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The sensitivity of growth, conservation, feedback & neutrality hypotheses to sustainability accounting

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ABSTRACT

The relationship between energy consumption and national economic welfare, as measured by gross domestic product, has been evaluated statistically in numerous studies. We summarize and compare the results of several of these studies for 15 emerging economies. Considerable differences between studies and between nations are found. Then, we introduce two measures of welfare based on the "Index of Sustainable Economic Welfare" (ISEW). The first measure, "BISEW" (hereafter BISEW), modifies GDP to emphasize equality, capital stock, and spending on private consumption, education, and medical care. The second measure, "Solid ISEW" (hereafter SISEW), subtracts carbon dioxide emissions and various measures of resource depletion to the BISEW, thus combining economic and environmental considerations in the measure of welfare. We apply Granger causality analysis with a seemingly unrelated regression (SUR) to evaluate how energy consumption correlates with GDP, BISEW, and SISEW for 15 emerging economies over the period 1995–2013. The results are expressed in terms of the directionality of Granger causality. Although there is consistency in many cases, the direction of causality is found to vary substantially between countries and depending on which of the three measures of welfare is evaluated.

Introduction

Research on the relationship between energy consumption and economic output, as measured by gross domestic product (GDP) has shown ambiguous results (Kalimeris et al., 2014; Menegaki, 2014; Ozturk, 2010). Concurrently, there is an increased interest in whether GDP is an accurate measure of progress and welfare (Kubiszewski et al., 2013). These concerns have motivated new research on how energy consumption impacts on welfare that uses various measures of welfare to replace GDP. This paper uses an Index of Sustainable Economic Welfare (ISEW) to replace GDP.

The ISEW was first suggested by Daly and Cobb (1989) but was methodologically improved by Cobb and Cobb (1994). Previous insights had been provided in the Measure of Economic Welfare (MEW) by Nordhaus and Tobin (1972) which modified GDP in a way to subtract from it the value of activities harming human and environmental welfare. The ISEW is a modification of the MEW. The Genuine Progress Index (GPI) has been used interchangeably with ISEW (Lawn, 2013). While a variety of other welfare indexes have been developed up to date (The European Commission in its "2007 Beyond" conference presents an array of 24 indicators), each of them focuses on a certain aspect of welfare and does not encompass all the aspects of economy, environment and society as the ISEW does. Some examples are: the Capability Index (according to which, quality of life is what people do with their resources), the Ecological Footprint Indicator (measures the balance between the demand and supply for renewable resources for a given population or activity and the assimilative capacity for waste), the Environmentally Sustainable National Income — ESNI (measures the number of years that a country with its current production situation is away for a sustainable ideal benchmark), the happy planet index — HPI (ratio of the product of experienced welfare and life expectancy to the ecological footprint), and many others. Also, one of the long developed welfare indicators is the Human Development Index (HDI) that is used by the United Nations but it is criticized for its incompleteness (Dasgupta and Weale, 1992) in all the abovementioned three fields the ISEW can host. The HDI includes purchasing power, education, and longevity but leaves out many of the dimensions the ISEW takes into account. Overall, it may be impossible to find a perfect indicator but ISEW is an attempt to do better than others.

The calculation of the ISEW starts with personal consumption expenditure which is weighted for income inequality to account for the fact that the benefits from economic growth can favor the rich in a disproportional way. With this basis, several welfare generating magnitudes are added and welfare destroying magnitudes are subtracted. Among the former are education expenditure and health expenditure, while among the latter are defensive expenditures, costs of

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environmental degradation, natural resource extinction, noise pollution, cost of biodiversity loss, climate change costs, and air and water pollution costs etc. (Bagstad et al., 2014).

The depth of the magnitudes involved in the calculation of the ISEW is huge and goes through to the roots of Fisher's psychic income (Fisher, 1906) to account for human capital (Lawn, 2003). Beça and Santos (2010) present a calculation of the ISEW also including social factors such as value of household labor, cost of unintentional accidents, cost of crime, cost of leisure time, cost of family breakdown, cost of underemployment and cost of harmful lifestyle. Due to lack of availability to sophisticated data across countries, the ISEW calculated in his paper does not contain social variables. It also contains some of the environmental variables based on availability.

Up to date, Menegaki and Tugcu (2016) have produced the first piece of research that studies the energy-welfare growth nexus in sub-Saharan countries within this perspective. Hence, the questions typically raised in the conventional energy-economic growth nexus, for instance, how much total energy consumption or parts of energy consumption (nuclear, coal, oil, renewable etc.) contribute to economic growth, need to be compared with their sustainable economic welfare counterparts and be reformulated under the lens of sustainability concerns. Foremost, governments would be interested to know how much energy conservation measures may retard sustainable economic welfare, since conservation of energy without hindering sustainable economic welfare is a target for many of them.

The interest in studying emerging economies in this framework stems from the fact that they are large energy consumers because of their population size (which equals to about 80% of the global population) and the significant growth in investment and production taking place within their economies. Emerging economies are typically low or middle income countries undertaking serious developments and reforms, opening their markets to “emerge” in the global market. Economic growth of emerging countries has been accompanied by environmental and social costs.

In addition to that, nowadays, all countries are facing international pressure to comply with new guidelines about sustainability and to reach certain targets about climate change and renewable energy penetration. Europe in its sustainable strategy aims for 2020 has the following three priorities: To develop economies based on knowledge and innovation, to promote green and resource efficient economies and foster high employment with social and territorial cohesion (European Commission, 2010). Large emerging economies such as China have realized the importance of sustainability and thus set reduced economic growth targets (a reduction by 7% in 2015) in order to put the country to a more sustainable level of growth path (International Business Times, 2015). United nations Rio + 20 conference participating countries namely, all in our sample, have stipulated on the following: greening of the economies in a context of sustainable development and poverty eradication as well as setting and safeguarding the institutional framework for sustainable development (United Nations, 2015). However, the Doha amendment to the Kyoto Protocol, which is the second commitment period of the Kyoto Protocol that began in January 2013 to December 2020 and has been ratified only by few of the countries in our sample such as China, Indonesia, Mexico, Morocco, and South Africa (United Nations Framework on Climate Change, 2015) required that 75% of the parties to the Kyoto Protocol sign for this amendment to enter into force (United Nations Framework Convention on Climate Change, 2014). Being the core of all these international agreements, sustainability reveals the timeliness of the answers the energy-growth nexus study can provide, and hence a fresh research interest is more than justified. Thus, the novelty of our paper is threefold:

1) We summarize previous work on the energy-GDP growth nexus and expand on it.
2) We calculate the BISEW and SISEW for a set of 16 countries of emerging economies. Then we perform an econometric analysis of the energy-welfare nexus, the analytic procedure being similar to that of item 1.
3) We evaluate the results of both item 1 and item 2, so as to highlight insights on both the energy-welfare nexus and the usefulness and shortcomings of the econometric method.

