of 2016. *For the indicator on diversity of total primary energy supply, net exporters are given a weight of 0.2 since they are not scored for the indicator on diversification of import counterparts whereas net importers are given a weight of 0.1 to form a mini-index for diversity of supply. **The indicator on diversification of import counterparts only applies to net importers: for these countries, a weight of 0.1 is used (for net exporters, a weight of 0 is used).

| Dimension | Weight | Indicator Category | Weight | Indicator | Weight |
|---|---|---|---|---|---|
| Energy security | 30% | Security of supply and energy delivery | 15% | Diversity of primary energy supply | 5.0 |
| | | | | Energy consumption in relation to GDP growth | 5.0 |
| | | | | Import dependence | 5.0 |
| | | Resilience | 15% | Diversity of electricity generation | 5.0 |
| | | | | Energy storage | 5.0 |
| | | | | Preparedness (human factor) | 5.0 |
| Energy equity | 30% | Access | 10% | Access to electricity | 5.0 |
| | | | | Access to clean cooking | 5.0 |
| | | Quality of supply | 10% | Quality of electricity supply | 5.0 |
| | | | | Quality of supply in urban vs. rural areas | 5.0 |
| | | Affordability and competitiveness | 10% | Electricity prices | 3.3 |
| | | | | Gasoline and diesel prices | 3.3 |
| | | | | Natural gas prices | 3.3 |
| Environmental sustainability | 30% | Energy resource productivity | 10% | Final energy intensity | 5.0 |
| | | | | Efficiency of power generation and T&D | 5.0 |
| | | GHG emissions | 10% | GHG emission trend | 5.0 |
| | | | | Change in forest area | 5.0 |
| | | CO2 emissions | 10% | CO2 intensity | 3.3 |
| | | | | CO2 emission per capita | 3.3 |
| | | | | CO2 from electricity generation | 3.3 |
| Country context | 10% | Coherent and predictable policy framework | 2% | Macroeconomic environment | 0.5 |
| | | | | Effectiveness of government | 0.5 |
| | | | | Political stability | 0.5 |
| | | | | Perception of corruption | 0.5 |
| | | Stable regulatory environment | 2% | Transparency of policy making | 0.7 |
| | | | | Rule of law | 0.7 |
| | | | | Regulatory quality | 0.7 |
| | | Initiatives that enable RD&D and innovation | 2% | Intellectual property protection | 0.5 |
| | | | | FDI and technology transfer | 0.5 |
| | | | | Capacity for innovation | 0.5 |
| | | | | Number of patents issues by residents | 0.5 |
| | | Investability | 2% | Foreign direct investment net inflows | 1.0 |
| | | | | Ease of doing business | 1.0 |
| | | Air pollution, land and water impact | 2% | Wastewater treatment | 1.0 |
| | | | | Air pollution | 1.0 |

**Fig. 2.** WEC-ETI Index as of 2016.

indicators have been officially tested in only a few countries, but have not been officially reported on a continuous basis (United Nations, 2007). The EISD indicators have not been calculated for Iceland before, although some of the data is collected independently by various agencies within the country.

*Limitations of sustainability indices, frameworks and indicators*

Many international organisations, such as the United Nations Commission for Sustainable Development (UNCSD) (Pinfield, 1996), have made the case that indicators are needed to guide countries or regions towards sustainable energy development and the necessity of developing sustainability indicators is clearly set out in Agenda 21. After the UN Conference on Environment and Development (UNCED) held in 1992, the Agenda 21 action plan was draw up and states that: "Indicators of sustainable development need to be developed to provide solid bases for decision-making at all levels and to contribute to a self-regulating sustainability of integrated environment and development systems" (Agenda 21, Chapter 40). Sustainability indicators provide critical information on social, economic and ecological conditions (Devuyst et al., 2001) and can inform and empower policy-makers and laypeople by creating a means of measurement of progress in achieving sustainability objectives (Hak et al., 2007). As such, indicators have an important role in the policy cycle in providing decision support. However, the limitations of these tools have been recognised by various authors and relate to scalar mismatching; difficulty in defining or agreeing on definitions of SD; a misalignment with sustainable development principles; lack of fine-grained spatial information (particularly on causal linkages or socio-ecological aspects); failure to recognise national specificities; lack of broad public participation and being backward looking.

The difficulty of operationalizing sustainable development across geographical scales, in particular with regard to the use of sustainability indicator systems, has been highlighted in the literature (Kissinger et al., 2011; Cumming et al., 2006) and the effectiveness of methods designed for assessing sustainable development at global or national scales but implemented at local or regional scales remains little-studied (Graymore et al., 2008). In the arena of quality of life indicators, for instance, little work has been done to investigate how the importance of specific human needs varies depending on scale. Therefore little is known as to the best way to aggregate individual quality of life to a larger group, e.g. on the regional or national scale (Costanza et al., 2007).

One reason for such difficulty in operationalizing sustainability, is that although sustainability may be a well-known concept, and its global definition(s), although value-laden, more or less accepted, the development of local definitions must still take account of the complexity and context-specificity of sustainability problems (Renn et al., 1998; O'Toole et al., 2006). The notion of sustainable development now forms part and parcel of many of the publicly stated policies of many organisations or communities, yet its meaning and means of implementation are still very much contested (Russell and Thomson, 2009). Aggregate indices that attempt to describe progress towards sustainable development have been growing in popularity, but difficulties in measuring, weighting and the selection of indicators tend to be encountered (Pinter et al., 2005). Although indices may be useful for ranking countries according to the same yardstick, the usefulness of weighting and scoring each indicator to produce a final score is otherwise uncertain.

| SOCIAL | | | | |
|---|---|---|---|---|
| Theme | Sub-themes | Energy Indicator | | Components |
| Equity | Accessibility | SOC1 | Share of households (or population) without electricity or commercial energy, or heavily dependent on noncommercial energy | -Households (or population) without electricity or commercial energy, or heavily dependent on noncommercial energy<br>-Total number of households or population |
| | Affordability | SOC2 | Share of household income spent on fuel and electricity | -Household income spent on fuel and electricity<br>- Household income (total and poorest 20% of population) |
| | Disparities | SOC3 | Household energy use for each income group and corresponding fuel mix | -Energy use per household for each income group (quintiles)<br>-Household income for each income group (quintiles)<br>-Corresponding fuel mix for each income group (quintiles) |
| Health | Safety | SOC4 | Accident fatalities per energy produced by fuel chain | -Annual fatalities by fuel chain<br>-Annual energy produced |
| ECONOMIC | | | | |
| Theme | Sub-themes | Energy Indicator | | Components |
| Use and production patterns | Overall use | ECO1 | Energy use per capita | -Energy use (total primary energy supply, total final consumption and electricity use)<br>-Total population |
| | Overall productivity | ECO2 | Energy use per unit of GDP | -Energy use (total primary energy supply, total final consumption and electricity use)<br>-GDP |
| | Supply efficiency | ECO3 | Efficiency of energy conversion and distribution | -Losses in transformation systems including losses in electricity generation, transmission and distribution |
| | Production | ECO4 | Reserves-to production ratio | -Proven recoverable reserves<br>-Total energy production |
| | | ECO5 | Resources-to production ratio | -Total estimated resources<br>-Total energy production |
| | End use | ECO6 | Industrial energy intensities | -Energy use in industrial sector and by manufacturing branch<br>-Corresponding value added |

**Fig. 3.** IAEA-EISD Index.

| | | | | |
|---|---|---|---|---|
| | | ECO7 | Agricultural energy intensities | -Energy use in agricultural sector<br>-Corresponding value added |
| | | ECO8 | Service/ commercial energy intensities | -Energy use in service/ commercial sector<br>-Corresponding value added |
| | | ECO9 | Household energy intensities | -Energy use in households and by key end use<br>-Number of households, floor area, persons per household, appliance ownership |
| | | ECO10 | Transport energy intensities | -Energy use in passenger travel and freight sectors and by mode<br>-Passenger-km travel and tonne-km freight and by mode |
| | Diversification | ECO11 | Fuel shares in energy and electricity | -Primary energy supply and final consumption, electricity generation and generating capacity by fuel type<br>-Total primary energy supply, total final consumption, total electricity generation and total generating capacity |
| | | ECO12 | Non-carbon energy share in energy and electricity | -Primary supply, electricity generation and generating capacity by non-carbon energy<br>-Total primary energy supply, total electricity generation and total generating capacity |
| | | ECO13 | Renewable energy share in energy and electricity | -Primary energy supply, final consumption and electricity generation and generating capacity by renewable energy<br>-Total primary energy supply, total final consumption, total electricity generation and total generating capacity |
| | Prices | ECO14 | End-use energy prices by fuel and by sector | -Energy prices (with and without tax/subsidy) |
| Security | Imports | ECO15 | Net energy import dependency | -Energy imports<br>-Total primary energy supply |
| | Strategic fuel stocks | ECO16 | Stocks of critical fuels per corresponding fuel consumption | -Stocks of critical fuel (e.g. oil, gas, etc.)<br>-Critical fuel consumption |
| ENVIRONMENTAL | | | | |
| Theme | Sub-themes | Energy Indicator | | Components |

