energies

Article

A Conceptual Exploration of How the Pursuit of Sustainable Energy Development Is Implicit in the Genuine Progress Indicator

David Cook [1], Brynhildur Davíðsdóttir [2] and Ingunn Gunnarsdóttir [3,*]

[1] Faculty of Economics, University of Iceland, Sæmundargötu 2, 102 Reykjavík, Iceland; dac3@hi.is
[2] Faculty of Environment and Life Sciences, University of Iceland, Sæmundargötu 2, 102 Reykjavík, Iceland; bdavids@hi.is
[3] Landsvirkjun, Háaleitisbraut 68, 103 Reykjavík, Iceland
* Correspondence: ingunn.gunnarsdottir@landsvirkjun.is

Abstract: The Sustainable Development Goals (SDGs) represent a bridging point between the old, neoclassical, growth-based model of the economy and newer, emerging paradigms, such as the well-being economy. The importance of growth in Gross Domestic Product (GDP) is recognized within the SDGs, however, in addition, Target 19 of Goal 17 advocates the adoption of alternative measures of economic well-being. The Genuine Progress Indicator (GPI) has been found to be the indicator of alternative economic well-being most aligned with the SDGs. On the basis that increased, high-quality energy use leads to expanded macro-economic activity, as measured by GDP, this study conducts a conceptual exploration of the extent to which the pursuit of sustainable energy development (SED) can enhance GPI outcomes. Based on a recent Icelandic GPI study, a total of 46 SED themes were found to be linkable to 16 of its 39 sub-indicators, including 8 cost deductions and 7 benefit additions. The frequency of these was as follows: sustainable energy production (10), sustainable energy consumption (10), energy security (8), nature conservation (8), social benefits (7) and economically efficient energy system (3). The main implication of the study outcomes is that the pursuit of SED is likely to have considerable benefits in terms of fulfilling energy and climate policy, but also co-benefits with regard to the promulgation of economic and societal well-being, as reflected in the GPI. These outcomes, although applicable to Iceland, have ramifications for all nations who are simultaneously striving for greater economic prosperity, whilst tackling climate change and striving to deliver equitable, environmentally sound and resilient energy systems.

Keywords: economic well-being; energy; linkages; sustainability; sustainable development; trade-offs

Citation: Cook, D.; Davíðsdóttir, B.; Gunnarsdóttir, I. A Conceptual Exploration of How the Pursuit of Sustainable Energy Development Is Implicit in the Genuine Progress Indicator. *Energies* **2022**, *15*, 2129. https://doi.org/10.3390/en15062129

Academic Editors: Mircea Fuciu, Claudia Ogrean and Mihaela Herciu

Received: 7 February 2022
Accepted: 11 March 2022
Published: 14 March 2022

1. Introduction

The links between energy usage and sustainable human development have been widely discussed over the years [1–3], with the relationship reflected in the outcomes of well-being metrics such as the Human Development Index [4–7]. Increases in aggregate energy consumption and macro-economic growth, as measured by Gross Domestic Product (GDP), have also frequently been found to occur in tandem over the years [8–12]. There are flaws, however, in using GDP as a measure of well-being, and although energy consumption may be a driver of its expansion, this does not necessarily occur sustainably [13,14]. However, very few studies have explored potential relationships between pursuing sustainable energy development and impacts on alternative measures of economic well-being that seek to correct for GDP's deficiencies.

In recent times, the United Nations' World Energy Assessment report [2], the Millennium Development Goals [13] and the Sustainable Development Goals (SDGs) [14] have been prominent in gradually shifting the focus of policymakers from expanding energy consumption, with little consideration of the external costs, to sustainable energy development (SED) [15–17]. Sustainable energy development is "the provision of adequate energy services at affordable cost in a secure and environmentally friendly manner, in conformity with social and economic development needs" [18], p. 1. One study opined that "SED has become an international policy objective reflecting the various challenges facing modern energy systems, such as depleting fossil fuel sources, increasing energy consumption, and climate change" [15], p. 1. The concept is undoubtedly fundamental to the fulfilment of the SDGs. SDG 7 (Affordable and Clean Energy) aims to ensure access to affordable, reliable, sustainable and modern energy for all [14]. The SED agenda is driven not only by the SDGs, but also by the targets set by the Paris Accord to reduce greenhouse gas emissions and tackle climate change [17]. Extensive linkages were found between the pursuit of SDG 7 and the targets across all SDGs, finding 143 synergies and 65 trade-offs [19].

The SDGs also represent a bridge between older, growth-focused macro-economic models and new approaches which are more cognizant of human well-being [20,21]. On the one hand, the SDGs continue to recognize the importance of GDP growth, with SDG 8 (Decent Work and Economic Growth) requiring all nations to sustain per capita economic growth in accordance with national circumstances [14]. However, on the other hand, Target 19 of SDG 17 (Partnerships for the Goals) requires nations to develop measures of progress on sustainable development that can complement gross domestic product [14]. With regard to economic well-being, alternative measures of economic well-being are one such tool for this purpose [20,22]. Macro-economic indicators of economic well-being have been regularly recommended in recent decades [23–27]. Coscieme et al. (2020) voiced that "measuring progress towards SDG 8 needs to consider further macro-economic indicators that internalize social and environmental externalities" [23], p. 6, which is a major objective of most alternative measures of economic well-being. A recent study by [20] found that the Genuine Progress Indicator's (GPI) calculation methodology was closely aligned with the SDGs. Its cost and benefit components could be linked to targets within fourteen of the seventeen SDGs, a greater frequency than was evident with other indicators of economic well-being, including GDP, the Measure of Economic Welfare, Genuine Savings and the Inclusive Wealth Index. SDG 7 (Affordable and Clean Energy) was one of the fourteen SDGs that demonstrated alignment [20].

Various studies have explored the relationships between GDP, renewable energy and pollutants, particularly greenhouse gas emissions [28–30]. However, studies examining relationships between energy and alternative measures of economic well-being are relatively rare. The work of [31] calculated the relationship between 'green GDP' and energy consumption for thirty-six European nations over the period 2008 to 2016, finding a statistically significant relationship between levels of renewable energy utilization and increases in green GDP. A measurement of China's green GDP and its dynamic variation was undertaken, determining that the ratio of green GDP to GDP increases from 89.85% to 95.83% over the period 2005–2017 due to relative decoupling [32]. Another study provided a conceptual evaluation of how the unsustainable use of geothermal energy resources could be accounted for in the GPI [33]. These, though, are limited studies that do not capture the economic, environmental and social dimensions of SED.

As far as the authors are aware, no studies have attempted to assess, either conceptually or quantitatively, the extent to which the SED concept is implicit within alternative measures of economic well-being, such as the GPI. Energy development has been shown to be linked to expansion in GDP and some limited measures of green GDP, but the question remains: to what extent is sustainable energy development relevant to outcomes in alternative measures of macroeconomic performance, such as the GPI? The main aim of this study is to undertake a conceptual exploration of the extent to which the pursuit of SED themes can affect GPI outcomes, all other factors being equal. Data from the Icelandic GPI study [34] is used to provide simple illustrations of the likely links between SED dimensions and cost/benefit components in the GPI. The reason for focusing on the Icelandic GPI are as follows:

(a) The nation has largely embraced SED and transformed its economy from one based on fossil fuels to renewable energy resources [17,35–37];
(b) A recent GPI national dataset for Iceland has been compiled by [34];
(c) The GPI study [34] is the first national assessment completed using the GPI 2.0 methodology advocated by [38], which constitutes a transition towards a more standardized approach to its calculation.

With regard to (a), the uniqueness of Iceland's isolated energy system makes it an interesting case study, both in terms of its contribution to economic well-being and SED. Despite the nation's very high share (currently 90%) of domestic renewables in primary energy use [39], there remain considerable challenges to be overcome on the pathway to SED related to the decarbonization in the transportation and maritime sectors [35–37,40,41].

This paper is structured as follows. Section 2 provides a more detailed overview of the core concepts in this paper: SED and its underlying themes, the well-being economy and its capital asset foundations, and alternative measures of economic well-being. Section 3 details the paper's methodology, providing a summary of the GPI 2.0 method that was applied in the Icelandic GPI study by [34] and describing how the Icelandic SED themes were determined by [16,42]. Section 4 provides a combined results and discussion. It first describes the results of the conceptual exploration, summarizing the theoretical overlap between the SED concept and GPI calculation method, illustrating the likely positive and negative impacts on the GPI's monetary outcomes. The policymaking and practical implications of the study, both domestic and international, are then discussed. Section 5 sets out a brief conclusion and management implications.

2. Theoretical Overview

2.1. Conceptualization of Sustainable Energy Development

When defining and calling for indicators for the purposes of measuring progress towards SED, the IAEA/IEA depicted the concept as a series of interrelationships between three core states: economic, environmental and social [18]. Driving forces from the economic dimension caused impacts to the environmental and social state, with the three sustainability dimensions influenced by various institutional decisions, policies and regulations. In the period subsequent to the envisioning of SED as a series of interlinkages between 'states' and general influence by governance forces, there was the emergence of thematization of the SED concept [43], which has nowadays progressed in importance to the point that it constitutes a core objective of global-scale initiatives, such as via Goal 7 of the SDGs. The increased significance of SED has once again reinforced the importance of national energy sustainability performance analysis [44] and the development of analytical tools for this purpose, especially indicators [15,40,45].

The recent work of [16] has further advanced understanding of the thematic dimensions of SED and its interrelationships. In this study, SED was depicted as a series of uni- and bi-directional flows between four interrelated and overarching themes: access to affordable modern energy services; sustainable energy supply; sustainable energy consumption; and energy security. In much the same way that SDG 7 is just one of seventeen SDGs, SED is shown as an objective that underlies the overall fomentation of sustainable development. Derived from a systematic literature review and thematic analysis, the four interlinking strands of [16] clearly hark back to the definition of SED outlined by the IAEA/IEA (2001). Although this depiction implies rather than renders explicit the economic, environmental and social states discussed by [18], refs. [15,16] explain that these are embedded supply and demand-side facets of SED. A sustainable energy supply is a pre-requisite of sustainable development, and a necessary characteristic for energy security but it is insufficient on its own. Energy security is one element in sustainable energy consumption, which often requires expanded supply and energy efficiency measures in order to constrain upward pressure on energy consumption. A sustainable energy supply is needed to enable broad access to energy services, and this needs to be delivered at the lowest possible environmental and social cost, thus ensuring that the human well-being benefits of energy are maximized, with the disservices minimized. There are evident trade-offs between and within the pursuit of the respective themes—for example, a reduction in fossil fuel dependency due to an increased supply of energy from renewable resources could potentially increase the sustainability of energy supply; however, the intermittency of many renewables entails the risk of undermining energy security. Satisfying a need for an expanded energy supply might require an expansion in fossil fuel production, putting in peril the environmental and health components central to two themes: sustainable energy supply and access to affordable modern energy services.