The rest of this paper is organized as follows: After this brief introduction, we continue with a literature review on the energy-growth nexus for emerging countries as the second section. The third section discusses the sustainability and sustainable economic welfare for emerging countries, the fourth section shows the data and empirical analysis with results, while the last section concludes the paper.

Literature review of the energy-GDP growth nexus in emerging countries

The energy-growth nexus studies so far have identified four hypotheses on the effects energy conservation measures have on economic growth. To identify the existence of the hypotheses, Granger causality tools are employed. The Granger causality test is a statistical hypothesis test for determining whether one time series or panel data is useful in forecasting another. It can be said that a variable X that evolves over time, Granger causes another evolving variable Y, if predictions of the value of Y based on its own past values and on the past values of X are better than predictions of Y based only on its own past values. When an observation of the variable X Granger causes an observation of the variable Y, the patterns in X are approximately repeated in Y after some time lag.

Thus, if Granger's causality shows an increase (decrease) in energy consumption to consistently precede a corresponding increase (decrease) in GDP, we can say that increasing energy consumption has Granger-caused GDP growth or that decreasing energy consumption has Granger-caused a decrease in GDP. This gives reason to hypothesize that changes in energy consumption may cause corresponding changes in GDP. That is, the given statistical correlation suggests that a nation might promote GDP growth by promoting energy consumption.

Energy can be used in ways that promote economic growth or in ways that do not promote it and a full analysis of the hypothesis is not provided by the Granger method. Furthermore, a trend present during one period of time cannot necessarily predict the trend at another time.

Having said the above, next we explain in brief, what the content of the four hypotheses is. Also, we use the following notation for the content and direction of effect: G: growth, E: energy consumption, →: is causing, ↔: mutual causing and ~: no causal relationship.

i) Conservation hypothesis (G→E)
When the Granger method shows uni-directional causality running from GDP growth to energy consumption growth, the “conservation hypothesis” is suggested. That is, the statistical analysis may be used to support the hypothesis that efforts to conserve energy will not lead to a decrease in GDP and may even lead to an increase in GDP. However, just as energy may be used to support GDP growth or to not support it, differing energy conservation measures may differ in their effects on the economy. One may reasonably expect that certain energy conservation measures may promote (or at least not hinder) economic growth, even in an economy for which Granger causality supports the growth hypothesis. In all cases, analysis beyond the Granger method may either support or weaken the hypothesis.

ii) Growth hypothesis (E→G)
The “growth hypothesis” is characterized by uni-directional causality running from energy consumption to economic growth. In such a situation, conservation measures will hinder economic growth because energy consumption is very important for economic growth to take place, either directly or indirectly, as a complement to labor and capital (Apergis and Payne, 2012). The

growth hypothesis entails that increases in energy consumption increase economic growth, while decreases in energy consumption decrease economic growth.

iii) Feedback hypothesis (E↔G)
The "feedback hypothesis" is suggested when the Granger method shows bi-directional causality running from energy consumption to economic growth and then vice-versa. The corresponding hypothesis is that conservation measures will impact on economic growth and changes on economic growth will impact on energy consumption as well. The hypothesis to be examined in this case is that an economy may initiate an upward trend in both GDP and energy consumption by promoting either one of them and, conversely, a nation may set off a downward spiral of both GDP and energy consumption by implementing measures that promotes a decrease in either one of them.

iv) Neutrality hypothesis (G~E)
The "neutrality hypothesis" is characterized by the absence of any causality between energy consumption and economic growth. Energy consumption does not play a pivotal role in economic growth and economic growth does not impact on energy consumption. For economies where these two magnitudes are independent from each other, that means that growth is driven by other factors.

Few energy-growth nexus studies produce results at an aggregate level for emerging economies. For example, Sadorsky (2009) studies the relationship between renewable energy and economic growth in emerging countries and finds support for the conservation hypothesis (i.e. G→E); that is, a growing economy might lead to an increase in renewable energy consumption and a decrease in renewable energy consumption might not detract from economic growth. Apergis and Payne (2010) also find support for the conservation and feedback hypotheses (namely that renewable energy consumption increases economic growth and vice-versa (i.e. E↔G)) in their research on renewable electricity consumption-economic growth nexus for emerging countries. The rest of the studies provide different results for different emerging countries or sub-groups of emerging countries.

To demonstrate how the results of a Granger analysis may differ depending on the type of energy and on the economy studied, we have classified the relevant literature under the two broad groups shown in Table 1. The first group termed as "total energy consumption-economic growth literature" and the second group termed as "partial energy consumption-economic growth literature", which originates from papers that isolate various parts of energy consumption, for instance nuclear energy consumption, renewable energy consumption or even only a part of renewable energy consumption, but not the total quantity of that, as is done in Group 1.

In Table 1, the results of each study are characterized as supporting one of the four hypotheses discussed above.

In some cases, a single study is shown to support more than one hypothesis. This is because the study included analyses for more than one type of energy source. For example, Pao and Fu (2013b) found that in Brazil, analysis of non-hydroelectric renewable energy consumption supported the growth hypothesis (i.e. E→G) while the analysis of total renewable energy consumption supported the feedback hypothesis (i.e. E↔G). Also in Hungary, Omri et al. (2015) found support for the growth hypothesis (i.e. E→G) in renewable energy consumption and support for the neutrality hypothesis (i.e. E~G) for nuclear energy consumption.

It is also noteworthy that, for a single country, differing studies find support for differing hypotheses. Studies by various researchers based on total energy consumption in Indonesia, for example, provide support for any of the four hypotheses. When support of different hypotheses in the same study is the case, this is due to the different time horizon causality results. For example, Soares et al. (2014) find support of the neutrality hypothesis (i.e. E~G) in the long-run, and support for the conservation hypothesis (i.e. G→E) in the short-run. On the other hand, support of different hypotheses across authors is due to the different data time spans and the different methods of analysis. For example, Yildirim et al. (2014) for Indonesia find support for the conservation hypothesis (i.e. G→E), while Chiou-Wei et al. (2008) find support for the growth hypothesis (i.e. E→G). However, the two studies peruse different methods (bootstrap corrected panel and time series analysis for the former and non-linear Granger causality for the latter) and different time periods. The former uses data from 1971 to 2009, while the latter uses data from 1954 to 2006.