**Fig. 3** (*continued*).

| | | | | |
|---|---|---|---|---|
| Atmosphere | Climate change | ENV1 | GHG emissions from energy production and use per capita and per unit of GDP | GHG emissions from energy production and use -Population and GDP |
| | Air quality | ENV2 | Ambient concentrations of air pollutants in urban areas | -Concentrations of pollutants in air |
| | | ENV3 | Air pollutant emissions from energy systems | -Air pollutant emissions |
| Water | Water quality | ENV4 | Contaminant discharges in liquid effluents from energy systems including oil discharges | -Contaminant discharges in liquid effluents |
| Land | Soil | ENV5 | Soil area where acidification exceeds critical load | -Affected soil area -Critical load |
| | Forest | ENV6 | Rate of deforestation attributed to energy use | -Forest area at two different times -Biomass utilization |
| | Solid waste generation and management | ENV7 | Ratio of solid waste generation to units of energy produced | -Amount of solid waste -Energy produced |
| | | ENV8 | Ratio of solid waste properly disposed of to total generated solid waste | -Amount of solid waste properly disposed of -Total amount of solid waste |
| | | ENV9 | Ratio of solid radioactive waste to units of energy produced | -Amount of radioactive waste (cumulative for a selected period of time) -Energy produced |
| | | ENV10 | Ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste | -Amount of radioactive waste awaiting disposal -Total volume of radioactive waste |

**Fig. 3** (*continued*).

The implementation of sustainable development naturally differs between regions since it emerges from a contested local political context. In some cases, indices or indicator frameworks may include indicators that have no relationship to sustainable development principles and/or actions designed to make organisations or societies more sustainable (Russell and Thomson, 2009). Various indicator systems have been designed for comparisons across countries (Bock et al., 2005), but as a result they lack fine-grained spatial information or fail to take account or causal linkages or ecological aspects, which are necessary for effective decision-making at regional or ecosystem level (van Zeijl-Rozema et al., 2011). Sustainability challenges vitally need to be understood on the territorial or regional level, due to the specificities of each region (Péti, 2012; van Zeijl-Rozema et al., 2011) and without proper planning tools, sustainability policy cannot be effectively integrated at all levels. In spite of this, few frameworks exist that are specifically tailored to deal with assessment at the regional or local scale, with most methods having been originally developed to assess sustainability on a global or national scale (Graymore et al., 2008). As well as this, few mechanisms currently exist to harmonize sub-national scale assessment with national scale assessment (van Zeijl-Rozema et al., 2011). Often indicator development may be overly focused on the methodological validity and reliability of indicators, with little consideration of the context of their use (Klazinga et al., 2001).

Graymore et al. (2008) argue that the regional scale is the scale at which the most progress to achieving sustainability can be achieved. They argue that the most progress towards sustainable development can be made at this level since communities are prepared for collective action and the local government may build trust and dialogue with communities. However the local scale is also extremely important. The inclusion of local level community sustainability assessment for policy is not only desirable from the point of view of resource management. Lay knowledge is as valuable as scientific expertise valuable in policymaking. Local community-based initiatives may facilitate closer interactions between governments and citizens and provides communities with the means to influence local policymaking on issues that directly affect them and their environment, thereby resulting in improved public health, quality of life, social cohesion and awareness of local issues and networks (European Commission, 2013).

The majority of sustainability indices or frameworks for energy are “backward looking” and thereby do not enable sustainability assessment of alternative energy futures. van Zeijl-Rozema et al. (2011) propose that sustainability be measured through indicators that are tied to dynamic models and by using a variety of tools to measure SD, both qualitative and quantitative of SD.

Given the limitations associated with indices, frameworks and indicators Cash et al. (2002a, 2002b), propose that in order to be effective, sustainability indices should be salient, credible and legitimate. *Salience* refers to the relevance of information for an actor's decision choices, or for the choices that affect a given stakeholder. *Credibility* refers to whether an actor perceives information as meeting standards of scientific plausibility and technical adequacy. *Legitimacy* refers to whether an actor perceives the process in a system as unbiased and meeting standards of political and procedural fairness. Criteria for indicator selection have been put forward by the OECD (1993a, 1993b) and the IISD (2012). The guidelines can be summarised as follows. A good indicator must:

- have policy relevance and utility for users
- match the interests of the target audience
- provide a representative picture of environmental conditions, pressures on the environment or society's responses;
- be simple, accessible, easy to interpret and able to show trends over time;
- invite action (reading further, investigate, ask questions, do something)
- go with an explanation of causes behind the trends
- be comparable with other indicators that describe similar areas, sectors or activities
- be responsive to changes in the environment and related human activities
- provide a basis for international comparisons
- be either national in scope or applicable to regional environmental issues of national significance
- have a threshold or reference value against which to compare it so that users are able to assess the significance of the values associated with it
- be theoretically well founded in technical and scientific terms
- be based on international standards and international consensus about its validity
- lend itself to being linked to economic models, forecasting and information systems

Furthermore, the data required to support the indicator should be:

- readily available or made available at a reasonable cost/benefit ratio
- adequately documented and of known quality
- updated at regular intervals in accordance with reliable procedures

## Evaluation method for suitability of indices

This research has been informed by a comprehensive literature review and key interviews with industry practitioners and decision-makers in energy development in Iceland. Given the limited resources available to us, we took a simple approach, geared towards identifying key energy challenges, involving the triangulation of results on a small-scale: interviews were carried out and the results were then triangulated, whenever possible, for purposes of validity, using a method proposed by Patton (2002). Data triangulation is the collection of qualitative data using multiple data collection methods. These methods may include structured and semi-structured questions through surveys, in person interviews, telephone, and e-mails with researchers, policy experts, regulators, and industry leaders and literature reviews.

In order identify the country-specific energy challenges faced by Icelandic policy makers, five semi-structured interviews with five decision-makers and experts from Iceland were carried out. van Zeijl-Rozema et al. (2011) encourage taking a broader perspective of regional dynamics rather than focusing on rigid comparison between individual indicators: instead comparing common high level themes or goals. Hence, themes of sustainable energy development were identified in the international literature. The challenges identified by the interviewees were classified according to these themes. The indicators and results of our selected energy indices and framework were analysed to determine if they are suitable for measuring sustainable energy development in Iceland. To gather the data for the energy indicators designed by the IAEA, further documents such as industry reports, technology assessment documents, governmental publications and academic publications were analysed and reviewed.

## Discussion: suitability of the selected indices for measuring national energy sustainability

This section provides insight into the specific requirements of the Icelandic energy sector, and reveals whether the selected indices are suitable for measuring Icelandic performance in energy sustainability.

We examine the indicators, composition and published results of the chosen indices and framework. The indicators are first evaluated on their fulfilment of the criteria for good indicators as described in the section Indices and indicator frameworks of sustainable energy development, namely, their policy relevance; utility; interest to the target audience; representativeness of environmental or social conditions, pressures or responses; simplicity; accessibility; ease of interpretation; transparency; responsiveness; technical or scientific soundness; quality of data. We then look at the suitability of the indicators for Iceland in particular, in the context of the challenges identified in the interviews and in the literature. The main challenges identified from the interviews are presented, categorised according to themes of sustainable energy development in the following sections. Given that five interviews can provide limited insights, the results of the interviews were also complemented by literature searches by the authors. We structure this discussion according to the sustainable energy themes identified in Introduction section. A summary of the main observations regarding the indicators and challenges are found in Tables 3 and 4.

### *Access & electrification*

Having access to high quality energy sources and fuels is directly related to higher living standards and providing energy access to the worlds' poor has top priority on the international agenda. Access to modern energy is essential for the provision of clean water, sanitation and healthcare and for the provision of reliable and efficient lighting, heating, cooking, mechanical power, transport and telecommunications services. For instance, it is estimated that worldwide 1.2 billion people do not have access to high quality electricity, of which more than 95% live in countries in sub-Saharan Africa and developing Asia, and 2.7 billion people still cook with traditional biomass, which is linked to 3.5 million deaths per year from indoor air pollution (International Energy Agency, 2015a, 2015b). Therefore, in these countries, the issue of energy should be closely monitored.

The WEC and WEF indices refer to energy access specifically as a concern for all countries, and use similar, globally accepted indicators, like those used by the United Nations to measure this. Yet it is clear that its policy importance will vary depending on country circumstances. Energy access was considered by interviewees only as an urgent issue for developing countries but not for Iceland. The idea of providing energy to other countries from Iceland was, however mentioned as a possibility and seen as a way by some for Iceland to contribute to the sustainability of other nation's energy supply.