Following the identification of the four overarching themes, a set of SED indictors for Iceland has been developed following extensive stakeholder consultation involving stakeholder mapping, semi-structured interviews and focus groups, as well as a Delphi survey [40,42]. Stakeholder consultation revealed six themes specific to the Icelandic context: nature conservation; social benefits; energy security; economically efficient energy system; sustainable energy production; and sustainable energy consumption. The differences between the four overarching themes of SED in [16] and the six identified as being specific to Iceland in [40] are that the national context placed more emphasis on the issues of nature conservation and social benefits. The six Iceland-specific themes were used in the conceptual exploration with respect to the identification in aim (2). The scope of the six themes is set out in Table 1 below, with the core features articulated by participants during the stakeholder consultation and Delphi survey discussed in [15,16,40].

Table 1. SED themes in Iceland and respective scope (adapted with permission from [40]).

SED Theme	Scope and Core Features
Nature conservation	➢ Protecting nature and wilderness from future energy development. ➢ Minimizing environmental impacts of energy production and distribution. ➢ Visual pollution of the energy system to be minimized.
Social benefits	➢ Long-run local benefits to communities—job creation, socially beneficial initiatives and infrastructure upgrades. ➢ Public participation in decision-making and policy development as an underlying aspect of public acceptance and a social license.
Energy security	➢ Increased diversity of energy resources utilized, including an energy transition from imported fossil fuels to domestically produced renewables. ➢ Sustainable utilization of resources. ➢ Strengthening the transmission and distribution system.
Economically efficient energy system	➢ A profitable energy supply through appropriate investments and technological advancements. ➢ Economic incentives to transition towards SED, e.g., taxes on fossil fuels and subsidies on renewables. ➢ Increasing diversity in consumption and maintaining affordable energy prices for households.

Table 1. *Cont.*

SED Theme	Scope and Core Features
Sustainable energy production	➢ Minimizing the environmental impacts of production, including emissions of carbon dioxide and air pollutants. ➢ Increased focus on carbon sequestration and carbon capture and storage. ➢ Sustainable utilization of renewable resources.
Sustainable energy consumption	➢ A reduction in overall energy consumption and increase in energy efficiency. ➢ Minimizing the environmental impacts of consumption, including emissions of carbon dioxide and air pollutants. ➢ Greater awareness of the harmful impacts of energy consumption—changing government and public attitudes as a necessary feature of an energy transition.

2.2. Well-Being Economy and Capital Asset Foundations

In recent times, there has been deeper focus on not only the productive capacities of economies but their capacity to support human well-being. Considerable work has gone into the conceptualization of the well-being economy, including the development of frameworks which seek to identify its capital asset foundations. Three pillars of economic well-being have been identified: material living conditions, quality of life and sustainability [46]. Referencing the three pillars, [47] outlined five core objectives of the well-being economy, summarized as follows: (1) stay within planetary boundaries; (2) meet all fundamental human needs; (3) create and maintain a fair distribution of resources, income and wealth; (4) have an efficient allocation of resources, including common natural and social capital assets; and (5) create governance systems that are fair, responsive, just and accountable.

Building on these conceptual foundations, various well-being economy frameworks have been developed by nations seeking to evaluate progress using more nuanced metrics than GDP. New Zealand's Living Standards Framework provides a recent example, a plan that places the importance of maintaining and enhancing human well-being at the heart of government policymaking. A capital asset framework underpins twelve domains of well-being: civic, engagement and governance; cultural identity; environment; health; housing; income and consumption; jobs and earnings; knowledge and skills; time use; safety and security; social connections; and subjective well-being. A dashboard of 61 well-being indicators are then connected to the twelve domains [48]. Other nations have been following suit—in September 2019, Iceland published a set of 39 well-being indicators [49], subsequently approved by the government in April 2020, and Scotland has identified the well-being economy as a national priority and one of its key strategic objectives in the recovery from the damages of the COVID-19 pandemic [50,51].

2.3. Alternative Measures of Economic Well-Being

Alternative measures of economic well-being have been developed in response to widespread recognition of the limitations of GDP as a measure of economic well-being [23,52]. GDP is a measure of aggregate economic output, focused overwhelmingly on market-based production, although inclusive of non-market aspects such as government expenditure on healthcare and the military [53,54]. However, many non-market components of economic well-being are excluded, including the value of volunteer work and parenting. Additionally, the calculation of GDP regards the costs of negative externalities as benefits—for instance, the clean-up costs of pollution or the impacts of crime [53,55,56].

Such flaws in GDP have led to the advancement of several alternative measures of economic well-being. These are typically classified according to how they differ from GDP, specifically the extent to which they either supplement or adjust its calculation [20,52].

Supplementary indicators often complement GDP with enhanced information on societal and environmental conditions, or examine GDP alongside other environmental, economic and social indicators [57]. This is akin to the approach of New Zealand in their development of well-being indicators and related budgets. Indicators seeking to adjust GDP are ones which monetize externalities [58,59], both the positive and negative aspects unaccounted for in the System of National Accounts used to calculate GDP. Sometimes these are referred to as corrective indicators to GDP [53] or green accounting approaches [52]. The latter also embrace stock and asset-based measures of economic well-being, including the UN's System of Environmental and Economic Accounting [60].

Reference [52] charts the historic development of alternative measures of economic well-being, finding a large assortment of metrics. Some have become more popular and widely adopted than others. A recent assessment was conducted on the extent to which five alternative measures of economic well-being have direct links to targets in the SDGs. This assessment included the Environmentally Adjusted Net Domestic Product (EDP), Measure of Economic Welfare (MEW), Genuine Savings (GS) (also known as Adjusted Net Savings), Genuine Progress Indicator (GPI) and Inclusive Wealth Index (IWI) [20]. These measures all use a monetary metric for estimating the economic value of sub-components and aggregation, which means that they constitute adjusting rather than supplementary approaches and their outcomes can be compared to GDP.

It was found that the GPI had the greatest number of links to the SDGs, covering fourteen of the seventeen SDGs [53]. The GPI has been defined by [38], p. 142, as "a monetary measure of economic welfare for a given population in a given year that accounts for benefits and costs experienced by that population in association with investment, production, trade, and consumption of goods and services". A capital-asset approach is applied to the various flows of well-being benefits, grouping 'services from essential capital' into human, social, built and natural capital [20]. Financial capital is already included within market-exchange value, so it is excluded in order to avoid the potential double counting of benefits. With regard to the capital asset framework of the well-being economy set out in Table 2, physical capital is synonymous with the built capital term used by [38].

Table 2. GPI calculation components in equation (1). (Reprinted with permission from ref. [34]. Copyright 2021 Elsevier).

Theoretical Component	Utility from Consumption of Goods and Services	Utility Sourced from Essential Capital	Disutility Linked to Undesirable Environmental and Social Conditions
Functional form	$U_i((HBE_1 - DEFR - HI_i) \times INQ + PP)_i$	$U_i(s(KH_i + KS_i + KB_i + KN_i))$	$dU_i(DKN_1 + POL_i + SC_i)$
Sub-category	HBE = household budget expenditures DEFR = defensive and regrettable expenditures HI = household investments INQ = inequality adjustment PP = public provision of goods and services	s = services KH = services from human capital KS = services from social capital KB = services from built capital KN = services from natural capital	DKN = depletion of natural capital POL = pollution SC = social costs of economic activity

3. Methodology

A conceptual assessment was conducted concerning the extent to which the GPI's calculation methodology includes SED themes. Each of the cost and benefit components in the GPI were reviewed in turn. The full details of the calculation methodology for the Icelandic GPI, on which this analysis relies, are provided in the Appendix A (Table A1). A summary of the GPI's calculation procedure is set out in equation (1) and Table 2. In this paper, the GPI 2.0 methodology is referred to, which differs slightly from earlier versions and aims to have a coherent capital asset framework as a basis for its calculation components. In equation (1) [38], for a given time period and population, the GPI aggregates net utility from consumption of market-based goods and services to utility from essential capital, then deducts disutility linked to undesirable social and environmental conditions.

$$GPI_t = \frac{1}{N}\sum_{i=1}^{N}[U_i((HBE_1 - DEFR - HI_i) \times INQ + PP)_i + U_i(s(KH_i + KS_i + KB_i + KN_i)) - dU_i(DKN_1 + POL_i + SC_i)] \quad (1)$$

where: U is utility (welfare gains), dU is disutility (welfare losses), i denotes an individual, N is number of individuals in a population, and t is time period of a year.

The conceptual exploration focused on two aspects: (1) whether there was a direct or indirect link, between the respective cost and benefit components in the GPI and the concept of SED leading to either increases or decreases in the GPI; and (2) identifying which of the six SED themes for Iceland could be related to any direct or indirect linkages between the GPI and SED. In relation to (1), when analyzing the Icelandic GPI's data inputs and considering whether the pursuit of SED would lead to increases or decreases in the GPI, the principle of ceteris paribus applied. Direct links were considered to apply when the pursuit of the various objectives in the SED themes could have a monetary impact on a GPI cost or benefit component. Indirect links were deemed by the authors to be secondary effects occurring in relation to the pursuit of SED, e.g., more research and innovation to advance a theme's objectives.

4. Results and Discussion

4.1. Summary Evaluation

The outcomes of the conceptual exploration are presented in Table 3. These link together the capital asset dimensions and calculation components of the Icelandic GPI [34] with the six SED themes for Iceland identified by [16]. The SED theme and increase-decrease columns are grey-scaled where specific GPI calculation components are deemed to be irrelevant in the context of SED.

Table 3. SED and GPI overlap.