Overall, roughly the same number of findings (studies) has been collected for the two main groups in Table 1. There are more findings providing support for the conservation hypothesis (i.e. G→E) in Group 1, rather than Group 2. In the latter group, most studies are concentrated under the growth hypothesis column (i.e. E→G). The smallest number of studies in both groups concerns the neutrality hypothesis (i.e. G~E). Growth in these countries is probably led by less energy intensive production sectors. Also, there are countries with a balanced number of studies across the two main groups, such as Turkey and South Africa, but there are also countries with a dearth of studies in Group 1, such as Chile, China and Colombia. Similarly, we observe countries with no studies falling within Group 2 such as: Morocco and the Philippines.

Our results are included in Table 1 and are denoted with the phrase "current study". Our results for Brazil, Chile, China, Colombia, Hungary, India and Mexico have not been encountered in the literature so far. However, results for Indonesia, Malaysia, Mexico, Morocco, Philippines, Poland, South Africa, Thailand and Turkey have been found in other studies and are also supported in ours.

To facilitate comparison, we have also placed in Table 1 our findings with respect to the energy-sustainable economic welfare nexus (demonstrated in the Concluding remarks section of the current paper). We denote these findings with the notation "current paper" too. These results are either the first ones to be reported to support a certain hypothesis in a specific country or they are supporting already observed results but within the conventional energy-GDP growth nexus. The former are noted for countries such as Brazil, Colombia, Hungary and the latter are observed for Indonesia, Malaysia, Poland, South Africa, Thailand and Turkey.

The calculation of the Index of Sustainable Economic Welfare for emerging economies

To the best of our knowledge, the calculation of an ISEW has not been uniformly calculated for the emerging economies. The only emerging economies for which an ISEW has been calculated and published in the Scopus bibliographic database are: Brazil (Torras, 2005), Chile (Castañeda, 1999), China (Cheng et al., 2005; Xiu et al., 2007), Indonesia (Torras, 2005), and Thailand (Clarke, 2004; Clarke and Islam, 2005). Therefore, there was a need to calculate ISEW through a uniform method and using a consistent data base for all of the 16 emerging economies we include in our analysis.

Our formal proposition of the ISEW for the emerging countries is the following (Menegaki and Tsagarakis, 2015):

$$\text{BISEW} = C_w + G_{eh} + K_n + S \tag{1}$$

$$\text{SISEW} = \text{BISEW} - \sum_{i=1}^{4} N_i \tag{2}$$

where C_w is the weighted consumption, G_{eh} stands for non-defensive public expenditure, K_n is the net capital growth, S is the unpaid work benefit, and N is the depletion of natural environment. The parameters shown in Eqs. (1) & (2) (except for S) are also defined in Table 2 with more detail. And a detailed example of the ISEW calculations for 2003 are shown in Table 7.

Table 1
Literature review of the energy-growth nexus in emerging countries.

	Total energy consumption & economic growth (Group 1)				Partial energy consumption & economic growth (Group 2)			
	Conservation (G→E)	Growth (E→G)	Feedback (E↔G)	Neutrality (E~G)	Conservation (G→E)	Growth (E→G)	Feedback (E↔G)	Neutrality (E~G)
Brazil	Pao and Fu (2013a)	Current paper	Current paper		Pao and Fu (2013b) non-renewable/renewable	Yoo and Kwak (2010) electricity Pao and Fu (2013b) non-hydro renewable energy Bildirici et al. (2012) electricity	Omri et al. (2015) renewable Pao and Fu (2013b) renewable	Cowan et al. (2014) electricity
Chile		Joo et al. (2015)	Current paper			Yoo and Kwak (2010) electricity		
China			Current paper			Bildirici et al. (2012) electricity		Cowan et al. (2014) electricity
Colombia		Current paper	Current paper			Yoo and Kwak (2010) electricity		
Hungary		Current paper	Ozturk and Acaravci (2010) Caraiani et al. (2015)	Current paper	Caraiani et al. (2015), gas/renewable	Omri et al. (2015), renewable		Omri et al. (2015), nuclear
India		Chang et al. (2013)	Current paper		Bildirici et al. (2012) electricity	Omri et al. (2015) renewable		Cowan et al. (2014) electricity
Indonesia	Hwang and Yoo (2014) Soares et al. (2014) Yildirim et al. (2014) Shahbaz et al. (2013) Aslan and Kum (2010)	Pao et al. (2014) Asafu-Adjaye (2000) Chiou-Wei et al. (2008) Current paper	Current paper	Soares et al. (2014) Razzaqi et al. (2011) Asafu-Adjaye (2000)	Yoo (2006) electricity	Pao et al. (2014) renewable Chandran and Tang (2013) transport energy	Pao et al. (2014) nuclear	
Malaysia	Yildirim et al. (2014) Saboori and Sulaiman (2013) Islam et al. (2013) Ang (2008)	Aslan and Kum (2010) Chiou-Wei et al. (2008)	Tang (2008) Tang and Tan (2014) Current paper	Saboori and Sulaiman (2013)		Chandran and Tang (2013) transport energy Chandran et al. (2010) electricity	Yoo (2006) electricity Tang and Tan (2013) electricity Tang (2008) electricity	
Mexico	Bozoklu and Yilanci (2013) Galindo (2005)	Pao et al. (2014)	Pao et al. (2014)	Current paper		Pao et al. (2014) renewable	Pao et al. (2014) nuclear	
Morocco		Raheem and Yusuf (2015)		Issa Shahateet (2014) Current paper				
Philippines	Yildirim et al. (2014) Aslan and Kum (2010) Chiou-Wei et al. (2008) Current paper	Chang et al. (2013)	Asafu-Adjaye (2000)					
Poland	Lach (2015) Current paper	Lach (2015) Current paper		Wolde-Rufael (2014), Current paper	Caraiani et al. (2015), gas	Bildirici and Özaksoy (2013), biomass Caraiani et al. (2015) primary energy		Gurgul and Lach (2011) coal
S. Africa	Esso (2010a) Esso (2010b)	Odhiambo (2012) Raheem and Yusuf (2015) Current paper	Current paper	Liu (2013) Current paper	Cowan et al. (2014) electricity Bildirici et al. (2012) electricity		Bildirici et al. (2012) electricity	
Thailand		Aslan and Kum (2010) Current paper	Asafu-Adjaye (2000) Yildirim et al. (2014) Chang et al. (2013)	Chiou-Wei et al. (2008)	Yoo (2006) electricity			
Turkey	Ozun and Cifter (2007) Ozturk et al. (2013) Current paper	Pao et al. (2014)	Ozun and Cifter (2007) Fuinhas and Marques (2012)	Nazlioglu et al. (2014)	Bildirici et al. (2012) electricity Ocal and Aslan (2013) renewable Caraiani et al. (2015) electricity		Aslan (2014) electricity Aytaç and Güran (2011) electricity	Ocal et al. (2013) coal
Total number of studies	20	15	11	9	11	15	10	6