Iceland scores highly relative to other countries in the WEF-EAPI and WEC-ETI indices for access related indicators. In Iceland, solid fuels usage is practically non-existent. Electrification is countrywide and the quality of the electricity supply is high. Table 3 shows the indicators in each of the three indices that relate to access and electrification along with their suitability to measuring sustainable energy development and the Icelandic case. We collected data for EISD SOC1 indicator for Iceland, which shows that all households have access to electricity and around 90% of the country uses geothermal space heating (National Energy Authority, 2014).

Whilst energy access is an important theme of sustainable energy development globally, indicators on electricity or high quality fuel access have little policy relevance to Icelandic policy makers since they do not match the interests of the target audience. What may be of more interest is access to low or zero carbon fuels, for those people without access to geothermal heating and for the transportation sector, for instance.

**Table 3**
Comments on suitability of indicators for measuring sustainable energy development.

| Index | Related indicators | General suitability for measuring sustainable energy development | Suitability to Icelandic case |
|---|---|---|---|
| *Access and electrification theme* | | | |
| WEF-EAPI | Percentage of population using solid fuels for cooking; quality of electricity supply; electrification rate | Mainly a concern in sub-saharan Africa and Asia. | No solid fuels used for cooking, high quality electricity supply: Electrification rate is 100% |
| WEC-ETI | Access to electricity; access to clean cooking; quality of electricity supply; | | |
| IAEA-EISD | SOC 1: share of households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy. | | |
| *Affordability and equity theme* | | | |
| WEF-EAPI | Degree of artificial distortion to gasoline and diesel pricing; electricity pricing for industry. | Diesel and gasoline a small part of energy supply. Electricity pricing for industry by itself is not informative re. equity. | Diesel only used in transportation, a small percentage of total energy usage. |
| WEC-ETI | Quality of electricity supply in urban vs. rural areas; electricity prices; natural gas prices; gasoline and diesel prices | Energy affordability a household issue, pricing is uninformative without benchmarks of affordability; Low prices for industry not synonymous with economic prosperity or energy equity | Natural gas not used in Iceland. |
| IAEA-EISD | Share of household income spent on fuel and electricity (SOC 2); energy use disparity (SOC 3) | Affordability and disparity not a concern in all countries | Affordability not an issue in Iceland but equity between different sectors may be |
| *Energy security theme* | | | |
| WEF-EAPI | Diversification of import counterparts; import dependence; diversity of total primary energy supply. | Diversity not a reliable measure of energy security. | Iceland produces most electricity domestically. Energy security mainly concerns fuels used in transport and fishing. |
| WEC-ETI | Diversity of primary energy supply; energy consumption in relation to GDP growth; import dependence; diversity of electricity generation; energy storage; preparedness (human factor). | Diversity not a reliable measure of energy security Stockpiles only relevant for countries relying on them. | Iceland is not a fuel- exporting nation and has a modern and reliable electricity infrastructure. Indicators measuring short-term and long term risks are relevant to Iceland but should take consideration of the predominant energy types used, namely geothermal and hydropower. |
| IAEA-EISD | Diversification of fuel mix (ECO 11–13) Net energy import dependency (ECO 15) Stocks of critical fuels per corresponding fuel consumption (ECO 16) Reserves-to-production ratio (ECO 4) Resources-to-production ratio (ECO 5) | Long term risks not considered | |
| *Energy efficiency theme* | | | |
| WEF-EAPI | Fuel economy for passenger cars | Cars are only one part of the transportation sector. Does not measure all aspects of efficiency (from generation to end use). | Iceland has a relatively efficient distribution system. |
| WEC-ETI | Efficiency of power generation and T&D | Distribution loss not a big concern in some countries GDP denominator is uninformative. | Efficiency of Icelandic energy types may require special measurement techniques, going beyond electricity generation. |
| IAEA-EISD | Supply efficiency (ECO3) End use efficiency or intensity (ECO 6–10) | May disregard non-electrical uses or cogeneration. | End use efficiency of energy could be improved, particularly households. |
| *Renewables theme* | | | |
| WEF-EAPI | Ratio of alternative (including biomass) and nuclear energy in the energy mix | Nuclear energy may not be a policy option for some countries | Increasing renewables is only relevant in the transportation and fishing sector for Iceland. |
| WEC-ETI | None | Renewable energy is of utmost importance for sustainable energy transition | |
| IAEA-EISD | ECO 13: renewable energy share in energy and electricity. | | |
| *Economic and cost efficiency theme* | | | |
| WEF-EAPI | Cost of energy imports; value of energy exports | Economic efficiency of energy projects themselves is not captured by macro indicators; not all countries can or should export energy. | Project level economic viability important as it can impact on affordability. Iceland imports little energy and does not export. |
| WEC-ETI | Macroeconomic environment; foreign direct investment and inflows | | Measurement of economic benefits of energy would be more appropriate than traditional indicators. |
| IAEA-EISD | None | | |
| *Environmentally benign and clean theme* | | | |
| WEF-EAPI | Emissions Impact Ratio of low carbon fuels in the energy mix Carbon emissions | Impact of nuclear and renewables, other impacts apart from GHG emissions ignored | Carbon emissions of end users (e.g. heavy industry) a concern in Iceland. Other emissions like H2S concern from geothermal. |
| WEC-ETI | Final energy intensity; GHG emission trend; $CO_2$ intensity, $CO_2$ emissions per capita; $CO_2$ from electricity generation; change in forest area; waste water treatment; air pollution. | GDP not useful for measuring energy or $CO_2$ intensity. Forest area not relevant in all countries and may be affected by other factors than energy Country specific indicators are weighted much less than Co2/GHGs | Other environmental impacts are possible Iceland does not have deforestation or use nuclear energy. Energy type-specific indicators are lacking. |
| IAEA-EISD | GHG emissions from energy production and use; ambient concentrations of air pollutants in urban areas; air pollutant emissions from energy systems; contaminant discharges in liquid effluents from energy systems; soil acidification; deforestation attributed to energy use; solid waste generation from energy, radioactive waste. | Impacts for country-specific energy mix may be ignored | |

**Table 3** (*continued*)

| Index | Related indicators | General suitability for measuring sustainable energy development | Suitability to Icelandic case |
|---|---|---|---|
| *Contribution to wellbeing theme* | | | |
| WEF-EAPI | None | Wellbeing is something that should result from sustainable energy systems and should be measured. | Hydropower safety relevant to Iceland. Iceland scores highly for objective wellbeing: subjective well-being with regard to energy development should be measured |
| WEC-ETI | Effectiveness of government, political stability; perception of corruption; transparency of policy making; rule of law; regulatory quality | Indicators not directly related to energy development | |
| IAEA-EISD | Accident fatalities per energy produced by fuel chain (SOC4). | Objective wellbeing measures only. Subjective well-being indicators missing. | |

*Affordability and equity*

It has been well established in the literature that energy poverty is an important concern in many countries, where many households struggle to afford high quality fuels or electricity and thus have lower standards of living. Poverty alleviation takes place at the household level where the supply of modern energy can improve air quality, sanitation, provide access to water, as well as freeing up time for other economic activities.

The WEF and WEC indices look at gasoline price distortion and electricity pricing for industry, yet not all nations will have gasoline as a main fuel. This rationale has little to do with energy affordability for households themselves, especially in countries where people live below the poverty line with no disposable income for the purchase of consumer goods. It is also not clear how price distortion is intended to indicate affordability. Subsidies are often used to promote affordability, but may also increase consumption. Taxes, on the other hand, might decrease affordability but promote an overall equitable distribution of wealth (e.g., rich people might use more transportation fuel than poor people do so the taxes tend to help the poorer people). In addition, whilst it may also be important to show affordability of energy for industry as well as households, such indicators do not demonstrate energy affordability for industry either, since there is no benchmark for what an ideal energy price would be. It is not clear whether higher prices yield a higher overall score or a lower one because the scoring system is not explained in sufficient detail. Affordability of electricity is considered but other fuel prices are not given the same attention. Furthermore, electricity prices may or may not include subsidies depending on government policy. Such indicators are not easy to interpret and therefore are unlikely to promote clear actions. They also lack clear benchmarks as to what level of pricing is desirable. The usefulness of absolute values is limited since they express little about the perceived worth of a unit of energy to individual households and thus the fairness of the changes observed.

The IAEA-EISD includes indicators (SOC2) which look at how much of a household's income is spent on energy needs as well as indicators on energy use disparity (SOC3) to measure the equity of energy supply across income groups. Thus, it measures affordability at the household level, although it does not state benchmarks for desirable values as such.