Sub-Indicator	Type of Capital	Operation	SED Theme(s)	Direct or Indirect link	Likely Decrease or Increase in GPI
Household budget expenditures (HBE)	Financial	Addition	Sustainable energy consumption Sustainable energy production Economically efficient energy system Energy security	Direct Direct Direct Direct	Decrease Increase Increase Increase
Costs of food waste Insurance Welfare neutral goods Costs of family changes Costs of maintaining dwelling services	Human Financial Human Human/Social Built	Deduction Deduction Deduction Deduction Deduction	Economically efficient energy system Energy security	Direct Direct	Decrease Decrease
Consumer durables Household repairs and maintenance Goods and services for household repairs and maintenance	Built Built Built	Deduction Deduction Deduction			
Income inequality adjustment (INQ)	Financial	Deduction			
Education Healthcare Local government services External benefits from higher education	Human Human Human and social Human	Addition Addition Addition Addition			
Research and development	Human	Addition	Nature conservation Sustainable energy consumption Sustainable energy production Economically efficient energy system Energy security Social benefits	Indirect Indirect Indirect Indirect Indirect Indirect	Increase Increase Increase Increase Increase Increase

Table 3. *Cont.*

Sub-Indicator	Type of Capital	Operation	SED Theme(s)	Direct or Indirect link	Likely Decrease or Increase in GPI
Value of leisure time	Social	Addition			
Value of unpaid labour in the volunteering sector	Social	Addition			
Recreation, culture and religion	Social	Addition			
Community development	Social	Addition	Social benefits	Direct	Increase
Services from preserved nature	Natural	Addition	Nature conservation Sustainable energy consumption Sustainable energy production	Direct Direct Direct	No change Increase Increase
Value of transportation infrastructure	Built	Addition	Sustainable energy consumption	Direct	Increase
Value of energy and water infrastructure	Built	Addition	Sustainable energy production Energy security Social benefits	Direct Direct Direct	Increase Increase Increase
Waste treatment by sewer infrastructure	Built	Addition			
Housing development	Built	Addition			
Manufacturing	Built	Addition			
Construction	Built	Addition	Sustainable energy production Energy security Social benefits	Direct Direct Direct	Increase Increase Increase
Non-renewable resource depletion	Natural	Deduction	Nature conservation Sustainable energy consumption Energy security	Direct Direct Direct	Increase Increase Increase
Ozone depletion	Natural	Deduction	Nature conservation Sustainable energy consumption Sustainable energy production	Direct Direct Direct	Increase Increase Increase
Overharvesting of fisheries	Natural	Deduction			
Avoided depletion	Natural	Deduction	Nature conservation Sustainable energy production	Direct Direct	Increase Increase
External benefits from higher education	Human	Addition			
Air pollution	Natural	Deduction	Nature conservation Sustainable energy production Sustainable energy consumption Energy security	Direct Direct Direct Direct	Increase Increase Increase Increase
Climate change contribution	Natural	Deduction	Nature conservation Sustainable energy production Sustainable energy consumption Energy security Social benefits	Direct Direct Direct Direct Direct	Increase Increase Increase Increase Increase
Solid waste	Natural	Deduction			
Avoided damages	Natural	Deduction	Sustainable energy production Sustainable energy consumption	Direct Direct	Increase Increase
Unemployment	Social	Deduction	Social benefits	Direct	Increase
Overemployment and lost leisure time	Human	Deduction			
Crime	Social	Deduction			
Commuting	Human	Deduction	Nature conservation Sustainable energy consumption Social benefits	Indirect Indirect Indirect	Increase Increase Increase
Vehicle accidents	Social	Deduction			

4.2. Summary of SED and GPI links and Monetary Changes

The conceptual evaluation determines that there is overlap between SED themes and the GPI's cost and benefit components in 16 of the 39 sub-indicators (41.03%). In total, 46 SED themes were linked to the 16 applicable sub-indicators. The frequency of these was as follows: sustainable energy production (10), sustainable energy consumption (10), energy security (8), nature conservation (8), social benefits (7) and economically efficient energy system (3). GPI benefits likely to increase or stay the same included household budget expenditures and services from preserved nature. Pursuit of the SED themes that related to the minimization of environmental impacts could reduce costs in the Icelandic GPI in relation to air pollution, non-renewable resource depletion and climate change contribution.

Each of the aligned calculation components are now discussed in turn. Where data inputs and outcomes from the Icelandic GPI are referred to, these are all stated in constant 2019 prices. The respective cost and benefit components are highlighted in bold for ease of reference.

Four SED themes are likely to result in direct impacts on household budget expenditures in the GPI, two resulting in increases and one in a decrease. Sustainable energy production inevitably entails matching supply with the demand, which is an overlapping feature of energy security. An economically efficient energy system also involves increasing diversity in consumption, which also tends to increase overall consumption and related expenditure. However, pursuit of more sustainable energy consumption is likely to act as a constraining factor on energy consumption and related expenditures. This theme requires reductions in overall energy consumption. Overall, the recent evidence in Iceland suggests that energy consumption and related expenditure has been increasing. Total gross energy consumption in Iceland increased from 133,744 TJ (Terajoules) to 267,159 TH over the period 2000–2019 [61], which was the timespan for the Icelandic GPI study. This is effectively a doubling over a twenty-year period. Much of the expansion has been to satisfy the electricity demands of new heavy industry projects in Iceland [62], however, residential demand has also expanded due to population growth and the energy transition in transportation [37,63]. The Icelandic population has increased in number by 77,942, amounting to growth of 27.9% over the period 2000–2019 [64]. Household consumption expenditure on electricity and fuels, a component of the HBE in the GPI, increased from 19,499 to 32,228 million Icelandic krona (ISK) over the period 2000–2019, an expansion of 65.28% [34].

The economically efficient energy system theme involves maintaining affordable energy prices for households. This can be partially achieved by establishing a secure energy supply, which is efficient and reliable, thus reducing the need for households to incur costs of maintaining dwelling energy services. In the Icelandic GPI study, these costs never exceed ISK 16,844 million, approximating to a peak of 1% of aggregate HBE, but only a fraction of these costs are likely to relate to household expenditure on maintaining domestic energy services [34]. Electricity prices for households in Iceland are very low in comparison to other Nordic nations [65].

The research and development component in the GPI include annual government expenditure on fuel and energy-related studies [66]. This is a broad topic and has the capacity to embrace research across all SED themes, leading, indirectly, to increased benefits in the GPI. Research could focus on reducing pollutants caused by fossil fuel consumption in Iceland, thus likely contributing to the nature conservation theme as long as it did not lead to increased use of electricity. Investigations into more sustainable utilization of energy resources are necessary to advance the energy security theme, whilst research into technological advancements are important for the economically efficient energy system dimension. The sustainable energy production and consumption themes could be advanced subsequent to research on issues such as carbon capture and storage and energy efficiency, respectively. Social benefits could be progressed via analysis of the long-run benefits of research and development with respect to energy infrastructure enhancements, for example, grid strengthening and cascading use of energy resources such as the Reykjanes Geopark [67]. The overall extent of this benefit in the Icelandic GPI study was in the range of ISK 4471 to 11,171 million over the period 2000 to 2019 [34], always equating to less than 1% of HBE. This suggests that the scale of the relationship between the SED themes and this GPI benefit is currently negligible, even more so since the monetary benefit is not disaggregated and incorporates expenditure on several non-energy-related sectors.

Pursuit of the social benefits theme in SED entails the delivery of long-run benefits in terms of community development, including employment opportunities. Thus, this could translate in the GPI into increased government expenditure on local energy initiatives or economic projects that depend on the construction of new energy infrastructure, for example, projects such as CarbFix [68], Carbon Recycling International [35] and the Blue Lagoon [69]. In the Icelandic GPI, this benefit is not disaggregated and was in the range of ISK 357 to 635 million in the period 2000 to 2019 [34]. It is therefore currently negligible in scale.

In advancing the SED theme of nature conservation, and therein protecting nature and wilderness from future energy developments, there is the direct potential for the economic value of Iceland's services from preserved nature to be undiminished. The economic value of Iceland's ecosystem services, although lightly studied, could potentially be significant, to the extent that they exceeded GDP in a preliminary national estimate of their aggregate value using the benefit transfer method [22]. It is likely that retaining human well-being benefits from ecosystem services at their current level will necessitate the preservation of natural areas in Iceland, resources that would likely be impacted negatively by new energy projects. Previous economic studies have shown that the development of geothermal and wind energy power projects in Iceland, based on design proposals and likely environmental and socio-cultural impacts, could be welfare declining [70], whilst a willingness to pay and willingness to accept study provided evidence of the extent of public discontent concerning a hydropower development in the Icelandic highlands [71]. Pursuit of the sustainable energy production and consumption themes would lead to reductions in environmental impacts and have the potential to indirectly increase the quality of Iceland's ecosystem services, enhancing their overall economic value. In the future, the pursuit of sustainable energy production in Iceland is thought likely to involve less intensive harnessing of renewable energy resources, which would likely lead to lower greenhouse gas and hydrogen sulfide emissions [17,72] and thus enhance the pursuit of three SED themes: nature conservation, sustainable energy production and sustainable energy consumption.

The sustainable energy consumption theme of SED is linked to investments in public transportation infrastructure and installation of charging points for electric cars because such endeavors result in reduced fossil fuel consumption. Increased government expenditure on these types of issues will lead to greater benefits in the GPI. In the Icelandic GPI, these amounts were in the range of ISK 26,307 to 59,391 million over the period 2000 to 2019, albeit it is unclear how much of this expenditure related to investments in sustainable transportation infrastructure [34].

The value of energy and water infrastructure benefit component in the GPI includes government expenditures on electricity infrastructure, investments which will increase in tandem with the pursuit of the sustainable energy production, energy security and social benefits themes of SED. Total government expenditure on electricity infrastructure in the period 2000–2019 was in the range of ISK 1271 to 4069 million, negligible amounts in the context of overall GPI outcomes of between ISK 5,053,062 and 7,163,300 million [34].

The sustainable energy production, energy security and social benefits themes can be related to the construction benefit in the GPI. This value is very low in the Icelandic GPI, at never more than ISK 1000 million, and the amounts reported are only non-zero from 2016 onwards when no new Icelandic power plants or major energy infrastructure have been constructed. However, any future construction expenditure by the government on new energy plants would fall into this category [34].

Adherence to the nature conservation, sustainable energy consumption and energy security themes will result in reduced fossil fuel consumption in Iceland, leading to lower costs for non-renewable resource depletion. Although no fossil fuels are produced in Iceland, and thus this GPI cost is unrelated to the sustainability of energy production theme, consumption of non-renewable resources has increased considerably in Iceland in recent years. From consumption of 5,475,776 barrels of oil equivalent (boe) in 2010, Iceland's fossil fuel consumption increased to 8,058,381 boe in 2018. The replacement cost of non-renewable amounted to ISK 655 million in 2018 [34].

Pursuit of the environmental objectives in the SED themes of nature conservation, sustainable energy consumption and energy security will place downward pressure on the costs of ozone depletion. Although very low compared to the costs of air pollution and greenhouse gas emissions, Icelandic GPI's ozone depletion costs peaked at ISK 2296 million in 2018 and 2019 [34].

The GPI's costs of avoided depletion relate to the annual government expenditure on the protection of biodiversity and landscape. Pursuit of the nature conservation and sustainable energy production directly linked to this cost, which is likely to increase with SED.