Table 2
ISEW components, sign, calculation methods and data sources.

Component	Sign	Calculation method	Source/available from
1. Adjusted personal consumption with durables (C_w)	+	We multiplied personal consumption and durables' expenditure (PC) with Gini coefficient (G) and poverty index (P) as: PC × (1 − G) × (1 − P)	PC: http://data.worldbank.org/indicator/NE.CON.PRVT.CDT.CD Gini coefficient: http://data.worldbank.org/indicator/SI.POV.GINI Poverty index (headcount ratio): http://data.worldbank.org/indicator/SI.POV.2DAY
2. Education expenditure (G_{eh})	+	Public expenditure on education (current operating expenditures in education, including wages and salaries and excluding capital investments in buildings and equipment). Assuming that half of it is defensive, we multiply this amount by 50%.	http://data.worldbank.org/indicator/NY.ADJ.AEDU.CD
3. Health expenditure (G_{eh})	+	Public health expenditure is also multiplied with 50% for the same reason as above.	http://data.worldbank.org/indicator/SH.XPD.PUBL
4. Net capital growth (K_n)	±	We have used data on fixed capital accumulation (FCA). We subtracted consumption of fixed capital (CFC) to find the net capital and then calculated its growth rate.	FCA: http://data.worldbank.org/indicator/NE.GDI.TOTL.CD CFC: http://data.worldbank.org/indicator/NY.ADJ.DKAP.CD
5. Mineral depletion (N_1)	−	Mineral depletion is the ratio of the value of the stock of mineral resources to the remaining reserve lifetime (capped at 25 years). It covers tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite, and phosphate.	http://data.worldbank.org/indicator/NY.ADJ.DMIN.CD
6. Energy depletion (N_2)	−	It is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years). It covers coal, crude oil, and natural gas.	http://data.worldbank.org/indicator/NY.ADJ.DNGY.CD
7. Forest depletion (N_3)	−	Net forest depletion is calculated as the product of unit resource rents and the excess of roundwood harvest over natural growth.	http://data.worldbank.org/indicator/NY.ADJ.DFOR.CD
8. Damage from CO_2 emissions (climate change-long-run environmental damage) (N_4)	−	It is estimated to be $20 per ton of carbon dioxide (the unit damage in 1995 U.S. dollars) times the number of tons of carbon dioxide emitted. World bank estimations are based on Samuel Fankhauser's "Valuing Climate Change: The Economics of the Greenhouse" (1995). No other greenhouse gases are included.	http://data.worldbank.org/indicator/NY.ADJ.DCO2.CD

Note: This type of ISEW calculation has been applied by Menegaki and Tsagarakis (2015). The notation following the definition of components in this table is the one in Eqs. (1) & (2). Due to data lack, S has not been calculated and is not included in the table.

Fig. 1 provides an overview of the differences between GDP/capita, the BISEW/capita and the SISEW/capita. Apparently, very small differences exist between BISEW and SISEW in countries such as Hungary, India, Indonesia, Morocco, Philippines, Poland, South Africa and Turkey.

Next, Fig. 2 (divided into four sub-graphs to improve its readability) shows the exact percentage difference between sustainable economic welfare and GDP with reference point being the GDP. Thus, the difference is derived from the ratio (GDP − SISEW)/GDP. Based on this figure, the lowest difference between the sustainable economic welfare and GDP is observed in Thailand and the highest in South Africa. This means that the difference of the SISEW from GDP is 44% of GDP in Thailand, while this is 93% in South Africa for the whole period of 1995–2013.

Foremost this difference is shown to have a rather decreasing trend, with the exception of some countries where it is mostly stable, such as in Turkey or Poland in Part 4 of Fig. 2. A decreasing trend indicates that GDP is generally increasing at a faster rate than SISEW. This might indicate that, by focusing on GDP as a measure of welfare, we are overestimating the extent of welfare improvement during 1995–2013.

Data and empirical analysis

As emerging economies we have used 16 countries available in Morgan Stanley Capital Income MSCI emerging economy category (www.mscibarra.com) for which there were available data for the calculation of the BISEW and SISEW. From those countries we have retained only 15 because only those offered full available data for the purpose of energy-GDP growth and energy-welfare model estimation. Following the typical inclusion of control variables in the production function that reduce bias from omitted variables (Camarero et al., 2015; Menegaki, 2014), our data set includes GDP per capita in current US dollars (GDPPC), gross fixed capital formation in current US dollars (GFCF), total labor force (LABOR), the sum of exports and imports of goods and services measured as a share of GDP in current US dollars (OPENNESS) and energy consumption per capita measured as kg of oil equivalent (ENERGY). The data set covers annual panel data covering the period 1995–2013. All the panel series were attained from World Bank, World Development Indicators database. The data used for the calculation of the ISEW have been presented in the Unit root testing section.

Unit root testing

Panel unit root tests are applied in order to examine whether a panel data variable is stationary.[1] Necessary precondition for implementing an Engle–Granger based panel cointegration analysis is to provide that the variables in consideration are integrated of order one. In this regard, panel unit root tests developed by Im et al. (2003) (IPS) and Choi (2001) (Fisher ADF) were utilized and findings were reported in Table 3.