Historically, Icelanders are accustomed to an abundance of relatively cheap heating and electricity, in both rural and urban areas, since the beginning of geothermal development in the country. Interviewees agreed that this situation is desirable and should remain so for the future. The majority of households (over 90%) have access to geothermal district heating. Government subsidies are paid to equalize the

**Table 4**
Challenges for sustainable energy development in Iceland identified by Icelandic interviewees classified by sustainable energy theme.

| Theme | Explanation/rationale | Country-specific challenge |
|---|---|---|
| Access & electrification | All members of society have access to readily available modern energy sources. | Iceland can play a part in supplying renewable energy to other countries. Access to low-carbon high quality fuels for each sector is required. |
| Affordability and equity | Energy is equitably affordable for all members of society. | Energy should continue to be affordable for Icelanders, and pricing should be equitable among all sectors. |
| Security | Energy supplied is reliable, effective and secure. Energy systems are stable, resilient and adaptive. | Developing new technologies to use geothermal energy should be priority, energy independence is most urgent for the fishing and transport sectors. |
| Efficiency | Energy is efficiently generated, supplied and used. | Increasing the efficiency of energy production and use is required.<br>Reducing energy consumption and waste, particularly for houses |
| Renewables | Energy sources are kept available for future generations. | Using geothermal resources so that they are not depleted for future generations<br>Properly define what is meant by sustainable yield for geothermal energy. |
| Economic or cost-efficiency | Energy production is economically and financially viable. | Ensuring economic and financial viability of energy projects<br>Ensuring other economic sector e.g. recreation and tourism is not adversely impacted by energy developments |
| Environmentally benign and clean | Energy production avoids or mitigates negative environmental impacts in whichever form they occur. Impacts in all domains: air, water, land, forests, oceans, biodiversity, etc. should be considered on all scales. | Ensuring environment is not adversely impacted by energy development, in particular impacts from geothermal and hydropower.<br>Using a systems rather than an narrow perspective<br>De-carbonising the transportation sector and fishing fleet<br>Ensuring that increased tourism does not have a negative impact due to increased energy usage<br>Ensuring that the end-use of energy produced leads to sustainable outcomes<br>Develop a clear policy for energy and related challenges such as climate change |
| Contributes to well-being | Energy is fundamentally a means to the end of enhancing intergenerational human wellbeing and prosperity within the capacity of the biosphere. Energy production should be socially acceptable and free from negative health impacts. | Implementing effective and legitimate, socially acceptable decision-making methods for energy planning (as experience lacking with this).<br>Ensuring that the end-use of energy produced leads to sustainable outcomes<br>Using a systems rather than an narrow perspective |

cost of space heating for families that do not enjoy geothermal heat National Energy Authority (2010). Table 3 shows the indicators in each of the three indices that relate to affordability and equity along with their suitability to measuring sustainable energy development and the Icelandic case.

In Iceland, gasoline or diesel only count for a small portion of energy consumed, and there is no natural gas used hence the WEF and WEC indicators are only partially relevant in demonstrating overall energy affordability. Organisations such as INFORSE suggest a value of 10% as the energy poverty threshold. We found that Icelandic household expenditure falls well below this value. In 2012, the average expenditure on electricity, gas and other fuels for Icelandic households was 3.6% of disposable income (Statistics Iceland, 2016). This tells us that poverty and energy poverty are not major issues in Iceland, since households have adequate access to relatively cheap power and heating (which has been subsidised for certain households since 1982) (Orkustofnun, 2014). Whilst indicators on energy use disparity, such as used in the IAEA-EISD (SOC3) are important for countries in measuring energy equity, in Iceland there is overall little difference in the affordability of energy between households. The equity of pricing would be of more interest in this case, for example the difference in pricing for industry vs. households or its perceived fairness, since it is difficult to specify an ideal price for energy.

*Security*

The various types of risks that energy systems face include internal and external threats and these may be short term or long term and occur at any point in the energy chain. For instance, short term threats such as sudden disruptions in the electricity grid can be managed by real-time management/automated systems to provide stability, medium term threats such as geopolitical disputes may be managed by diversification of supply for resilience, and long term threats such as a depletion in energy reserves may be managed by adapting through research and innovation (Kucharski and Unesaki, 2015).

Both WEC and WEF indices turn to diversity of energy supply as a measure of security, which is unreliable since it may not reduce uncertainty and may in fact contribute to poor system performance or clash with other policy goals (Kucharski and Unesaki, 2015). The WEF-EAPI index covers the short to medium term risks of disruptive impacts of price shocks or unanticipated disruptions in energy supply, which are of particular concern in electricity markets where energy import dependency is often high. Whilst the WEC does include new indicators on energy storage and preparedness, as well as innovation and R&D, the metrics for these indicators are not clearly defined in the latest report, nor can they be said to offer adequate measures of energy security overall. The EISD set provides an indicator for stockpiles of fuel; however this indicator is not relevant in all countries. The WEC-ETI and IAEA-EISD also cover some potential short term risks using indicators on diversification and energy independence. However, indicators for energy import dependence will treats a nation's dependence on oil from countries with which it has friendly relations, the same way it treats those with which it has a troubled relationship. In addition, the WEC-ETI indicator on distribution losses, shows the reliability of the energy system in real-time. It also measures emergency stockpiles which can be effective for the short-term mitigation of supply disruptions. However, most long term, systemic factors are not considered by any of the frameworks studied. For example, societal threats arising from lack of public acceptance of energy activities, social inequities or impacts from climate change are not dealt with. Greenhouse gas emissions are included in both rating systems as an environmental issue but they are not taken into account as a security issue. In any case, a country's own actions are not solely what determine its vulnerability to climate change.

In terms of energy independence, Iceland is currently in a favourable position as it produces most of its energy indigenously. During the interviews, the need to reduce fossil fuel usage in the transportation sector and fishing fleet was mentioned as a way to increase energy security. This is something that would be possible for the transport and fisheries sector through the use of electric vehicles, given the abundance of indigenous, low-carbon energy available (Shafiei et al., 2017; Árnason and Sigfússon, 2000). Furthermore, two areas on the Icelandic Continental Shelf are thought to have potential for commercial accumulations of oil and gas, although research and exploration are still in the early stages Orkustofnun (2017). Hence Iceland has several options for becoming oil-independent in the medium term at least.

Interviewees also mentioned challenges relating to raising awareness of the other potential uses of geothermal energy apart from electricity generation and space heating and developing new technologies to use geothermal energy better, hence increasing energy security. Table 3 shows the indicators in each of the three indices that relate to energy security along with their suitability to measuring sustainable energy development and the Icelandic case.

The IAEA-EISD indicator ECO 15: *Net energy import dependency* is intended to provide a measure of energy stability or security and Iceland performs well here in that it imports only around 15%, even though the overall amount of imported fuel has increased in the period 1998–2014. The indicator ECO 16: *Stocks of critical fuels per corresponding fuel consumption* provides another measure of energy security for Iceland. Iceland has no national fossil fuel reserves and the NEA has not carried out a comprehensive assessment of this issue. Indicators ECO 4 *Reserves-to-production ratio*[1] and ECO 5 *Resources-to-production ratio*[2] may also provide a measure for energy security in Iceland. Unfortunately, there is very little available data on the available reserves and resources of geothermal energy, Iceland's biggest gross energy source. Probable reserve[3] calculations using an average areal production from a report by the national energy authority were used by Bjarnadottir (2010) to estimate the reserve capacity [4] ratio for a number of geothermal plants in Iceland. It has been estimated that reserve capacity is below the recommended level of 50% for several power plants in Iceland (Theistareykir, Krafla-Namafjall, Hengill and Svartsengi-Eldvorp).

In terms of long term risks, the assumption is made that renewables, including geothermal resources will sustain the same yield perpetually. However this is not always the case. It is commonly recommended that geothermal resources are gradually developed in steps, so that the resource capacity and behaviour can be determined, otherwise the developer risks prematurely depleting the resource to levels where the initial rate of production cannot be maintained, which can result in difficulties in meeting energy demands. Such has been the case at the Hellisheiði plant (Gunnarsson et al., 2011), the largest geothermal combined heat and power plant in Iceland. Once a geothermal resource

[1] Measures the availability of national energy reserves with respect to corresponding fuel production. Reserves are generally defined as identified (demonstrated and inferred) resources that are economically recoverable at the time of assessment. Reserves are also defined as those quantities that geologic and engineering information indicates can be recovered with reasonable certainty in the future from known or identified energy resources under existing economic and technical conditions The indicator considers fuels such as oil, natural gas, coal and uranium, and provides a relative measure of the length of time that proven reserves would last if production were to continue at current levels.

[2] Measures the availability of national energy resources with respect to corresponding fuel production. Resources are generally defined as concentrations of naturally occurring solid, liquid or gaseous material in or on the Earth's crust in a form that makes economic extraction potentially feasible. Total resources include reserves, and hypothetical and speculative undiscovered resources. This indicator considers fuels such as oil, natural gas, coal and uranium. It provides a relative measure of the length of time that resources would last if production were to continue at current levels.

[3] The term **reserves** refers to those portions of proven or probable **resources** that are generally accepted to be commercially extractable with existing technology and prevailing market conditions. Probable geothermal **reserves** are estimated after the drilling of successful exploration wells.