The air pollution cost component has overlap with four SED themes: nature conservation, sustainable energy production, sustainable energy consumption, and energy security. Predominantly, the negative impacts of air pollution in Iceland relate to fossil fuel consumption, especially by the vehicular fleet. Annual premature deaths from air pollution in Iceland were in the range 33–49 over the period 2000–2019 [73]. These corresponded to GPI costs in the range of ISK 23,171 to 34,635 million [34]. In addition, this issue partly relates to externalities pertaining to production. Although only a mildly poisonous gas except in very high concentrations, there is some limited evidence that hydrogen sulfide emissions from geothermal power production may have led to additional mortalities, and it is difficult to separate these impacts from those deriving from fossil fuel consumption [74]. Additionally, this cost component relates to energy security, which also focuses on reducing the environmental impacts of the Icelandic energy system. The SulFix project at the Hellisheiði Geothermal Power Plant in Iceland reduces the potentially damaging health impacts of around 70% of hydrogen sulfide emissions by dissolving the gas in water and injecting it into bedrock [68,75].

The costs of Iceland's climate change contribution were in the range of ISK 55,718 to 73,343 million in the period 2000–2019, peaking in 2008 [34]. The GPI's cost component for Iceland's climate change contribution has similar conceptual overlap with the SED themes linked to the costs of air pollution, however, these also extend to the theme of social benefits due to its focus on technological advancements (such as carbon capture and storage) and knowledge creation. This is because energy production from Iceland's geothermal plants, especially electricity generation to serve heavy industry, contribute nearly 10% of the nation's greenhouse gas emissions, based on 2019 data [76]. This is much less than would be the case if a fossil fuel plant was used for this purpose, however, the aim of the sustainable energy production theme is to further reduce the environmental impacts of production. Novel approaches to the carbon capture of greenhouse gas emissions from geothermal power plants are currently being piloted and advanced in Iceland, foremostly via the CarbFix project at the Hellisheiði Power Plant [68,77,78]. Reducing consumption of fossil fuels and greater reliance on domestic production of alternatives, such as synfuels and e-fuels, will boost the sustainability of energy consumption, aid energy security and assist in fulfilling nature conservation objectives. Effluent carbon dioxide from the Svartsengi Geothermal Power Plant in Iceland is already used in methanol production, a synfuel [35].

Avoided damages are expenditures incurred by the government on pollution abatement. Pursuit of the sustainable energy production and consumption themes will result in reduced GPI costs, since there will be diminished need for the government to incur these expenditures. However, they are already a very insignificant component in the Icelandic GPI, only appearing as a non-zero entry once in 2001 [34].

Advancement of the social benefits theme in SED will facilitate job creation, helping to reduce the costs of unemployment, as has been evident in relation to Alcoa's Fjarðaál aluminum smelter in Iceland [79]. This has been the case in Iceland with advanced, innovative technologies, such as the aforementioned CarbFix and SulFix projects, and cascading use of geothermal energy resources.

Pursuit of SED is likely to have indirect benefits by reducing the costs of commuting in the GPI. These were estimated to be ISK 145,128 million in 2019, more than double their value at the start of the decade [34]. Improved and more efficient public transport services could reduce the number of people commuting to work by the private car, with spillover benefits for nature conservation, sustainable energy consumption and social benefits in SED.

4.3. Icelandic Policy, the Pursuit of SED and GPI Implications

The results of the study suggest that government policies targeting the advancement of SED themes are likely to lead to co-benefits in national economic well-being. This is because most of the alignments between SED themes and the GPI's costs relate to minimizing the environmental impacts of energy that is supplied and consumed, and the creation of social benefits. Current Icelandic energy and climate policy would appear to be very well aligned with SED objectives that would induce higher GPI outcomes, all other aspects of the GPI being equal. Iceland has the highest share of renewable energy among OECD member states and already generates 99.99% of electricity production and 84% of primary energy use from renewable energy resources [76]. However, the emphasis of national government policies is on further reducing reliance on fossil fuels [37], all of which are imported. This induces benefits applicable to several SED themes, including nature conservation, energy security, sustainable energy production, sustainable energy consumption and an economically efficient energy system.

Iceland's proposed new energy policy provides a national government strategy which aims to realize a sustainable energy future by the year 2050. Its eight envisioned features of a sustainable energy future correspond closely to the ambitions of SED, including several with direct overlap: renewable energy; energy efficiency, smart technology and diversity; benefits to society and consumers; nature conservation and minimized environmental impact; competitiveness and value creation; sound and resilient countrywide infrastructure; a secure energy supply; and energy transition and climate matters [37]. Several gaps are identified in terms of the performance of the Icelandic energy system in 2020. These include fossil fuel consumption on land, sea and air; limited efficiency in the energy market; the need for infrastructure development; discord regarding development and benefits; unequal access to energy and infrastructure; and an uncertain energy supply [37].

Reducing fossil fuel consumption contributes to the sustainable consumption theme of SED in an Icelandic context. Increasing efficiency in the energy market will assist in the pursuit of an economically efficient energy system. Expanding infrastructure development will boost the sustainability of energy production and energy security. Overcoming concerns about the distribution of benefits and access to energy and infrastructure relates to the social benefits and energy security themes of SED. Addressing an uncertain energy supply will involve improvements to energy security, potentially also enhancing the sustainability of energy production. The simultaneous pursuit of these objectives is likely to induce several GPI benefits, most likely involving reductions in the environmental costs of energy production and consumption. Benefits will likely involve reduced air pollution from fossil fuel consumption, especially particulate matter, reduced depletion of non-renewable resources and a reduced contribution to climate change from fossil fuel consumption by the vehicular fleet, ships and domestic aviation. Although an expanded energy supply would be likely to boost the GPI's consumption component, some trade-offs might result, such as a drawing down on provisioned ecosystem services and diminishment in visual aesthetics due to the erection of new transmission lines. The latter could be mitigated in the future through subterranean transmission lines. This would reduce the economic value of the benefits from ecosystem services in the GPI's calculation. On this subject, there is currently a vigorous ongoing debate in Iceland about the establishment of a new national park in the Central Highlands, an initiative that could greatly reduce available opportunities to develop new energy infrastructure [80–82]. In addition, plans to considerably expand electricity production from wind energy are advanced; however, unlike for geothermal energy or hydro power, there is currently no regulatory framework for assessing the sustainability impacts of proposed wind farms.

Iceland's climate policy is very closely aligned with its energy-related ambitions. This sets out several targets that the Icelandic Government intends to meet in the coming years. These include a 29% reduction in greenhouse gas emissions by 2030 compared to a 2005 baseline in order to contribute to the EU's fulfilment of the Paris Agreement; a 10% renewable energy share in the maritime sector by 2030; and the pursuit of carbon neutrality by 2040 [36]. Key measures in the pursuit of the latter objective include expanding the supportive infrastructure and number of electric vehicles, increasing electrical infrastructure at ports, banning the use of heavy fuel oil and increasing carbon capture from geothermal power plants and heavy industry [36]. These endeavors will simultaneously boost energy security, improve the sustainability of energy production and enhance the sustainability of energy consumption by reducing the environmental impacts of fuel combustion.

The transition to reduced fossil fuel demand in domestic transportation is likely to require the continuation of economic incentives for electric vehicles, such as subsidies and tax reliefs, and additional support for charging infrastructure [41,83], which will support the pursuit of sustainable energy production, sustainable energy consumption and economically efficient energy system SED themes. In turn, the same GPI synergies and potential trade-offs apply as were evident under Iceland's energy policy—considerable reductions in environmental costs linked to diminished fossil fuel consumption and potential trade-offs in maintaining the services from nature conservation if, as [84] suggest is necessary, Iceland's energy supply is expanded to meet increased demand from the electric vehicle fleet.

It is also the case that future domestic energy projects in Iceland developed for the purposes of greater energy security do not necessarily have to entail trade-offs with the nature conservation objective of SED. The development of the Svartsengi Power Plant in Reykjanes has led to the utilization of effluent carbon dioxide emissions which are used in the production of methanol by Carbon Recycling International [35], and the facility's wastewaters led to the formation of the adjacent Blue Lagoon, a famous recreational spa [85]. The adoption of circular economy principles involving greater use of waste products from geothermal power constitutes an aspect of sustainable production, minimizing the environmental impacts of production and reducing reliance on fossil fuels [86].

This has been exemplified in Iceland through the ongoing creation of an industrial park at the Hellisheiði Geothermal Power Plant, focused on multifunctional uses of geothermal energy, including algae production [87]. Furthermore, provisioning ecosystem services provides important inputs into energy generation—for example, geothermal heat [88] and flowing water from glacial rivers [89]—and therefore nature conservation objectives could be aligned with the aim of sustainable production. Indeed, it is estimated that flow rates from melting glaciers in Iceland had already increased by 10% in the year 2015 compared to historical records, and inflow rates will rise by a further 15% in the period 2015–2050, increasing potential energy production from hydropower [90,91].

4.4. International Implications

Given that Iceland has already largely embraced the energy transition, the overlap between SED and the GPI probably has far more significant implications for human well-being in developing nations that are heavily reliant on fossil fuels for energy production and consumption. In Iceland to date, the main GPI costs regarding energy utilization—air pollution, greenhouse gas emissions and non-renewable resource depletion—relate to how energy is ultimately consumed, including renewable energy used for electricity generation to power heavy industries. Developed nations are focused predominantly on maintaining a current level of energy services and economic activities that support human well-being through focusing on energy security and decarbonizing the energy that is supplied and consumed via shifts to renewable energy. However, in other national contexts, especially involving economies currently heavily reliant on primitive fuels for cooking and heating, transitions towards SED could have a much more significant impact on the monetary cost and benefit components within alternative measures of economic well-being, principally because of a short-term need to expand fossil fuel production to satisfy emerging economic demands and human needs in the transportation, industrial and residential sectors, among others [92]. In addition, the social benefits theme may be much more pronounced in importance, especially in communities that are currently without an electricity supply.

In developing nations, currently unmet basic human needs could potentially increase significantly in the coming decades, not least because nearly all population growth is likely to take place in these countries [93]. This is one of the main reasons why the economic growth objective remains in Target 1 of SDG 8, with its caveat that its rate should be determined by national governments in accordance with national needs, and Target 1 of SDG 7 focuses on increasing the provision of affordable, reliable and modern energy services. In 2019, more than 75.0% of the populations in thirteen of Africa's poorest nations still lacked any access to electricity, amounting to 573 million people [94]. The continent of Africa thus provides an excellent example of likely economic expansion, with the African Economic Outlook 2020 forecasting economic growth of 4.0% in 2019 and 4.1% in 2020 [94] (2020), and the World Economic Outlook predicting that the real annual GDP growth rate of all African nations will increase to 5.2% in 2024 [95]. It is contended by [92] that energy demand is likely to increase in proportion to population growth in Africa, and that increased urbanization, inward migration to cities, industrialization and a demand for higher standards of living will all challenge the extent to which a swift energy transition can take place.