The first test (Im et al., 2003) is based on the following specification:

$$\Delta y_{i,t} = \rho_i y_{i,t-1} + \sum_{j=1}^{\rho_i} \delta_{i,j} \Delta y_{i,t-j} + \varepsilon_{i,t}. \tag{3}$$

It assumes p_i to be heterogeneous across the different countries. The null hypothesis is H_0: $p_i = 0$ against the alternative H_1:$p_i < 0$ $(i = 1, \ldots N_i)$; $\rho_i = 0$ $(i = N_1 \ldots N)$ for all i. Acceptance of the alternative hypothesis allows the panel data series to be integrated. Integration concerns the stability of a linear combination of variables.

The second test (Choi, 2001) is based on the following specification:

$$\Delta y_t = a + \beta_t + \gamma y_{t-1} + \delta_1 \Delta y_{t-1} + \ldots + \delta_{\rho-1} \Delta y_{t-\rho+1} + \varepsilon_t.$$

p is the lag order of the autoregressive process which is determined by the minimum AIC (Akaike Information Criterion). The rejection of the H_0: $\gamma = 0$ versus the H_1:$\gamma < 0$ entails that no unit root is present. Acceptance of the null hypothesis suggests using differences to make variables stationary. More detailed information on stationarity tests, cointegration and causality work is available in all standard econometrics textbooks, e.g. (Maddala, 1992).

According to IPS and Fisher–ADF test results, there is no restriction for conducting an Engle–Granger based panel cointegration analysis.

[1] Stationarity is a very important property of a time series variable or a panel data variable and means that the mean and variance of a series do not change over time.

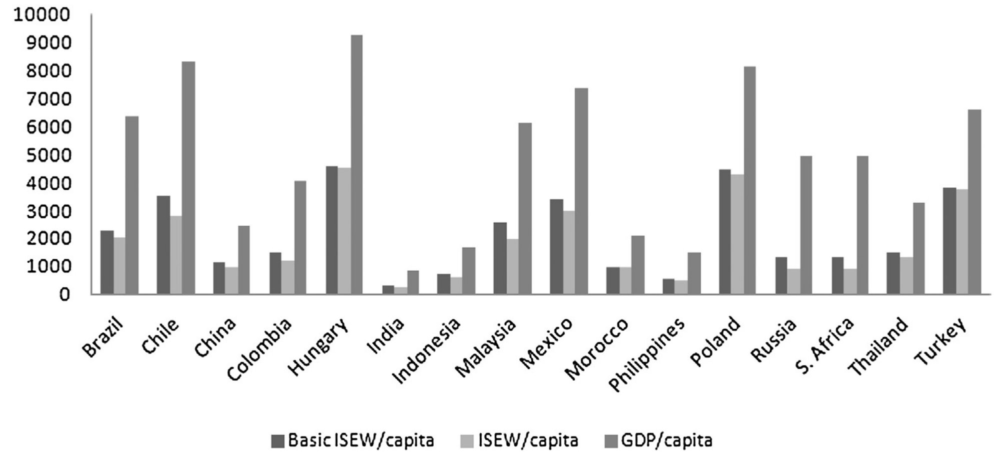

Fig. 1. GDP/capita, SISEW/capita and BISEW/capita in the years 1995–2013.

Based on the results from Table 3, we observe that none of the variables are stationary at levels (note that p-values are not smaller than 5%). This means that we cannot use them for estimation since regressions will be spurious. On the other hand, we observe that taking first differences of the variables solves the problem of non-stationarity (p-values are smaller

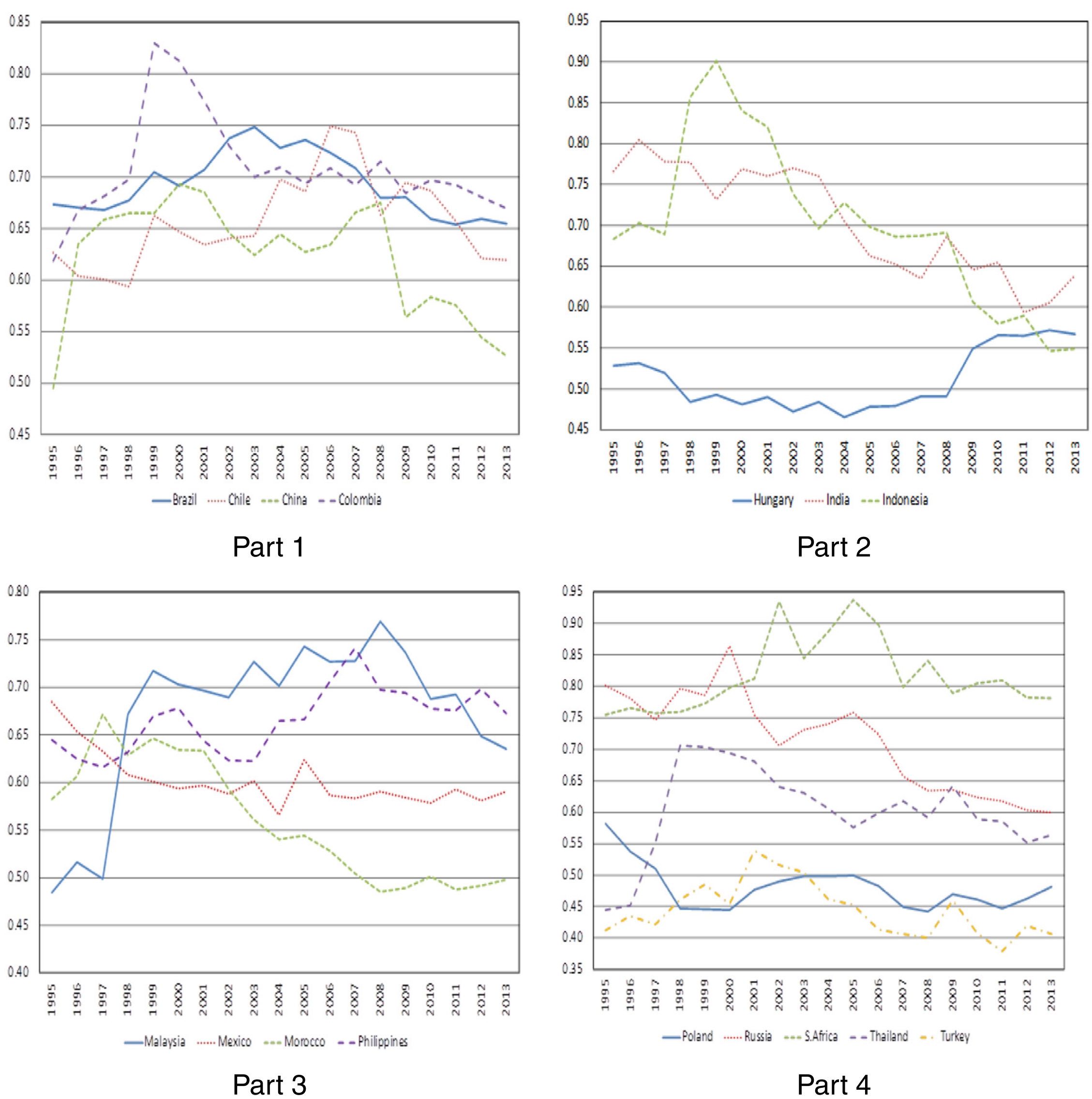

Fig. 2. Percentage difference of SISEW/capita from GDP/capita.