[4] Reserve capacity is the amount of available energy reserves in a geothermal system that is not being utilized or can be utilized from existing wells in the field. A single geothermal system that usually is associated with a central volcanic system can have a few geothermal fields that can be utilized. The reserve capacity ratio measures how much of the probable reserve is not being utilized.

has been depleted, it may take decades or centuries to replenish the natural energy flow (O'Sullivan et al., 2010; Pritchett, 1998), which means that the sustained yield of the resource may become compromised.

Furthermore, the estimation of resources and reserves of geothermal energy is difficult. Other long term risks that may impact Icelandic energy supplies include the impact of climate change on hydropower. Glaciers in the Nordic countries are predicted to lose 50% of their volume by 2100. This increased glacial melt will have a positive effect on hydropower production in Iceland in the 21st century, but for a finite period only (Thorsteinsson et al., 2013). Similarly, geothermal resources, although considered generally as renewable, may run into problems such as those encountered by the Hellidheiði plant, if exploited in an unsustainable manner. Although Iceland has not been an energy exporting country, the possibility of exporting electricity from Iceland via undersea cable may also have implications for energy security, depending on how much energy is sold and how aggressively geothermal resources are exploited.

Icelandic energy security concerns in the future will require adaptation strategies, for instance the replacement of fossil fuels in the transportation and fisheries sectors with indigenous energy sources, and ensuring the sustained yield of existing geothermal resources, hence indicators to measure these actions would be more appropriate.

### *Efficiency*

Sustainable energy is energy that is produced and distributed with maximum efficiency. Energy efficiency is encouraged for energy sustainability because it reduces the amount of emissions produced and for importing countries also reduces reliance on imports in general and within the international community. The IEA recommends the decoupling of energy use from GDP and population growth in order to achieve a 2DS scenario (International Energy Agency, 2015a, 2015b). Efficiency should be a concern for all three stages of generation, transmission and end-use of electricity.

Both indices and the EISD indicators highlight the importance of energy efficiency to sustainability. The WEF-EAPI index only includes an indicator on the fuel economy of passenger cars in this regard, which is a measure of the end use efficiency of one sector only and not a measure of the efficiency of generation, distribution or transmission of energy. The WEC index uses indicators for power generation, transport and distribution but not end use, whilst the EISD set provides indicators for all of these. The WEF-EAPI operates on the rationale that GDP per unit energy use provides an indication of the efficiency of energy use, and whether there is an opportunity to improve energy availability by reducing energy intensity. However, there are arguments against using GDP as a unit in the measurement of energy intensity, since changes in GDP per unit energy over time are influenced greatly by changes in the structure of the economy as well as changes in sectoral energy intensities. The environmental impact of different energy sources also varies and a variety of factors affect energy consumption. Thus, the ratio of total energy consumption to GDP is not a reliable indicator of energy efficiency or sustainability.

Iceland has a modern and reliable electricity infrastructure and has made very good use of geothermal energy to create comfortable living conditions for the population, with an emphasis on abundance of heat and energy at low prices. Whilst an unreasonable waste of energy cannot be said to occur, the usage of energy in Iceland may not be described as particularly frugal. Perhaps this is due to the small population and a general feeling of abundance of energy as a result. As geothermal energy may be exhausted in the long term, however, tightening building energy efficiency requirements has been recommended, as well as removing subsidies for electric and oil heating for the 10% of the population that does not have access to geothermal heat (OECD, 2014).

The interviewees identified general challenges relating to increasing the efficiency of energy production and use and reducing energy consumption and waste in Iceland. Table 3 shows the indicators in each of the three indices that relate to energy efficiency along with their suitability to measuring sustainable energy development and the Icelandic case. The efficiency ratio of final electricity consumption to electricity supply has increased from 91.45% in 1990 to 94.57% in 2013 (Statistics Iceland, 2016). However, this only tells part of the story for Iceland, i.e. it does not consider other uses of geothermal energy apart from electricity. In terms of energy supply efficiency, geothermal energy generation efficiency may be measured using utilization efficiency, which considers that the efficiency of a geothermal energy project will depend on the efficiency of utilization of all extracted energy. Cogeneration and cascading can increase utilization efficiency. Exergy analyses can be performed to determine the efficiency of utilization. In 2008 the efficiency of geothermal power plants was calculated. Nesjavellir and Svartsengi had the best result with utilization efficiencies of 60% and 46% since they are both co-generation plants and provide district heating water to neighbouring communities. Krafla, Hellisheidi and Reykjanes only produce electricity and have utilization efficiencies of around 37% (Bjarnadottir, 2010). Very little data was available on end-use energy efficiency for households, a sector that may need to improve its efficiency.

Hence, more suitable indicators for Iceland with regard to energy efficiency should focus on generation, transmission and distribution but particularly on the end use of energy supplied, such as in household and the other uses of geothermal energy.

### *Renewables*

The use of renewable energy is important for sustainable development as it uses resources that remain available for future generations and can reduce a nation's dependence on fossil fuels and increase its energy security. For the theme of renewables, the WEC index does not include any indicators relating to the share of renewables in energy supply. It does include "country context" indicators that generally refer to technological innovation such as *FDI and technology transfer, capacity for innovation, number of patents issued by residents, intellectual property protection* (World Energy Council, 2016). However, these indicators do not directly measure energy related developments. Furthermore, their methodologies are not transparently explained in the latest report so it is difficult to establish their links to sustainable energy development. The WEF index places renewable energy and nuclear energy in the "alternative" energy category. Such an indicator may not be appropriate for countries with strong opposition to nuclear power. The EISD indicators include the share of renewables in the energy supply and indicators for radioactive waste.

Geothermal energy and hydropower are classified as renewable sources of energy. The Icelandic interviewees did not mention increasing the use of renewables in Iceland as a major concern, apart from in the transportation sector and fishing fleets. Table 3 shows the indicators in each of the three indices that relate to renewables along with their suitability to measuring sustainable energy development and the Icelandic case. The Icelandic data for the IAEA-EISD ECO 13: *Renewable energy share in energy and electricity* shows that in 2015, around 99% of electricity produced in the country was from domestic energy resources with approximately 27% of total electricity production from geothermal energy and the rest from hydropower (National Energy Authority, 2014). The Icelandic government has set a target of 10% renewable energy sources to be used in transport by 2020 (Ministry of Industries and Innovation). Since Iceland uses such a high percentage of renewables for electricity and heating, indicators for the percentage of renewables used in transport or fishing would be of more interest, as would indicators to monitor the sustained yield of geothermal resources.

*Economic or cost-efficiency*

Sustainable energy development requires that an energy project must provide positive net economic benefits, be economically viable and carry minimal financial risk (Alanne and Saari, 2006). To be economically viable, the project must produce a net positive result, after all social and environmental costs have been considered. Economic benefits should be considered at the macro and micro levels. At the project level, aspects such as energy efficiency and environment and health-related costs should be considered, whereas at the macro level, benefits in the form of employment creation, economic developments due to the multiplier effect, or the effects on other economic activities such as tourism and farming should be considered.

For the theme of economic or cost-efficiency the WEF-EAPI indicators are intended to measure the macro level effects of energy development. The WEC-ETI indicators, similarly, refer to the macroeconomic environment but not to the impact of energy development on the economy as such. However, since many other factors impact on macroeconomic performance, such indicators are not informative as to the micro or macroeconomic impacts of energy developments specifically. The EISD set does not provides any indicator for directly measuring economic or cost-efficiency of energy. Indicators in the economic dimension of the EISD indicator set are focused on energy intensity, prices, efficiency and security.

The Icelandic interviewees, on the micro level, considered ensuring economic viability of energy projects as important, whilst on the macro level, considered ensuring wellbeing and that other economic sector e.g. recreation and tourism is not adversely impacted by energy developments as important. Table 3 shows the indicators in each of the three indices that relate to efficiency along with their suitability to measuring sustainable energy development and the Icelandic case. In Iceland, certain cases have arisen of power plants (e.g. Hellidheidi) being uneconomical with serious consequences.

The thermal production from the Hellisheiði geothermal station is mainly used by households and businesses in the capital area of Reykjavík. Most of the electricity generated by the plant is sold to the Nordural aluminium smelter owned by Century Aluminium. In 2010 Reykjavík Energy had accumulated 233 billion ISK debt (2 billion USD or 1.4 billion Euros), nearly four times the city's annual budget of 60 billion ISK, much of which was in the form of highly fluctuating foreign currency loans. The bulk of Reykjavík Energy's debt can be attributed to the construction of the Hellisheiði plant. In 2006, the company signed a power purchase agreement to sell electricity to aluminium smelting company Century Aluminum Norðurál. However following the financial crisis, the company's foreign debts became unmanageable. A rescue plan for the company involved mass layoffs of employees in 2010 and raising the price of heating and electricity by 27% between November 2010 and January 2011. Since most banks refused loans to the company, the city of Reykjavík had to supply a 12 billion ISK (105 million USD) loan, almost the entire reserve fund set aside for the company, but still only a fraction of the company's debt (Reykjavik Grapevine, 2011).