Even though African nations have considerable endowments of renewable energy, including solar, hydropower, wind, biomass and geothermal, and capacity is increasing, most of the new energy demand is likely to be satisfied via fossil fuels [92], which would have negative implications for SED and the monetary costs of environmental impacts in economic welfare indicators such as the GPI. A study by [96] found that long-term planning is necessary to facilitate an energy transition, lasting many decades from the first market uptake of renewables [97]. It has been reported that barriers to leapfrogging include the slow pace of technological change, especially when capital-intensive investments are involved. This has been due to the co-evolution of long-lived technologies, dynamic competition between technologies rather than a smooth progression from 'old' to 'new' options, and non-linear patterns of technological adoption with respect to income [98]. The study by [92] adds that there are various other barriers specific to the African context, including the upfront costs of renewable energy infrastructure for African governments, undeveloped or poorly maintained grid infrastructure, sprawling populations making it difficult to implement electrification projects, and limited political willpower and lack of policy coherence to enact the energy transition and deliver on climate change strategies. The author of [99] opines that although these barriers to leapfrogging and pursuit of SED in developing nations are not inconsiderable, they can be mitigated to some extent through the adoption and implementation of already commercially viable technologies, by increasing the participation of citizens in energy planning and policymaking, and by democratically restructuring governance institutions.

In the short to medium term, fossil fuel consumption is likely to go up considerably in developing nations as the pursuit of various SED themes gathers pace, particularly an economically efficient energy system, energy security and social benefits. This implies upward pressure on the consumption component in the GPI, but also costs associated with the relative lack of sustainability associated with energy production and consumption, and inconsiderable focus on the importance of nature conservation. The costs associated with air pollution, water pollution, greenhouse gas emissions and non-renewable resource depletion can be expected to increase, and the benefits of ecosystem services from preserved nature may diminish.

4.5. Limitations and Further Research

This study was based on a GPI methodology by [34], which was developed in accordance with the GPI 2.0 method of [38], and SED themes articulated by [16,40,42]. Both the former and latter were prepared with respect to the case study of Iceland, the latter following extensive stakeholder consultation. As [42,44], nation-specific analysis is important when developing SED themes and related indicators, an observation that was echoed by [62] concerning any indicators or indices developed for the purposes of measuring sustainability. This means that although the GPI methodology and SED themes for Iceland are specific to the case study, the components of national economic well-being and important SED themes may be slightly different in other nations. However, it should be noted that the six Iceland-specific SED themes set out by Gunnarsdóttir et al. [40] differed only slightly in content from the four general themes identified in [16].

This research was limited to a conceptual exploration, an important first stage on the road to understanding the linkages between SED and economic well-being. The assumption of ceteris paribus is useful for conceptual exploration but flawed in practice given the complexities of national economies. Further research needs to be undertaken to better understand the short and long-term extent of relationships, including whether there are statistically significant relationships between key variables—for example, a transition to more sustainable energy production/consumption and what this entails for environmental costs in the GPI linked to air pollution, non-renewable resource depletion and climate change contributions. This would involve the development of dynamic macro-economic modelling of the GPI, something that has been called for by [34,58].

One of the weaknesses of the GPI is that it is a measure of weak rather than strong sustainability [100,101]. Thus, increases in energy consumption through fossil fuels, if the monetary value of these benefits exceeded the environmental and social costs, would lead to an increased GPI outcome. Therefore, although the GPI captures environmental costs, a component of SED captured in its nature conservation, sustainable production and sustainable consumption themes, the GPI could potentially increase at the same time as a nation transitions away from SED. Indirect synergies and trade-offs in the GPI might relate to the pursuit of SED in certain national contexts, especially developing nations. The pursuit of SED might spawn economic growth, leading, potentially, to greater indirect costs such as increased income inequality, lost leisure time and greater solid waste generation. These deeper dynamics need to be better understood in the context of alternative measures of economic well-being. In addition, since certain benefit and cost components in the GPI are unrelated to SED, such as the value of leisure time for the former and crime for the latter, it is not a given that the pursuit of SED will always lead to higher GPI outcomes.

Finally, the GPI is just one of several alternative measures of economic well-being. It was chosen for analysis in this paper due to the comprehensiveness of its methodology, a feature demonstrated in terms of the extent to which it can be linked to the SDGs [20]. Other measures of economic well-being, such as the Genuine Savings Indicator or a stock-based measure such as the Inclusive Wealth Index, may also integrate the SED concept and also satisfy the call by Target 19 of SDG 17 (Partnerships for the Goals) for nations to develop alternative measures of economic progress to GDP.

5. Conclusions

This paper conducted a conceptual exploration of the extent to which the SED concept can be linked to the calculation components in the GPI, a widely used alternative measure of national economic well-being to GDP. Based on a GPI methodology recently applied to the case study of Iceland and the six SED themes determined for Iceland following robust stakeholder consultation, the exploration considered whether there was alignment, either direct or indirect, between the SED themes and each of the thirty-nine cost and benefit components in the GPI. Due to the overlapping characteristics of the SED themes, often several could be linked to the GPI's sub-indicators. Overall, 46 SED themes were found to be potentially of influence on 16 of the 39 sub-indicators, comprising 8 cost deductions and 7 benefit additions. The frequency of these was as follows: sustainable energy production (10), sustainable energy consumption (10), energy security (8), nature conservation (8), social benefits (7) and economically efficient energy system (3).

All other factors being equal, the core management outcomes of the study are that policymakers seeking to advance SED through progressive energy policies and actions undertaken to tackle climate change are likely to stimulate enhancements to national economic well-being, as measured by alternative measures such as the GPI. The study suggests there is considerable merit to aligning energy and climate policies, since the integration of sustainability considerations means that the former promotes the fulfilment of the latter. In particular, pursuing SED will likely lead to reduced GPI costs for environmental externalities of energy production and consumption, and greater focus will be afforded to the importance of nature conservation, thus maintaining important ecosystem services for the benefit of future generations. Co-benefit arguments in favor of increasing the use of renewable energy technologies are thus reinforced by this study.

The results of this study may differ in other national contexts, especially developing countries that are not as advanced as Iceland in terms of the energy transition and may require greater production of fossil fuels in the short term in order to increase energy security and drive macro-economic expansion. Furthermore, although these results have some international generalizability, the components of national economic well-being will also vary according to national specificities. Deeper knowledge is needed of these contextual aspects, along with further research on macro-economic dynamics in the GPI, both in general and focused on implicit concepts such as SED.

Author Contributions: Conceptualization, D.C., B.D. and I.G.; validation, D.C., B.D. and I.G.; formal analysis, D.C. and I.G.; investigation, D.C. and I.G.; resources, B.D.; data curation, D.C.; writing—original draft preparation, D.C.; writing—review and editing, D.C., B.D. and I.G.; visualization, D.C.; supervision, B.D.; project administration, D.C.; funding acquisition, not applicable. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Detailed methodology used in the calculation of Iceland's GPI (Reprinted with permission from ref. [34]. Copyright 2021 Elsevier).

Sub-Indicator	Type of Capital	Summary of Calculation Method (all Values Adjusted to 2019 Icelandic Prices)	Operation	Data Source(s)
		Utility from consumption of goods and services		
Household budget expenditures (HBE)	Financial	Household final consumption expenditure (HFCE).	Addition	Statistics Iceland (2020a)
Costs of food waste	Human	Derived from estimate of the aggregate economic value (market price) of food waste in the capital area in 2016 (Environment Agency, 2016), scaled to the size of the Icelandic population.	Deduction	Environment Agency of Iceland (2016)
Insurance	Financial	Derived from itemized HFCE.	Deduction	Statistics Iceland (2020a)
Welfare neutral goods	Human	Derived from itemized HFCE. Followed assumption of Lawn (2013) that 25% of alcohol consumption and 80% of tobacco and narcotics consumption were purchases likely to be welfare declining.	Deduction	Statistics Iceland (2020a)/Lawn (2013)
Costs of family changes	Human/Social	Benefit transfer approximation based on estimate by Spitzer (2017) concerning mean costs of divorce in the US ($15,000 per person), multiplied by number of Icelandic divorces per annum.	Deduction	Spitzer (2017)/Statistics Iceland (2021)
Costs of maintaining dwelling services	Built	Derived from itemized HFCE—water supply and other dwelling services, e.g., waste.	Deduction	Statistics Iceland (2020a)
		Household investments (HI)		
Consumer durables	Built	Aggregated value of purchases of cars, houses and appliances in HFCE from previous five years multiplied by 0.2 as per approach of Kenny et al. (2019).	Deduction	Statistics Iceland (2020a)/Kenny et al. (2019)
Household repairs and maintenance	Built	Derived from itemized HFCE.	Deduction	Statistics Iceland (2020a)
Goods and services for household repairs and maintenance	Built	Derived from itemized HFCE.	Deduction	Statistics Iceland (2020a)
Income inequality adjustment (INQ)	Financial	Index-derived adjustment based on extent of the Gini coefficient deviation from baseline—lowest year of income inequality given a base value of 100.	Deduction	Statistics Iceland (2020c)
		Public provision of goods and services (PP)		
Education	Human	Itemized expenditure by central government in GDP calculation.	Addition	Statistics Iceland (2020e)
Healthcare	Human	Itemized expenditure by central government in GDP calculation.	Addition	Statistics Iceland (2020e)
Local government services	Human and social	Itemized expenditure by local government in GDP calculation, related to health, education, recreation, social protection, housing and community amenities, environmental protection, public order and safety, defence and other public services.	Addition	Statistics Iceland (2020e)
		Utility sourced from essential capital		
		Services from human capital (KH)		
External benefits from higher education	Human	Benefit transfer approach—annual number of Icelandic college graduates (ISCED (2011) Levels 5–8) multiplied by annual social payoff as per Talberth et al. (2007) study.	Addition	Statistics Iceland (2020g)/Talberth et al. (2007)
Research and development	Human	Annual government expenditure in GDP calculation on research and development in economic and labour affairs; agriculture, forestry and fishing; fuel and energy; mining, manufacturing and construction; and other industries.	Addition	Statistics Iceland (2020e)
		Services from social capital (KS)		
Value of leisure time	Social	To calculate the measure for leisure time, the method outlined by Talberth et al. (2007) was utilized, leading to an imaginary base year with mean leisure time of 1770 h per person (derived by assuming a 40 h work week and five weeks of annual vacation time for a total of 235 working days). Adjusted mean leisure time per person was multiplied by the total number of workers in the labour force to arrive at a total number of leisure hours for the nation per annum, which was multiplied by the mean gross hourly wage rate in the private sector.	Addition	Statistics Iceland (2020d; 2020f)/Talberth et al. (2007)