Table 3
Panel unit root test results.

Variables	IPS				Fisher–ADF			
	Constant		Constant & trend		Constant		Constant & trend	
GDPPC	6.117	(1.000)	1.660	(0.951)	5.967	(1.000)	1.701	(0.955)
SISEW	4.609	(1.000)	0.574	(0.717)	4.476	(1.000)	0.558	(0.711)
BISEW	5.168	(1.000)	0.205	(0.581)	5.042	(1.000)	0.293	(0.615)
GFCF	5.203	(1.000)	1.964	(0.975)	5.077	(1.000)	2.013	(0.977)
LABOR	0.517	(0.697)	1.491	(0.932)	0.590	(0.722)	1.511	(0.934)
OPENNESS	0.244	(0.596)	−0.850	(0.197)	0.221	(0.587)	−0.895	(0.185)
ENERGY	3.538	(0.999)	0.289	(0.613)	3.428	(0.999)	0.230	(0.591)
ΔGDPPC	−7.142	(0.000)	−5.687	(0.000)	−6.922	(0.000)	−5.475	(0.000)
ΔSISEW	−9.367	(0.000)	−8.665	(0.000)	−8.638	(0.000)	−7.669	(0.000)
ΔBISEW	−8.250	(0.000)	−6.702	(0.000)	−7.851	(0.000)	−6.233	(0.000)
ΔGFCF	−6.135	(0.000)	−4.772	(0.000)	−6.125	(0.000)	−4.686	(0.000)
ΔLABOR	−7.359	(0.000)	−6.319	(0.000)	−6.697	(0.000)	−5.438	(0.000)
ΔOPENNESS	−12.343	(0.000)	−10.665	(0.000)	−10.505	(0.000)	−8.964	(0.000)
ΔENERGY	−9.724	(0.000)	−8.109	(0.000)	−8.669	(0.000)	−7.100	(0.000)

Notes: Δ is the first-difference operator. Numbers in parentheses are p-values.

than 5%) and thus we will use first differences of the variables in the estimations that follow.

Cointegration

Cointegration analyses are used to investigate whether the variables in consideration move along the same path over the long-run. In this regard, these kinds of analyses are important especially for macroeconomics that is intended to deal with the aggregate behavior of different economic agents. Besides, availability of a cointegration relationship among the variables indicates that causality should exist in at least one direction. Thus, cointegration relation may be accepted as a necessary condition for the causal relationships.

Since the variables in consideration are integrated of order one, this study employs an Engle–Granger based panel cointegration analysis which was developed by Pedroni (1999, 2004) for the investigation of a possible cointegration relationship. A stationary linear combination of the variables converges to a long-run equilibrium over time and this is called the cointegrating equation.

Pedroni (1999, 2004) has proposed seven test statistics that assume that the variables are not level-stationary and the cointegration vector is heterogeneous across the cross-section units. In this sense, the null of no cointegration among energy consumption and welfare indicators was tested against the alternative hypothesis of cointegration by using the tests, four of which are termed as "panel statistics" and the others as "group statistics". The first four are the so-called panel cointegration statistics that are pooled across different countries taking into account time and heterogeneity across countries. The last three are based on averages of the individual autoregressive coefficients for each country. Both types of tests follow a standard normal distribution asymptotically. We estimate GDP per capita, BISEW per capita, and SISEW per capita using the same procedure and the same independent variables, namely labor, exports and imports and energy consumption (in first differences). Findings presented in Table 4 show that in all three models there is a cointegration relationship in terms of energy consumption and is verified by the perused tests.

Causality

As aforementioned, while cointegration suggests that there may be a causal relationship, it does not reveal its direction. In order to investigate the direction of the causal relationship between energy consumption and economic welfare indicators as well as the conventional GDP, the present study employs a bootstrap panel Granger causality test which was developed by Konya (2006). In the light of the existing literature, causality analysis is based on a functional relationship which can be simply formulated in the following manner:

$$Y = f(C, L, O, E) \tag{4}$$

where Y is the vector of dependent variables (i.e. GDP per capita, SISEW per capita and BISEW per capita), C is the gross fixed capital formation, L is the total labor force, O is the trade openness ratio and E is the energy consumption. The causality analysis is built on a system that contains two sets of equations which are presented below (Konya, 2006: 981):

$$\begin{aligned}
y_{1,t} &= \alpha_{1,1} + \sum_{l=1}^{mly_1} \beta_{1,1,l} y_{1,t-1} + \sum_{l=1}^{mlx_1} \gamma_{1,1,l} x_{1,t-1} + \varepsilon_{1,1,t} \\
y_{2,t} &= \alpha_{1,2} + \sum_{l=1}^{mly_1} \beta_{1,2,l} y_{2,t-1} + \sum_{l=1}^{mlx_1} \gamma_{1,2,l} x_{2,t-1} + \varepsilon_{1,2,t} \\
&\vdots \\
y_{N,t} &= \alpha_{1,N} + \sum_{l=1}^{mly_1} \beta_{1,N,l} y_{N,t-1} + \sum_{l=1}^{mlx_1} \gamma_{1,N,l} x_{N,t-1} + \varepsilon_{1,N,t}
\end{aligned} \tag{5}$$

and

$$\begin{aligned}
x_{1,t} &= \alpha_{2,1} + \sum_{l=1}^{mly_2} \beta_{2,1,l} y_{1,t-1} + \sum_{l=1}^{mlx_2} \gamma_{2,1,l} x_{1,t-1} + \varepsilon_{2,1,t} \\
x_{2,t} &= \alpha_{2,2} + \sum_{l=1}^{mly_2} \beta_{2,2,l} y_{2,t-1} + \sum_{l=1}^{mlx_2} \gamma_{2,2,l} x_{2,t-1} + \varepsilon_{2,2,t} \\
&\vdots \\
x_{N,t} &= \alpha_{2,N} + \sum_{l=1}^{mly_2} \beta_{2,N,l} y_{N,t-1} + \sum_{l=1}^{mlx_2} \gamma_{2,N,l} x_{N,t-1} + \varepsilon_{2,N,t}
\end{aligned} \tag{6}$$

where y is the vector of dependent variables, x is the vector of independent variables, N is the number of cross-section units, t is the

Table 4
Panel cointegration test results.