From 2012, the management of Reykjavík Energy realised that the Hellisheiði geothermal plant was unable to deliver expected sustainable generation due to declining steam. The company's scientists predicted that due to over-exploitation of the geothermal resource, the performance of Hellisheiði station would decline by an equivalent of seven MW on average annually. It was therefore decided to connect the plant with the nearby geothermal area called Hverahlíð, at a cost of more than ISK three billions (USD 25 million, EUR 19 million) (Gunnlaugsson, 2012). As well as this, the company will spend close to USD 44 million during next six years in pumping water back into wells (to maintain steam). Thus, in total it will cost the company close to USD 263 million to maintain the power generation of the Hellisheiði station over the next six years: an amount almost equivalent to the total cost of building Landsvirkjun's new 90 MW Þeistareykir station (Askja Energy, 2017). The Hellisheiði plant generates 20% of all company revenues for Reykjavík Energy. The profitability (return on investment (ROI)) of the plant is considered too low. The combined ROI of the two geothermal plants at Hellisheidi and Nesjavellir was 4.8% for hot water production and 4.9% for electricity generation (Reykjavik Energy, 2015), which is much lower return than the normal target for profitability in competitive energy services, where 7–8% return is considered acceptable.

This would imply that monitoring economic efficiency at the project level is just as important in Iceland as monitoring national level indicators such as those proposed by the energy indices studied. In the case of macro level indicators, indicators with clear links to energy development would be more appropriate, such as those that measure benefits in the form of employment creation, economic developments due to the multiplier effect, etc.

*Environmentally benign and clean*

Energy developments may have impacts on the atmosphere, water, forest, land and biodiversity. In order to ensure energy sources are exploited within the capacity of the biosphere, it is imperative to take account of the environmental impacts that may occur during the energy system lifecycle and set appropriate indicator targets that take account of thresholds and tipping points. This includes taking account of systemic impacts that may arise as a result of the end-use of the energy produced.

The impacts of nuclear energy usage and renewables are not assessed at all by the WEF-EAPI or WEC-ETI, even though they recommend its usage in the energy mix. The WEF and WEC indices focus on energy intensity and GHG emission trends as indicators of environmental sustainability. The WEF index also has an indicator on PM 2.5. The impacts of nuclear energy or other sources are not accounted for directly by the WEF index. The WEC index includes indicators on air and water pollution said to be country specific yet these are weighted much less than the other environmental indicators. The IAEA-EISD framework includes two indicators relating to radioactive waste amounts, but no other indicators relating to the potential environmental or well-being/health impacts of nuclear energy. The environmental dimension of the IAEA-EISD is quite comprehensive and contains indicators for Atmosphere, Water and Land. These indicators deal with the point source pollution from energy production (i.e. emissions, concentration of air pollutant, contaminant discharges. They also deal with indirect environmental impacts such as soil acidification or deforestation. However, there are many other direct or indirect environmental impacts that could occur for different energy types, e.g. H2S from geothermal plants in Iceland. Within the IAEA-EISD indicators there are no indicators to measure GHG emissions from different sectors. Only energy intensity is measured by sector.

The main transboundary impact considered by the WEF-EAPI and WEC-ETI indices is climate change. Within the IAEA-EISD indicator set, there are indicators for various transboundary issues such as climate change, acid rain and nuclear waste, but they still only partially cover the potential transboundary issues that could occur. For example, transboundary issues associated with energy development include desertification or loss of habitats due to land use changes, far reaching pollution such as leaks of radioactivity (such as has been observed with Chernobyl and Fukushima), or impacts on water resources from extraction or from damming.

Since 2013 in the WEF-EAPI index, Iceland has received particular attention due to its "Remarkable Environmental Sustainability Journey", ranking 9th for environmental sustainability in 2013 and ranked 1st in 2016. In 2016, Iceland was ranked 2nd in for environmental sustainability in the WEC-ETI index. Nonetheless, challenges remain. The need for decarbonisation of the transportation sector and fishing fleet in Iceland and conversion to renewable energy sources was mentioned as a challenge by interviewees. The systemic impacts of energy development were mentioned as requiring more consideration, such as the impacts that arise from the end-use of energy produced, for example from aluminium smelting. The reduction of energy consumption and waste in general was mentioned as a concern for Iceland, as well as the increased energy usage that is likely to arise from increased tourism. Table 3 shows the indicators in each of the three indices that relate to environmental impacts along with their suitability to measuring sustainable energy development and the Icelandic case.

The main energy-related environmental concerns in Iceland are linked to the use of geothermal and hydropower. Although Iceland's usage of geothermal and hydropower has replaced fossil fuels, Iceland has the highest ecological footprint (EF) in the world (Olafsson et al., 2014). Geothermal energy projects may emit relatively little CO2 during energy production, but the entire lifecycle should nonetheless be taken into account, since those may be higher. Of more concern in Iceland is the amount of GHGs that are emitted by end users of the energy sources or the other sectors that emit GHGs i.e. the fishing fleet and transportation sector. Around 80% of electricity in Iceland is consumed by industry with 68% of total electricity produced being consumed by the aluminium industry (National Energy Authority). In 2010, 46.3% of Iceland's total $CO_2$eq emissions came from metals, in particular, aluminium reduction, in contrast to the 5% of total emissions that were emitted from geothermal sources (United Nations). Hydropower may also have various environmental impacts such as land use, impacts on forest, wildlife habitat, agricultural or scenic lands, or impact on aquatic ecosystems. As well as this it may require relocation of communities. During strategic energy planning in Iceland (Thórhallsdóttir, 2007), geothermal options were ranked more favourably than hydropower since hydropower projects had greater surface transformations and more extensive direct losses and were located in regions with valuable ecosystems. Geothermal areas tended to be located in areas with unique landscape and hydrology and or geology.

Iceland's per capita energy use has increased steadily since 1990, which is mainly due to industrial energy use. However, as noted by the IAEA (IAEA, 2005) the actual value of this indicator is strongly influenced by a multitude of economic, social and geographical factors. For instance, in Iceland measuring GHG per capita is problematic in Iceland due to the small population and large portion of GHGs emitted by industrial users.

Unlike the WEC and WEF indices, the IAEA-EISD indicators require the collection of data on ambient concentrations of air pollutants in urban areas and air pollutant emissions from energy systems. In Iceland, SOx is a contaminant of concern, with these emissions mostly coming from geothermal energy production. $SO_x$ emissions rose by 255% in Iceland between 1990 and 2010. A similar trend can be observed for $SO_2$ equivalent emissions as a result of a large increase (×15) in geothermal electricity production since 1990 (Olafsson et al., 2014). The EISD guidelines only recommend measuring lead emissions but in Iceland there may be other emissions of concern from geothermal plants, which may include ammonia, hydrogen, methane, radon and the volatile species of boron, arsenic, mercury, or silica though generally in very low concentrations (Shortall et al., 2015). Also noteworthy are $H_2S$ emissions from geothermal plants: at certain concentrations H2S may have significant consequences for health since it is toxic to humans and may indirectly cause acid rain. $H_2S$ concentrations have increased on average across Iceland, particularly in Reykjavík, where the European Environment Agency has reported 24-h readings as high as 170 $\mu g/m^3$, well above the WHO's maximum guideline (Olafsson et al., 2014).

IAEA also recommend collecting contaminant discharges in liquid effluents from energy systems and soil acidification. Since Iceland uses very little fossil fuel for energy production, oil discharges are of little concern. Of greater concern in the case of geothermal energy is water contamination from the release of more acidic/alkaline effluent from the power plant, or metals such as arsenic, boron, aluminium, or thermal pollution (Shortall et al., 2015). Deforestation attributed to energy use, solid waste generation from energy and radioactive waste are not issues of concern in Iceland. For Iceland, specific indicators dealing with the environmental impacts of geothermal energy and hydropower are more appropriate, which should include impact on air, water, ecology and landscape. More attention could be given to GHG or CO2 emissions from the transportation and fishing sector. The impacts of different economic sectors such as tourism or heavy industry are also more important to consider than the emissions from energy sources such as geothermal energy and hydropower, since these have relatively low emissions themselves.

*Contribution to well-being*

The provision of energy should have delivery of wellbeing as its core purpose. One well known definition of wellbeing has been put forward by the UN, listing having several key components: the basic material needs for a good life, freedom and choice, health, good social relations, and personal security. Poverty has been defined as “pronounced deprivation in well-being” (Millennium Ecosystems Assessment, 2003). Wellbeing can be measured in objective or subjective terms. The Human Development Index for example (HDI) uses objective measures, however a critique of this approach is that objective well-being indicators may be seen as too generalised or fail to account for psychological well-being (Mazur, 2011). Subjective measures of well-being, such as the OECD Better Life Index or the World Happiness Report are based on well-established psychological research and used internationally to measure wellbeing.