Table A1. *Cont.*

Sub-Indicator	Type of Capital	Summary of Calculation Method (all Values Adjusted to 2019 Icelandic Prices)	Operation	Data Source(s)
Value of unpaid labour in the volunteering sector	Social	Although data is limited for Iceland, the most recent completed study of the World Values Survey, Wave 4, estimated that 29% of Icelanders took part in voluntary work in 2014. Scaled to the Icelandic population and assuming mean volunteering hours of 89 per volunteer per year in line with the US national estimate of 2018, the total number of Icelandic volunteering hours was multiplied by the mean gross hourly wage rate in the private sector.	Addition	AmeriCorps (2018)/World Values Survey (Inglehart et al., 2014)/Statistics Iceland (2020d)
Recreation, culture and religion		Annual national government expenditure in GDP on recreation, culture and religion.		Statistics Iceland (2020e)
Community development		Annual national government expenditure in GDP on community development.		Statistics Iceland (2020e)
		Services from natural capital (KN)		
Services from preserved nature	Natural	Uses outcome from the study by Cook and Davíðsdóttir (2021b), which provides an estimate of the economic value of Iceland's ecosystem services using the benefit transfer approach, CORINE land use classes and land cover data for Iceland, and monetary unit values for specific biomes from the Ecosystem Services Valuation Database.	Addition	National Land Survey of Iceland (2018)/Cook and Davíðsdóttir (2021b)
		Services from built capital (KB)		
Value of transportation infrastructure	Built	Aggregated annual government expenditures in GDP on road, water and air transportation, infrastructure and maintenance.	Addition	Statistics Iceland (2020e)
Value of energy and water infrastructure	Built	Aggregated annual government expenditures in GDP on electricity, non-electric energy generation and the water supply.	Addition	Statistics Iceland (2020e)
Waste treatment by sewer infrastructure	Built	Aggregated annual government expenditures in GDP on waste and water waste management.	Addition	Statistics Iceland (2020e)
Housing development	Built	Aggregated annual government expenditures in GDP on housing development.	Addition	Statistics Iceland (2020e)
Manufacturing	Built	Aggregated annual government expenditures in GDP on manufacturing.	Addition	Statistics Iceland (2020e)
Construction	Built	Aggregated annual government expenditures in GDP on construction.	Addition	Statistics Iceland (2020e)
		Disutility linked to undesirable environmental and social conditions		
		Depletion of natural capital (DKN)		
Non-renewable resource depletion	Natural	Nominal replacement cost of biomass fuel in barrels of oil equivalent as per study by Babcock (2017) ($81.3 in 2019 prices) multiplied by volume of fossil fuels (oil and coal) in primary energy in Iceland in barrels of oil equivalent.	Deduction	National Energy Authority of Iceland (2020)/Babcock (2017)
Ozone depletion	Natural	Emissions of HFCs in tonnes carbon dioxide equivalent multiplied by the social cost of carbon using the mean outcome from the meta-analysis of Wang et al. (2019).		UNFCCC (n.d.)/Wang et al. (2019)
Overharvesting of fisheries	Natural	Difference between total catch and total allowable catch multiplied by value of catch per tonne.	Deduction	Icelandic Directorate of Fisheries (2020)/Statistics Iceland (2020j)
Avoided depletion	Natural	Avoided depletion costs approximated by annual government expenditure in GDP on protection of biodiversity and landscape.	Deduction	Statistics Iceland (2020e)
		Pollution (POL)		
Air pollution	Natural	Economic cost of mortality impact calculated by number of premature deaths from outdoor (particulate matter and ozone) and indoor air pollution (Ritchie and Roser, 2019) multiplied by average cost of each death from air pollution using the value of statistical life (VSL) measure, estimated for Iceland by the World Health Organization in 2010.	Deduction	Ritchie and Roser (2019)/WHO Regional Office for Europe, OECD (2015)
Climate change contribution	Natural	Quantity of man-made greenhouse gas emissions multiplied by average social cost of carbon using the mean outcome from the meta-analysis of Wang et al. (2019).	Deduction	UNFCCC (n.d.)/Wang et al. (2019)
Solid waste	Natural	Volume in tonnes of total waste generation multiplied by external cost of Icelandic waste generation in the study by Kinnaman (2009). Note that total waste generation has only been reported in Iceland since 2014, however, municipal waste volumes were reported throughout the assessment period. Derived from the mean proportion of total waste constituting municipal waste (19.1%) from 2014 onwards, municipal waste data was upscaled for 2000–2013 to estimate total waste generation.	Deduction	Statistics Iceland (2020k)/Kinnaman (2009)
Avoided damages	Natural	Avoided costs to human well-being approximated by annual government expenditure in GDP on pollution abatement.	Deduction	Statistics Iceland (2020e)

Table A1. *Cont.*

Sub-Indicator	Type of Capital	Summary of Calculation Method (all Values Adjusted to 2019 Icelandic Prices)	Operation	Data Source(s)
		Social costs of economic activity (SC)		
Unemployment	Social	Total unprovided hours of individuals aged 16–74 multiplied by gross mean private sector wage (ISK/hr).	Deduction	Statistics Iceland (2020d; 2020f; 2020h)
Overemployment and lost leisure time	Human	Mean working week compared to Icelandic legal expectancy of forty hours; hours of overtime scaled to labour force size and mean gross hourly wage.	Deduction	Statistics Iceland (2020d; 2020f; 2020h)
Crime	Social	Total annual government cost of operating prisons and law courts in Iceland.	Deduction	Statistics Iceland (2020e)
Commuting	Human	Aggregation of direct cost of commuting, indirect time spent commuting to work, and direct costs of public transportation. Commuting cost calculated by multiplying annual commuting distance by cost of driving per km and the number of vehicles owned by households. Cost per one km of driving was calculated through the calculation of average cost of fuel per km in Iceland (Global Petrol Prices, 2020) Indirect cost of commuting times was obtained by the approximate amount of time spent reaching work multiplied by the mean gross hourly wage for full-time work in the private sector.	Deduction	Statistics Iceland (2020d; 2020i); Reynarsson (2008); Global Petrol Price (2020)
Vehicle accidents	Social	Approach of Kubiszewski et al. (2015) was followed, whereby cost of vehicle accident equalled number of deaths (Samgöngustofa, 2020) multiplied by cost per accident. The road administration conducted a study in 2013 on the cost of deaths in a car accident (Sigþórsson and Hilmarsson, 2014). The research calculated not only individual cost, but also reflected the social cost of an accident to arrive at an estimated VSL.	Deduction	Kubiszweski et al. (2015); Samgöngustofa (2020); Sigþórsson and Hilmarsson (2014)

References

1. Martinez, D.M.; Ebenhack, B.W. Understanding the role of energy consumption in human development through the use of saturation phenomena. *Energy Policy* **2008**, *36*, 1430–1435. [CrossRef]
2. UNDP (United Nations Development Programme). World Energy Assessment: Energy and the Challenge of Sustainability. United Nations Department of Economic and Social Affairs, World Energy Council. 2000. Available online: https://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_energy/world_energy_assessmentenergyandthechallengeofsustainability.html (accessed on 2 February 2022).
3. Van Tran, N.; Van Tran, Q.; Do, L.T.T.; Dinh, L.H.; Do, H.T.T. Trade off between environment, energy consumption and human development: Do levels of economic development matter. *Energy* **2019**, *173*, 483–493. [CrossRef]
4. Millward-Hopkins, J.; Steinberger, J.K.; Rao, N.D.; Oswald, Y. Providing decent living with minimum energy: A global scenario. *Glob. Environ. Change* **2020**, *65*, 102168. [CrossRef]
5. Ray, S.; Ghosh, B.; Bardhan, S.; Bhattacharyya, B. Studies on the impact of energy quality on human development index. *Renew. Energy* **2016**, *92*, 117–126. [CrossRef]
6. Steinberger, J.K.; Roberts, J.T. From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005. *Ecological Economics* **2010**, *70*, 425–433. [CrossRef]
7. Steinberger, J.K. Energising Human Development. United Nations Development Programme–Human Development Reports. 2016. Available online: http://hdr.undp.org/en/content/energising-human-development (accessed on 2 February 2022).
8. Yang, H.Y. A note on the causal relationship between energy and GDP in Taiwan. *Energy Econ.* **2000**, *22*, 309–317. [CrossRef]
9. Oh, W.; Lee, K. Causal relationship between energy consumption and GDP revisited: The case of Korea 1970–1999. *Energy Econ.* **2004**, *26*, 51–59. [CrossRef]
10. Mahalingam, B.; Orman, W.H. GDP and energy consumption: A panel analysis of the US. *Appl. Energy* **2018**, *213*, 208–218. [CrossRef]
11. Chontanawat, J.; Hunt, L.C.; Pierse, R. *Causality between Energy Consumption and GDP: Evidence from 30 OECD and 78 Non-OECD Countries (No. 113)*; Surrey Energy Economics Centre (SEEC), School of Economics, University of Surrey: Guildford, UK, 2006.
12. Leiva, B.; Rubio Varas, M.D.M. The energy and gross domestic product causality nexus in Latin America 1900–2010. *Int. J. Energy Econ. Policy* **2020**, *10*, 423–435. [CrossRef]
13. MEA (Millennium Ecosystem Assessment). *Ecosystems and Human Well-Being: Synthesis*; Island Press: Washington, DC, USA, 2005.
14. UN (United Nations). *Transforming Our World: The 2030 Agenda for Sustainable Development*; UN Publishing: New York, NY, USA, 2015; Available online: https://sustainabledevelopment.un.org/post2015/transformingourworld (accessed on 26 January 2022).
15. Gunnarsdóttir, I.; Davidsdottir, B.; Worrell, E.; Sigurgeirsdóttir, S. Review of indicators for sustainable energy development. *Renew. Sustain. Energy Rev.* **2020**, *133*, 110294. [CrossRef]