Statistics	GDP per capita	SISEW per capita	BISEW per capita
Panel-v	−1.494 (0.932)	−1.676 (0.953)	−1.807 (0.964)
Panel-rho	3.111 (0.999)	2.716 (0.996)	2.843 (0.997)
Panel-PP	−6.465 (0.000)*	−2.517 (0.005)*	−3.854 (<0.001)*
Panel-ADF	−5.158 (0.000)*	−3.943 (0.000)*	−4.567 (0.000)*
Group-rho	4.677 (1.000)	3.934 (1.000)	3.773 (0.999)
Group-PP	−9.904 (0.000)*	−7.243 (0.000)*	−6.660 (0.000)*
Group-ADF	−4.271 (0.000)*	−5.867 (0.000)*	−5.543 (0.000)*

Note: Numbers in parentheses are p-values. Asterisk denotes significance at 5%.

time interval and l is the lag length. According to Konya (2006: 981), this specification has two distinctive features. First, each equation in Eq. (5) and also in Eq. (6) has different predetermined variables. The only possible link among individual regressions is the contemporaneous correlation within the systems. Hence, these sets of equations are SUR systems. A set of equations that has contemporaneous cross-equation error correlation (i.e. the error terms in the regression equations are correlated) is called a seemingly unrelated regression (SUR) system. The SUR is a generalization of a linear regression model that consists of several regression equations, each having its own dependent variable and potentially different sets of exogenous explanatory variables.

Second, since country specific bootstrap critical values are used, y_t and x_t are not supposed to be stationary. They denote the levels of economic growth indicators, irrespectively of the time-series properties of these variables.

In terms of the mentioned SUR systems, in country i there is one-way Granger causality running from x to y if in Eq. (5) not all $\gamma_{1,i}$'s are zero but in Eq. (6) all $\beta_{2,i}$'s are zero, there is one-way Granger causality from y to x if in Eq. (5) all $\gamma_{1,i}$'s are zero but in Eq. (6) not all $\beta_{2,i}$'s are zero, there is two-way Granger causality between y and x if neither all $\beta_{2,i}$'s nor all $\gamma_{1,i}$'s are zero, and there is no Granger causality between y and x if all $\beta_{2,i}$'s and $\gamma_{1,i}$'s are zero (Konya, 2006: 981).

Konya (2006) also states that, since the causality test results rely critically on the lag structure, one should determine the optimal lag length. However, there is no simple rule for this purpose. Thus, as offered by the same author (Konya (2006): 982), the present study allows different maximal lags for y and x, but does not allow them to vary across countries. This means that altogether there are four maximal lag parameters. Assuming that their range is 1–4, Eqs. (5) and (6) were estimated for each possible pair of ly_1, lx_1 and ly_2, lx_2, respectively, and the combinations which minimize the Akaike Information Criterion (AIC) were selected.

Estimated causal relationships which are presented in Table 5 show that, except for Hungary and Poland in which there exists no causality in the case of GDP per capita and SISEW per capita, countries have mixed causal patterns. The causal statuses of eight out of the fifteen countries are the same for each model, whereas the other seven exhibit different causal links with respect to energy and the sustainable economic welfare nexus.

Results in Table 5 were estimated by using the TSP software with an econometric code for causality that was developed by Konya (2006). In Table 5, we follow the p-values to decide whether a causal link exists or not. A p-value lower than 0.10 indicates that the variable X (i.e. independent variable) Granger causes Y (i.e. dependent variable). Table 6 further summarizes Table 5 and illustrates the estimated causal relationships between variables in consideration.

The statistics in Table 5 are summarized qualitatively in Table 6, which shows which of the four hypotheses is supported for each country and for each measure of welfare. In this regard Table 6 shows that, for eight out of the fifteen countries, the support of a hypothesis does not change between GDP and SISEW. Furthermore, for 13 of the 15 countries, support of a hypothesis does not change between BISEW and SISEW. These results are some evidence for the sensitivity of the hypotheses with respect to the different measures of welfare, but still no generalizations can be made and future research is necessary.

Furthermore, we observe that for 13 out of the 15 countries in the sample, the same hypothesis is observed for BISEW and SISEW. Also, for 8 out of the 15 countries, the same hypothesis is observed for GDP, BISEW and SISEW and hence no sensitivity of the hypothesis is observed for different measures of welfare.

Concluding remarks

Based on the results from this paper, there are differences for the effects of energy consumption on GDP and on the two variations of ISEW

Table 5
Panel causality test results.