The concept of sustainable development is linked to democracy and participation, with key documents such as the Brundtland et al. (1987) promoting effective citizen participation and greater democracy in decision-making as means to attain greater social equity. Principle 10 in the Rio Declaration of 1992 (UNEP, 1992) on Environment and Development formulated the idea of citizen participation and following the Earth Summit 1992 and Agenda 21 recognised the need for the broad participation of the public in order to successfully implement sustainable development strategies from local to national level (Agenda 21, Chapter 8 & 28).

On the theme of contribution to wellbeing, neither subjective nor objective indicators for well-being are included in WEF-EAPI index. In previous reports for the WEC index, some objective measures of wellbeing were included in previous years such as quality of education, quality of health and cost of living expenditure, but these are not used in the final calculation of the index scores. However, in 2016, following a change in methodology, the index no longer includes these indicators and instead includes country context indicators on effectiveness of government, political stability; perception of corruption; transparency of policy making; rule of law; regulatory quality. Whilst these indicators may be related to national wellbeing in general, they do not measure the impact of energy development on wellbeing. Within the IAEA-EISD, objective measures of wellbeing are included in the Health theme, relating to safety in the energy sector.

The interviewees cited a major concern for energy development in Iceland as the need for implementing effective and legitimate, socially acceptable decision-making methods for energy planning. All interviewees acknowledged that public participation was essential to gaining public acceptance for geothermal projects, as well as for improving the entire development process. However, the interpretation of the meaning of public participation differed widely. Some interviewees believed that governments should have the final say in the choice of energy projects whereas others believed that the public should be involved to a much greater extent in the choice and design of energy projects.

In Iceland, geothermal resources may be located beneath or next to national park zones. The Icelandic landscape is characterised by a lack of trees or vegetation, meaning that views are unobstructed for many kilometres in all directions. Geothermal plants have a visual impact on the landscape through the building of structures and visible pipelines and emitting plumes of steam. Particular concerns have therefore arisen among the public (Benediktsson, 2007) and experts (Thórhallsdóttir, 2007) regarding the impact of geothermal energy development on geology and hydrology, unique landscapes and wilderness, given the unspoilt nature of the countryside and its value to tourism. In Iceland, a process to draw up a master plan was started in 1999 in order to make decisions on where to develop geothermal resources and this takes into account protected areas. Comments and concerns from stakeholders have been sought and considered during the master planning process although a deliberative process was not used with members of the public (Thórhallsdóttir, 2007). Energy projects in Iceland are subject to environmental impact assessment (EIA) and EIA law calls for public involvement at various stages of the process, however, criticisms of this system in the past have related to the lack of regulation regarding requirements for public participation in EIA, adequately informing the public on environmental issues and their right to participate and the fact that EIA is not a decision-making tool in itself but a means of gathering information (Ogmundarson, 2009).

On the theme of wellbeing, Icelandic interviewees were able to point out many examples of how, in particular geothermal energy, has contributed to wellbeing in the past and present and how this should continue in the future so that Icelandic society can continue to prosper. Geothermal energy was described as contributing to both physical and psychological wellbeing due to its numerous benefits e.g. by reducing the emissions from coal and improving air quality and the restorative and therapeutic properties of geothermal waters which have been recognised for centuries. Locals and tourists enjoy the benefits of direct use geothermal bathing pools. One famous example is the Blue Lagoon spa, using the waste-water from nearby Svartsengi geothermal plant. Its clientele includes psoriasis patients who come to take advantage of the curative properties of the water's chemical composition. Most households in Iceland now enjoy affordable geothermal space heating and communities enjoy other benefits of geothermal energy such as under-path heating for snow melting in winter, all of which contribute to the nation's quality of life, even though this may not be measured directly at the moment. Interviewees had fewer such examples to offer in the case of hydropower, since it does not have multiple uses like geothermal. With regard to the wellbeing of future generations, interviewees mentioned the importance of using geothermal resources so that they are not depleted for future generations, which would require properly defining what is meant by “sustainable yield” for geothermal resources. Table 3 shows the indicators in each of the three indices that relate to energy's contribution to wellbeing, along with their relevance to measuring sustainable energy development and the Icelandic case.

Only the EISD indicators included an indicator on wellbeing, *Accident fatalities per energy produced by fuel chain* (SOC4). In terms of safety in the energy sector, fatalities in the energy sector in Iceland are not a large concern and little data is available for accidents in the energy sector in Iceland. Only data on total deaths in the country is available. A recent study on the risk of accidents in the energy sector found that accidents were most frequent in wind energy development, accounting for almost one third of accidents, whereas accidents at hydroelectric dams were the most fatal, accounting for 85% of fatalities. Nuclear power accidents are by far the most expensive, accounting for 70% of damages (Sovacool et al., 2015). In terms of fatalities, hydropower was shown to carry the most risk, whereas the risk for geothermal energy was non-existent (Sovacool et al., 2015). This implies that for Iceland, hydropower safety is probably of most concern, and data should be collected for this.

More direct and subjective wellbeing impacts arise from energy development than are currently being measured by the WEC and WEF indices and the EISD indicators. As Iceland is ranked among the countries with the highest level of human welfare in the world, as per the HDI index (UNDP, 2015), which uses objective measures of wellbeing, it would therefore be of more interest to measure psychological wellbeing in Iceland, with a focus on the impact of energy development, both positive and negative. The measurement of public perception in terms of participation levels would also be of interest for the Icelandic case.

## Summary and conclusion

In this study, we evaluated the indicators of the WEF-EAPI and WEC-ETI indices and the IAEA-EISD indicator framework for suitability for measuring sustainable energy development. Table 3 summarises the evaluation, grouping the indicators into the themes of sustainable energy development[5] and includes a summary of the suitability of the indicators to the Icelandic case. Finally, Table 4 summarises the Icelandic challenges to sustainable energy development which were discussed in detail in Discussion: suitability of the selected indices for measuring national energy sustainability section.

As noted by Russell and Thomson (2009), whilst organisations such as the WEC and WEF may declare promoting sustainable energy development to be part of their raison d'être, its meaning may differ very much from organisation to organisation and indeed from nation to nation. This is shown in the way the WEC and WEF treat for example, the themes of energy affordability and equity and environmental sustainability. The WEC or WEF indices address energy access, an issue mainly of concern in poorer countries, but neglect the issue of energy equity and affordability at household level. Environmental sustainability is limited mainly to GHG emissions or energy intensity. The WEF-EAPI does not consider the efficiency of energy generation, all transportation types (only automobiles) and end use, whereas the IAEA-EISD does. Renewable energy usage is not directly measured at all by the WEC-ETI index, whilst the WEF-EAPI includes renewables and nuclear in the same indicator, a potentially controversial statement, that might be seen as advocating energy policies without adequate consideration for unique national circumstances. For example, around three years after the Fukushima disaster, with approximately 140,000 people still living as evacuees, Japan released a new energy strategy with a focus on increasing renewables or alternative sources of energy. After Fukushima, international organisations such as IAEA (IAEA, 2010; IAEA, 2012) also predicted a decline in nuclear generation[6].

The micro or macroeconomic impacts of energy development are not clearly captured by any of the three indicator sets, nor are the various potential environmental impacts of different energy types. This is an example of the scalar mismatching that can occur when indexes fail to account for fine-grained spatial information and regional specificities. The IAEA-EISD Index provides the most comprehensive coverage of environmental impacts of all three organisations, but even then, does not provide indicators for each and every type of energy that could be used. All three sets of indicators provide measures of energy security but these may not be appropriate for measuring the varied short to long-term risks and uncertainties in different nations. For example, if energy imports are used as a measure of insecurity, this does not take into account differences in political relations between countries, or geographical factors. van Zeijl-Rozema et al. (2011) hence argue that the implementation of sustainable development policy, and the development of associated indicators, on sub-national scales makes more sense, given the need to understand sustainability challenges on the territorial or regional level and implement appropriate strategies. By implementing sustainability policies locally or regionally, the superimposition of generic global approaches, which may not be suitably aligned with regional needs or institutional capacities, may hence be avoided (Renn et al., 1998).

The reasoning behind the assignment of weights for the indices of the WEC and WEF is not provided in any of their publications. Without

[5] Within the indices themselves, the indicators are grouped differently.

[6] Between 2010 and 2012 the projections of the IAEA dropped from 546 to 803 GW (IAEA, 2010) of nuclear generation capacity by 2030 to 456-740GW.

adequate transparency, indices risk losing their legitimacy in the eyes of the public, since they could be said to obscure certain items of information and to report others Russell and Thomson (2009). van Zeijl-Rozema et al. (2011) discourage the use of aggregate or composite indices since these assume that a complex system can be reduced to a single metric, which masks the many complex functions within a system and neglects other qualitative aspects.