16. Gunnarsdóttir, I.; Davidsdottir, B.; Worrell, E.; Sigurgeirsdóttir, S. Sustainable Energy Development: History of the Concept and Emerging Themes. *Renew. Sustain. Energy Rev.* **2021**, *141*, 110770. [CrossRef]
17. Spittler, N.; Davidsdottir, B.; Shafiei, E.; Leaver, J.; Asgeirsson, E.I.; Stefansson, H. The role of geothermal resources in sustainable power system planning in Iceland. *Renew. Energy* **2020**, *153*, 1081–1090. [CrossRef]
18. IAEA/IEA (International Atomic Energy Agency/International Energy Agency). Indicators for Sustainable Energy Development. Presented at the 9th Session of the United Nations Commission on Sustainable Development. 2001. Available online: https://www.iaea.org/sites/default/files/indicators.pdf (accessed on 26 January 2022).
19. Fuso Nerini, F.; Tomei, J.; To, L.S.; Bisaga, I.; Parikh, P.; Black, M.; Borrion, A.; Spataru, C.; Castán Broto, V.; Anandarajah, G.; et al. Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nat. Energy* **2018**, *3*, 10–15. [CrossRef]
20. Cook, D.; Davíðsdóttir, B. An appraisal of the interlinkages between macro-economic indicators of economic well-being and the Sustainable Development Goals. *Ecol. Econ.* **2021**, *184*, 106966. [CrossRef]
21. Fioramonti, L.; Coscieme, L.; Mortensen, L.F. From gross domestic product to wellbeing: How alternative indicators can help connect the new economy with the Sustainable Development Goals. *Anthr. Rev.* **2019**, *6*, 207–222. [CrossRef]
22. Cook, D.; Davíðsdóttir, B. A preliminary estimate of the economic value of Iceland's terrestrial ecosystem services and opportunities for future research. *Sustain. Futures* **2022**. *under review*.
23. Coscieme, L.; Mortensen, L.F.; Anderson, S.; Ward, J.; Donohue, I.; Sutton, P.C. Going beyond gross domestic product as an indicator to bring coherence to the sustainable development goals. *J. Clean. Prod.* **2020**, *248*, 119232. [CrossRef]
24. Costanza, R.; Kubiszewski, I.; Giovannini, E.; Lovins, H.; McGlade, J.; Pickett, K.E.; Ragnarsdóttir, K.V.; Roberts, D.; De Vogli, R.; Wilkinson, R. Development: Time to leave GDP behind. *Nat. News* **2014**, *505*, 283. [CrossRef]
25. Costanza, R.; Fioramonti, L.; Kubiszewski, I. The UN Sustainable Development Goals and the dynamics of wellbeing. *Front. Ecol. Environ.* **2016**, *014*, 59. [CrossRef]
26. Costanza, R.; Daly, L.; Fioramonti, L.; Giovannini, E. Modelling and measuring sustainable wellbeing in connection with the UN Sustainable Development Goals. *Ecol. Econ.* **2016**, *130*, 350–355. [CrossRef]
27. Dasgupta, P. The Economics of Biodiversity: The Dasgupta Review. HM Treasury, London. 2021. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/957291/Dasgupta_Review_-_Full_Report.pdf (accessed on 2 February 2022).
28. Bekhet, H.A.; Othman, N.S. The role of renewable energy to validate dynamic interaction between CO2 emissions and GDP toward sustainable development in Malaysia. *Energy Econ.* **2018**, *72*, 47–61. [CrossRef]
29. Chen, Y.; Wang, Z.; Zhong, Z. CO2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. *Renew. Energy* **2019**, *131*, 208–216. [CrossRef]
30. Jebli, M.B.; Youssef, S.B. The environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia. *Renew. Sustain. Energy Rev.* **2015**, *47*, 173–185. [CrossRef]
31. Skare, M.; Tomic, D.; Stjepanovic, S. Energy Consumption and Green GDP in Europe: A Panel Cointegration Analysis 2008-2016. *Acta Montan. Slovaca* **2020**, *25*, 45–56.
32. Wang, F.; Wang, R.; Wang, J. Measurement of China's green GDP and its dynamic variation based on industrial perspective. *Environ. Sci. Pollut. Res.* **2020**, *27*, 43813–43828. [CrossRef] [PubMed]
33. Cook, D.; Davidsdottir, B.; Petursson, J.G. Accounting for the utilisation of geothermal energy resources within the genuine progress indicator—A methodological review. *Renew. Sustain. Energy Rev.* **2015**, *49*, 211–220. [CrossRef]
34. Cook, D.; Davíðsdóttir, B. An estimate of the Genuine Progress Indicator for Iceland, 2000–2019. *Ecol. Econ.* **2021**, *189*, 107154. [CrossRef]
35. Helgason, R.; Cook, D.; Davíðsdóttir, B. An evaluation of the cost-competitiveness of maritime fuels–A comparison of heavy fuel oil and methanol (renewable and natural gas) in Iceland. *Sustain. Prod. Consum.* **2020**, *23*, 236–248. [CrossRef]
36. MENR (Ministry of Environment and Natural Resources). Iceland's 2020 Climate Action Plan. 2020. Available online: https://www.government.is/library/01-Ministries/Ministry-for-The-Environment/201004%20Umhverfisraduneytid%20Adgerdaaaetlun%20EN%20V2.pdf (accessed on 6 February 2022).
37. MII (Ministry of Industries and Innovation). A sustainable Energy Future—An Energy Policy to the year 2050. 2020. Available online: https://www.stjornarradid.is/lisalib/getfile.aspx?itemid=e36477fd-3bc1-11eb-8129-005056bc8c60 (accessed on 6 February 2022).
38. Talberth, J.; Weisdorf, M. Genuine progress indicator 2.0: Pilot accounts for the US, Maryland, and City of Baltimore 2012–2014. *Ecol. Econ.* **2017**, *142*, 1–11. [CrossRef]
39. National Energy Authority Primary Energy Use in Iceland 1940–2019. 2021. Available online: https://orkustofnun.is/gogn/Talnaefni/OS-2021-T008-01.pdf (accessed on 1 March 2022).
40. Cook, D.; Karlsdóttir, I.; Minelgaite, I. Enjoying the heat? Co-creation of stakeholder benefits and sustainable energy development within projects in the geothermal sector. *Energies* **2022**, *15*, 1029. [CrossRef]
41. Shafiei, E.; Davidsdottir, B.; Stefansson, H.; Asgeirsson, E.I.; Fazeli, R.; Gestsson, M.H.; Leaver, J. Simulation-based appraisal of tax-induced electro-mobility promotion in Iceland and prospects for energy-economic development. *Energy Policy* **2019**, *133*, 110894. [CrossRef]
42. Gunnarsdóttir, I.; Davidsdottir, B.; Worrell, E.; Sigurgeirsdóttir, S. It is best to ask: Designing a stakeholder-centric approach to selecting sustainable energy development indicators. *Energy Res. Soc. Sci.* **2021**, *74*, 101968. [CrossRef]
43. Vera, I.; Langlois, L. Energy indicators for sustainable development. *Energy* **2007**, *32*, 875–882. [CrossRef]

44. Shortall, R.; Davíðsdóttir, B. How to measure national energy sustainability performance: An Icelandic case-study. *Energy Sustain. Dev.* **2017**, *39*, 29–47. [CrossRef]
45. Narula, K.; Reddy, B.S. Three blind men and an elephant: The case of energy indices to measure energy security and energy sustainability. *Energy* **2015**, *80*, 148–158. [CrossRef]
46. OECD. *OECD Framework for Statistics on the Distribution of Household Income, Consumption and Wealth*; OECD Publishing: Paris, France, 2013; Available online: https://read.oecd-ilibrary.org/economics/framework-for-statistics-on-the-distribution-of-household-income-consumption-and-wealth_9789264194830-en#page3 (accessed on 3 February 2022).
47. Costanza, R.; Caniglia, B.; Fioramonti, L.; Kubiszewski, I.; Lewis, H.; Hunter Lovins, L.; McGlade, J.; Mortensen, L.F.; Philipsen, D.; Pickett, K.E.; et al. *Towards a Sustainable Wellbeing Economy*; Club of Rome: New York, NY, USA, 2018.
48. New Zealand Treasury. The Wellbeing Budget. 2019. Available online: https://treasury.govt.nz/sites/default/files/2019-05/b19-wellbeing-budget.pdf (accessed on 3 February 2022).
49. Government of Iceland. Indicator's for Measuring Well-Being. Prime Minister's Office. 2019. Available online: https://www.government.is/lisalib/getfile.aspx?itemid=fc981010-da09-11e9-944d-005056bc4d74 (accessed on 29 October 2021).
50. Scottish Government. Scotland's Wellbeing—Delivering the National Outcomes. 2019. Available online: https://nationalperformance.gov.scot/sites/default/files/documents/NPF_Scotland%27s_Wellbeing_May2019.pdf (accessed on 27 October 2021).
51. Scottish Government. Scotland and the Sustainable Development Goals: A National Review to Drive Action. 2020. Available online: https://www.gov.scot/publications/scotland-sustainable-development-goals-national-review-drive-action/documents/ (accessed on 27 October 2021).
52. Hoekstra, R. *Replacing GDP by 2030*; Cambridge University Press: Cambridge, UK, 2019.
53. Costanza, R.; Hart, M.; Posner, S.; Talberth, J. Beyond GDP: The need for new measures of progress. *Pardee Pap.* **2009**, *4*, 46.
54. Stockhammer, E.; Hochreiter, H.; Obermayr, B.; Steiner, K. The index of sustainable economic wellbeing (ISEW) as an alternative to GDP in measuring economic wellbeing. The results of the Austrian (revised) ISEW calculation 1955–1992. *Ecol. Econ.* **1997**, *21*, 19–34. [CrossRef]
55. Stern, D.I.; Common, M.S.; Barbier, E.B. Economic growth and environmental degradation: The environmental Kuznets curve and sustainable development. *World Dev.* **1996**, *24*, 1151–1160. [CrossRef]
56. Tol, R.S. *Climate Economics: Economic Analysis of Climate, Climate Change And climate Policy*; Edward Elgar Publishing: Cheltenham, UK, 2014.
57. Goossens, Y.; Mäkipäa, A.; Schepelmann, P.; van de Sand, I.; Kuhndtand, M.; Herrndorf, M. Alternative progress indicators to gross domestic progress (GDP) as a means towards sustainable development. In *IP/A/ENVI/ST/2007–10*; Policy Department—Economic and Scientific Policy (European Parliament): Brussels, Belgium, 2007.
58. Kenny, D.C.; Costanza, R.; Dowsley, T.; Jackson, N.; Josol, J.; Kubiszewski, I.; Narulla, H.; Sese, S.; Sutanto, A.; Thompson, J. Australia's Genuine Progress Indicator Revisited (1962–2013). *Ecol. Econ.* **2019**, *158*, 1–10. [CrossRef]
59. Kubiszewski, I.; Costanza, R.; Franco, C.; Lawn, P.; Talberth, J.; Jackson, T.; Aylmer, C. Beyond GDP: Measuring and achieving global genuine progress. *Ecol. Econ.* **2013**, *93*, 57–68. [CrossRef]
60. UN (United Nations). System of Environmental Economic Accounting. Available online: https://seea.un.org/ecosystem-accounting (accessed on 13 December 2021).
61. Statistics Iceland. Gross Energy Consumption by Source 1940–2019. 2021. Available online: https://px.hagstofa.is/pxen/pxweb/en/Umhverfi/Umhverfi__4_orkumal__2_framleidslaognotkun/IDN02102.px/table/tableViewLayout1/?rxid=55bc612c-2e45-4242-b264-b7f3b5524865 (accessed on 18 February 2021).
62. Olafsson, S.; Cook, D.; Davidsdottir, B.; Johannsdottir, L. Measuring countries environmental sustainability performance—A review and case study of Iceland. *Renew. Sustain. Energy Rev.* **2014**, *39*, 934–948. [CrossRef]
63. Fazeli, R.; Davidsdottir, B. Energy performance of dwelling stock in Iceland: System dynamics approach. *J. Clean. Prod.* **2017**, *167*, 1345–1353. [CrossRef]
64. Statistics Iceland. Population—Key Figures 1703–2020. 2021. Available online: https://px.hagstofa.is/pxen/pxweb/en/Ibuar/Ibuar__mannfjoldi__1_yfirlit__yfirlit_mannfjolda/MAN00000.px/table/tableViewLayout1/?rxid=5e6ad9f4-da34-437f-93f9-dace5f09850f (accessed on 18 February 2021).
65. Nordic Council of Ministers. Energy in the West Nordics and the Arctic. 2018. Available online: https://norden.diva-portal.org/smash/get/diva2:1250846/FULLTEXT01.pdf (accessed on 28 January 2022).
66. Statistics Iceland. Central Government Total Expenditure by Function 1998-2019. 2020. Available online: https://px.hagstofa.is/pxen/pxweb/en/Efnahagur/Efnahagur__fjaropinber__fjarmal_rikissjods/THJ05242.px (accessed on 26 June 2021).
67. UNESCO. Reykjanes Geopark. Available online: https://reykjanesgeopark.is/ (accessed on 28 January 2022).
68. Kristjánsdóttir, H.; Kristjánsdóttir, S. Carbfix and SulFix in geothermal production, and the Blue Lagoon in Iceland: Grindavík urban settlement, and volcanic activity. *Balt. J. Econ. Stud.* **2021**, *7*, 1–9. [CrossRef]
69. Cook, D.; Davíðsdóttir, B.; Malinauskaite, L. A cascade model and initial exploration of co-production processes underpinning the ecosystem services of geothermal areas. *Renew. Energy* **2020**, *161*, 917–927. [CrossRef]
70. Einarsdóttir, S.R.; Cook, D.; Davíðsdóttir, B. The contingent valuation study of the wind farm Búrfellslundur—willingness to pay for preservation. *J. Clean. Prod.* **2019**, *209*, 795–802. [CrossRef]

71. Lienhoop, N.; MacMillan, D. Valuing wilderness in Iceland: Estimation of WTA and WTP using the market stall approach to contingent valuation. *Land Use Policy* **2007**, *24*, 289–295. [CrossRef]
72. Shortall, R.; Davidsdottir, B.; Axelsson, G. Geothermal energy for sustainable development: A review of sustainability impacts and assessment frameworks. *Renew. Sustain. Energy Rev.* **2015**, *44*, 391–406. [CrossRef]
73. Ritchie, H.; Roser, M. Outdoor Air Pollution. Our World in Data. 2019. Available online: https://ourworldindata.org/outdoor-air-pollution#citation (accessed on 14 October 2020).
74. Finnbjornsdottir, R.G.; Oudin, A.; Elvarsson, B.T.; Gislason, T.; Rafnsson, V. Hydrogen sulfide and traffic-related air pollutants in association with increased mortality: A case-crossover study in Reykjavik, Iceland. *BMJ Open* **2015**, *5*, e007272. [CrossRef]
75. Karlsdóttir, S.N.; Hjaltason, S.M.; Ragnarsdóttir, K.R. Corrosion behavior of materials in hydrogen sulfide abatement system at Hellisheiði geothermal power plant. *Geothermics* **2017**, *70*, 222–229. [CrossRef]
76. National Energy Authority Installed Capacity and Electricity Production in Icelandic Power Stations in 2019. 2020. Available online: https://orkustofnun.is/gogn/Talnaefni/OS-2020-T012-01.pdf (accessed on 16 February 2021).
77. Sigfússon, B.; Arnarson, M.Þ.; Snæbjörnsdóttir, S.Ó.; Karlsdóttir, M.R.; Aradóttir, E.S.; Gunnarsson, I. Reducing emissions of carbon dioxide and hydrogen sulphide at Hellisheidi power plant in 2014–2017 and the role of CarbFix in achieving the 2040 Iceland climate goals. *Energy Procedia* **2018**, *146*, 135–145. [CrossRef]
78. Snæbjörnsdóttir, S.Ó.; Sigfússon, B.; Marieni, C.; Goldberg, D.; Gislason, S.R.; Oelkers, E.H. Carbon dioxide storage through mineral carbonation. *Nat. Rev. Earth Environ.* **2020**, *1*, 90–102. [CrossRef]
79. East Iceland Sustainability Initiative. (n.d.). Proportion of Labor in East Iceland Working for Fjarðaál and Landsvirkjun. Available online: https://www.sjalfbaerni.is/en/economy/hlutfall-vinnuafls-a-austurlandi-sem-starfar-fyrir-fjardaal-og-landsvirkjun# (accessed on 28 January 2022).
80. Ingólfsdóttir, A.H.; Gunnarsdóttir, G.Þ. Tourism as a tool for nature conservation? Conflicting interests between renewable energy projects and wilderness protection in Iceland. *J. Outdoor Recreat. Tour.* **2020**, *29*, 100276. [CrossRef]
81. Sæþórsdóttir, A.D.; Hall, C.M. Contested development paths and rural communities: Sustainable energy or sustainable tourism in Iceland? *Sustainability* **2019**, *11*, 3642. [CrossRef]
82. Sæþórsdóttir, A.D.; Ólafsdóttir, R. Not in my back yard or not on my playground: Residents and tourists' attitudes towards wind turbines in Icelandic landscapes. *Energy Sustain. Dev.* **2020**, *54*, 127–138. [CrossRef]
83. Shafiei, E.; Davidsdottir, B.; Fazeli, R.; Leaver, J.; Stefansson, H.; Asgeirsson, E.I. Macroeconomic effects of fiscal incentives to promote electric vehicles in Iceland: Implications for government and consumer costs. *Energy Policy* **2018**, *114*, 431–443. [CrossRef]
84. Duenas, P.; Ramos, A.; Tapia-Ahumada, K.; Olmos, L.; Rivier, M.; Pérez-Arriaga, J.I. Security of supply in a carbon-free electric power system: The case of Iceland. *Appl. Energy* **2018**, *212*, 443–454. [CrossRef]
85. De Almeida, C. Performative by-products: The emergence of waste reuse strategies at the Blue Lagoon. *J. Landsc. Archit.* **2018**, *13*, 64–77. [CrossRef]
86. Moya, D.; Aldás, C.; Kaparaju, P. Geothermal energy: Power plant technology and direct heat applications. *Renew. Sustain. Energy Rev.* **2018**, *94*, 889–901. [CrossRef]
87. Think Geoenergy Algae Production to Be set up at Hellisheidi Geothermal Plant in Iceland. 2018. Available online: https://www.thinkgeoenergy.com/algae-production-to-be-set-up-at-hellisheidi-geothermal-plant-in-iceland/ (accessed on 15 January 2022).
88. Hastik, R.; Basso, S.; Geitner, C.; Haida, C.; Poljanec, A.; Portaccio, A.; Vrščaja, B.; Walzer, C. Renewable energies and ecosystem service impacts. *Renew. Sustain. Energy Rev.* **2015**, *48*, 608–623. [CrossRef]
89. Milner, A.M.; Khamis, K.; Battin, T.J.; Brittain, J.E.; Barrand, N.; Füreder, L.; Cauvy-Fraunié, S.; Gislason, G.M.; Jacobsen, D.; Hannah, D.; et al. Glacier shrinkage driving global changes in downstream systems. *Proc. Natl. Acad. Sci.* **2017**, *114*, 9770–9778. [CrossRef]
90. Cook, D.; Malinauskaite, L.; Davíðsdóttir, B.; Ögmundardóttir, H. Co-production processes underlying the ecosystem services of glaciers and adaptive management in the era of climate change. *Ecosyst. Serv.* **2021**, *50*, 101342. [CrossRef]
91. Landsvirkjun and Icelandic Met Office. Hydropower Expansion and Improved Management in Response to Increased Glacier melt in Iceland. Climate ADAPT Case Study of the European Environment Agency. 2018. Available online: https://climate-adapt.eea.europa.eu/metadata/case-studies/hydropower-expansion-and-improved-management-in-response-to-increased-glacier-melt-in-iceland (accessed on 6 February 2022).
92. Mutezo, G.; Mulopo, J. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. *Renew. Sustain. Energy Rev.* **2021**, *137*, 110609. [CrossRef]
93. UN (United Nations). The 2019 Revision of World Population Forecasts. 2019. Available online: https://population.un.org/wpp/ (accessed on 18 February 2021).
94. ADBG (African Development Bank Group. African Economic Outlook 2020. 2020. Available online: https://www.afdb.org/en/knowledge/publications/african-economic-outlook#:~{}:text=for%20the%20future-,African%20Economic%20Outlook%202020%3A%20Developing%20Africa\T1\textquoterights%20workforce%20for%20the%20future,to%20remain%20below%20historical%20highs (accessed on 6 February 2022).
95. IMF (International Monetary Fund). World Economic Outlook. 2020. Available online: https://www.imf.org/external/datamapper/datasets/WEO (accessed on 6 February 2022).
96. Sakah, M.; Diawuo, F.A.; Katzenbach, R.; Gyamfi, S. Towards a sustainable electrification in Ghana: A review of renewable energy deployment policies. *Renew. Sustain. Energy Rev.* **2017**, *79*, 544–557. [CrossRef]

97. Smil, V. Examining energy transitions: A dozen insights based on performance. *Energy Res. Soc. Sci.* **2016**, *22*, 194–197. [CrossRef]
98. Jeuland, M.; Fetter, T.R.; Li, Y.; Pattanayak, S.K.; Usmani, F.; Bluffstone, R.A.; Chávez, C.; Girardeau, H.; Hassen, S.; Jagger, P.; et al. Is energy the golden thread? A systematic review of the impacts of modern and traditional energy use in low-and middle-income countries. *Renew. Sustain. Energy Rev.* **2021**, *135*, 110406. [CrossRef]
99. Cantarero, M.M.V. Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries. *Energy Res. Soc. Sci.* **2020**, *70*, 101716. [CrossRef]
100. Huang, L. Exploring the Strengths and Limits of Strong and Weak Sustainability Indicators: A Case Study of the Assessment of China's Megacities with EF and GPI. *Sustainability* **2018**, *10*, 349. [CrossRef]
101. Lawn, P.A. A theoretical foundation to support the Index of Sustainable Economic Welfare (ISEW), Genuine Progress Indicator (GPI), and other related indexes. *Ecol. Econ.* **2003**, *44*, 105–118. [CrossRef]