Despite its recognition in the literature (Costanza et al., 2007) as being the end game of sustainable development, the theme of wellbeing is neglected by the three organisations. Apart from one indicator on health and safety in the IAEA-EISD set, neither objective nor subjective wellbeing are assigned explicit indicators by any of the three organisations. Additionally, a lack of clarity on the methodology behind the WEC-ETI index in particular makes it difficult to determine the rationale behind its current indicators. Since we have identified public participation in energy decision-making as an important sub-theme of wellbeing in Iceland, we propose that a more participative approach be taken in order to develop indicators for sustainable energy development. Whilst definitions of local sustainable development are likely to be conflicted, there is furthermore little consensus with regard to the correct methods for integrating scales in sustainability assessment. Whilst Renn et al. (1998) plead the case that existing regional political structures may be able to better integrate sustainability into their policies, Howlett and Ramesh (2014) argue that non-hierarchical governance modes may be more favourable than traditional hierarchical modes, since the latter are unsuited to addressing sustainability problems, which tend to be cross-sectoral or have multiple actors involved, making them difficult for hierarchies to handle. Hence 'network governance' or 'collaborative governance' arrangements may be better since they combine the best of both governmental and market-based alternatives by bringing together key public and private actors in a policy sector in a constructive and inexpensive way.

van Zeijl-Rozema et al. (2011) argue that it may be possible to compare between regions even if they have different indicators, as long as the indicators were developed using the same methods. They argue that comparison in this way is acceptable due to the need to take into account regional specificities. They explain weak and strong comparability in the context of sustainability assessment, stating that sustainability assessments can never have strong commensurability. Weak comparability can be operationalized through other means, such as multi-criteria evaluation. The solution offered is to measure sustainability through indicators that are tied to dynamic models and by using a variety of tools to measure sustainability in order to have visibility of all components, both qualitative and quantitative. Indicators such as those published by the WEC and WEF remain backward-looking since they lack the methodological transparency and necessary targets to allow them to be tied to dynamic models.

The authors realise that a full participative process would be necessary for the design of appropriate indicators for Iceland from local to national level. However, carrying out interviews with decision-makers serves as a preliminary step and serves to reveal at least partially the suitability of the indicators to the Icelandic national situation. In terms of their suitability and relevance to national circumstances, we found discrepancies with the indicators for each of the sustainable energy themes. Iceland is a developed country with modern energy infrastructure, based mainly on renewables, and universal energy access and relies on fossil fuels for a small portion of the energy mix. This situation has good prospects to be improved upon given the potential use of electric vehicles or hydrogen fuel cells in the fishing fleet, which would in turn improve energy security. Given that the country has potential to produce all of its energy indigenously, energy imports or exports have little relevance. The affordability of energy is well below the energy poverty threshold but given the high proportion of energy consumed by heavy industry in the country, there may be socio-ecological equity considerations that should be taken into account. The economic and financial viability of energy projects is of particular interest given the high risk level of geothermal developments, and need for careful resources management, for example. Certain environmental impacts arising from geothermal and hydropower, as well as more participative forms of decision-making around energy developments are relevant.

Energy access was not considered a major challenge in Iceland, since all households have access to electricity, geothermal heating or subsidised heating at the present time and the decision-makers drew attention to the fact that Iceland may rather be able to supply renewable energy to other countries. Access to low carbon fuels in sectors where they are not available is a more pressing concern. Whilst energy affordability is currently not a major concern for Icelandic households, decision-makers maintained that it is desirable that this continue to be the case into the future. In terms of energy equity, we believe that the equity of pricing between sectors (e.g. household vs. industry) is more of a concern in Iceland. With regard to energy security, energy independence for the transportation and fishing sectors is of greatest concern in Iceland. Furthermore, the sustained yield of geothermal resources is also considered to be an important challenge, an issue that overlaps with the financial viability of geothermal projects and the eventual affordability of energy supplied. With regard to efficiency, the focus on innovation in the geothermal sector is considered as a priority, as well as using geothermal energy for other uses apart from electricity and heating. We also believe that increased efficiency in the housing sector is important. Whilst renewable energy supplies much of Icelandic energy, the sustained yield of geothermal and indeed hydropower resources is a concern. Economic challenges are related to the macro and micro levels. The economic viability of energy projects was seen as important, and to a lesser extent, the further reaching systemic impacts of energy projects on other economic sectors. Decision-makers acknowledged the importance of avoiding environmental impacts from energy development as much as possible, as well as the need for a clear policy for energy and climate change. To this end, it was proposed that having a systems perspective was very important. In the interviews, much emphasis was given to the well-being benefits brought about from energy development in Iceland, particularly geothermal energy. However, the negative impacts on well-being (e.g. visual or landscape impacts) were neglected, as was the contested debate surrounding the development of previously unexploited areas. Nonetheless, the need for better decision-making methods around energy development was acknowledged, as this would likely lead to more socially acceptable energy projects. Interviewees did not agree, however, on the extent to which the public should be involved in energy policy making. Table 4 provides a summary of the main challenges categorised by sustainable energy theme.

## *Conclusion*

In this study, we evaluate the suitability of two recently published energy-focused indices and one indicator framework for measuring the sustainable energy development of an individual nation, using Iceland as a case-study. We identify challenges of sustainable energy development for Iceland by carrying out interviews backed up by literature review. We found that the published indices of the WEC and WEF do not facilitate effective measurement of progress towards sustainable energy development for individual nations.

The interpretation of sustainable energy development inherent in these indices or frameworks may be at odds with national or regional definitions and therefore may not be an appropriate measure for any nation, regardless of whether the indices allow comparisons and ranking across nations. We identified major sustainable energy development themes in the literature, and whilst we recognise that country interpretations will also differ for each theme, important issues relating to energy affordability, equity, environmental sustainability, efficiency, energy security and renewables are neglected by the indicators of each index or framework, although it should be said that the IAEA indicators are more comprehensive in their coverage of energy efficiency, renewables and environmental sustainability. The theme of wellbeing is almost completely neglected by all three of the organisations. The indices published by the WEC and WEF, furthermore, lack methodological transparency hence weakening their overall credibility and legitimacy. The indicators of each of the indices or framework fail to capture micro or local impacts that are crucial to sustainable energy development (e.g. project financial viability) and instead focus on macroeconomic indicators (such as cost of energy imports) whose causal relationship to energy development is much less apparent.

The structure of the indices and weightings applied therein make them unavoidably normative and because of this, could hijack or distort the sustainable development governing process if they were to be used as the sole guideline for country energy performance without regard for national circumstances. In some cases, the indicators are not theoretically sound. For instance, the indicators relating to affordability within the WEC and WEF indices are not clear measures of affordability since they do not measure prices of energy compared to any reference values, nor do they measure affordability for households. The level of price distortion is not a valid measure of affordability since it is not clear what impact it will have. The WEF-EAPI uses GDP as a unit to measure energy intensity which is not scientifically robust since GDP per unit energy may be impacted by a myriad of factors. Another example is the indicator for diversity of energy sources used by the WEC, WEF and EAPI, but it has been argued that this is not a reliable measure of energy security.

Indicators need to take account of the unique information needs of policy-makers for a given country, but as we have shown, the indicators of the WEF and WEC indices and the IAEA framework fail to capture the concerns of Icelandic decision-makers and national or regional specificities such as the unique Icelandic energy mix of mainly geothermal and hydropower for electricity and heating; the unique environmental challenges; the structure and small size of the economy and the high standard of living in the country. Individual indicators within the WEC and WEF indices or those proposed by the IAEA in their EISD indicator set may be useful for some countries but only if they are applied within a meaningful policy-relevant context. By identifying the limitations of indicators, indices and frameworks, and by examining the indicators in light of these and the criteria for good indicators as recommended by the OECD and IISD, we contribute to the discussion on the value and validity of indices and indicator framework. Knowing the potential pitfalls of indices and indicator frameworks, we are in a better position to design a more effective measurement tool. As well as this we present a set of general, high –level themes of sustainable energy development, which gives a loose framework within which customized indicators could be placed, according to the needs of a nation.

Much care needs to be taken therefore when choosing and using indicators, due to their potential shortcomings and limitations. This study shows that there is a need for extensive analysis of the country's energy circumstances before appropriate indicators can be chosen and that the design of indicators requires the input of multiple actors, and should include local and lay knowledge. Such indicators need not be identical between each locality but should cover essential themes of sustainable energy development and should lend themselves to being used in models and multicriteria evaluations. Hence both qualitative and quantitative indicators are possible. We propose that the development of a more comprehensive, multi-level, context-specific indicator framework is more appropriate for measuring national energy sustainability in Iceland. To accomplish this, a transparent and participative process will be necessary and should be carried out at all scales. Since few frameworks exist to deal with assessment on the regional or local scale (Graymore et al., 2008), or to harmonize local and national scale assessment (van Zeijl-Rozema et al., 2011) our further work will contribute to this research topic.

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