Countries	GDPPC		SISEW		BISEW	
	E→G	G→E	E→G	G→E	E→G	G→E
Brazil	24.867	2.987	5.380	1.714	22.424	1.624
	(0.000)*	(0.083)	(0.020)*	(0.190)	(0.000)*	(0.202)
Chile	4.628	18.618	5.609	32.417	2.825	23.792
	(0.031)	(0.000)*	(0.017)*	(0.000)*	(0.092)	(0.000)*
China	106.923	5.612	111.223	13.511	121.518	3.947
	(0.000)*	(0.017)*	(0.000)*	(0.000)*	(0.000)*	(0.046)*
Colombia	14.490	1.915	91.058	8.510	162.561	11.082
	(0.000)*	(0.166)	(0.000)*	(0.003)*	(0.000)*	(0.000)*
Hungary	2.594	1.072	4.833	0.027	42.268	0.138
	(0.107)	(0.300)	(0.027)*	(0.869)	(0.000)*	(0.709)
India	21.343	38.614	11.455	4.119	5.301	10.989
	(0.000)*	(0.000)*	(0.000)*	(0.042)*	(0.021)*	(0.000)*
Indonesia	46.849	0.017	93.928	4.583	219.941	3.759
	(0.000)*	(0.893)	(0.000)*	(0.032)*	(0.000)*	(0.052)
Malaysia	44.947	4.013	29.919	0.322	94.720	0.003
	(0.000)*	(0.045)*	(0.000)*	(0.570)	(0.000)*	(0.952)
Mexico	50.852	3.400	67.668	11.791	40.420	15.729
	(0.000)*	(0.065)	(0.000)*	(0.000)*	(0.000)*	(0.000)*
Morocco	290.778	16.323	62.294	32.057	65.799	36.903
	(0.000)	(0.000)*	(0.000)*	(0.000)*	(0.000)*	(0.000)*
Philippines	3141.704	1.050	170.412	0.170	117.020	0.140
	(0.000)*	(0.305)	(0.000)*	(0.679)	(0.000)*	(0.707)
Poland	43.241	1.453	2.294	1.082	8.432	2.532
	(0.000)*	(0.227)	(0.129)	(0.298)	(0.003)*	(0.111)
S. Africa	138.554	83.103	10.447	0.006	17.250	82.141
	(0.000)*	(0.000)*	(0.001)*	(0.979)	(0.000)	(0.000)
Thailand	118.751	0.589	76.568	0.177	76.760	0.734
	(0.000)*	(0.442)	(0.000)*	(0.673)	(0.000)*	(0.391)
Turkey	0.194	143.944	2.034	52.142	0.706	87.093
	(0.658)	(0.000)	(0.153)	(0.000)*	(0.400)	(0.000)*

Note: Numbers in parentheses are p-values. Asterisk denotes significance at 5%.

that we considered. Overall, for 7 out of the 15 sampled countries, under different measures of welfare, the support of different hypotheses applies. The fact that statistical results from different countries support differing hypotheses and causal relationships leads to a reasonable likelihood that there are factors not included in our analysis that impact on the relationship between energy consumption and welfare. Factors not included in our analysis of Granger causality lead to one set of results in one country and a completely different set of results in other countries. The analysis of those factors, some of which might not even be unrecognized today, may lead to useful recommendations as to how an economy can concurrently change welfare and energy consumption in the desired direction. Statistical analyses like the ones used in this paper might help to raise meaningful questions and to formulate useful hypotheses. The widely varying results demonstrated in this paper, however, show that the method does not yield consistent or useful conclusions and policy recommendations.

The causalities observed between SISEW and BISEW are different only between Poland and South Africa. For the rest of the countries with different causality results between GDP and sustainable economic welfare, causality results between SISEW and BISEW are the same.

For Brazil and Malaysia, the statistical method used in this paper supports the feedback hypothesis in regard to GDP. In regard to BISEW and SISEW, however, the growth hypothesis is supported. A possible interpretation of these results is that, if the hypotheses are valid, the effect of considering sustainability (either economic or environmental aspect together or just economic aspects alone) instead of just GDP is to invalidate the possibility of changing energy consumption by changing welfare. That is, policies that cause an increase in GDP would tend to also increase energy consumption but, if ISEW were increased, an increase in energy consumption would not follow. This raises the question of what would happen to energy consumption if both GDP and ISEW were increased. Would the bi-directionality between energy and GDP apply, resulting in an increase in energy? Or would the unidirectionality of energy to ISEW apply, resulting in no change in energy consumption? The fact that energy consumption cannot both increase and not increase at the same time implies that GDP and ISEW could neither increase at the same time nor could one increase while the other decreases at the same time. This however, requires additional research in the future.

Exactly the other way around occurs in Colombia and Indonesia. For these two countries the growth hypothesis applies when conventional GDP is the reference point of the economy. However, in a sustainable economic welfare context, the economy is found in a feedback hypothesis supporting situation which means that conservation measures bear their repercussions on sustainability and this in turn on energy consumption which might end up on a spiral route towards inertia and sustainable economic welfare decline.

Table 6
Country specific hypotheses.

Countries	GDP per capita	SISEW per capita	BISEW per capita
Brazil	Feedback	Growth	Growth
Chile	Feedback	Feedback	Feedback
China	Feedback	Feedback	Feedback
Colombia	Growth	Feedback	Feedback
Hungary	Neutrality	Growth	Growth
India	Feedback	Feedback	Feedback
Indonesia	Growth	Feedback	Feedback
Malaysia	Feedback	Growth	Growth
Mexico	Feedback	Feedback	Feedback
Morocco	Feedback	Feedback	Feedback
Philippines	Growth	Growth	Growth
Poland	Growth	Neutrality	Growth
S. Africa	Feedback	Growth	Feedback
Thailand	Growth	Growth	Growth
Turkey	Conservation	Conservation	Conservation

Table 7
Summary of results for the items building ISEW for emerging economies in 2013 in $.

			Brazil	Chile	China	Colombia	Hungary	India	Indonesia	Malaysia	Mexico	Morocco	Philippines	Poland	S. Africa	Thailand	Turkey
A	+	Private consumption weighted with Gini and poverty indexes	6.20×10^{11}	8.56×10^{10}	1.77×10^{12}	9.45×10^{10}	4.99×10^{10}	3.03×10^{11}	1.70×10^{11}	8.4×10^{10}	4.33×10^{11}	3.16×10^{10}	6.63×10^{10}	2.15×10^{11}	5.73×10^{10}	1.23×10^{11}	3.40×10^{11}
B	+	Public education expenditure	1.23×10^{11}	1.22×10^{10}	1.66×10^{11}	1.17×10^{10}	5.83×10^{9}	5.74×10^{10}	2.69×10^{10}	1.33×10^{10}	6.29×10^{10}	5.25×10^{9}	7.83×10^{9}	2.58×10^{10}	2.32×10^{10}	1.48×10^{10}	2.11×10^{10}
C	+	Public health expenditure	5.23×10^{10}	5.08×10^{9}	1.43×10^{11}	9.80×10^{9}	3.41×10^{9}	1.20×10^{10}	5.19×10^{9}	3.46×10^{9}	2.03×10^{10}	1.06×10^{9}	1.89×10^{9}	1.22×10^{11}	7.9×10^{9}	7.10×10^{9}	1.70×10^{10}
D	±	Net capital growth	1.31×10^{11}	3.17×10^{10}	2.88×10^{12}	4.96×10^{10}	2.68×10^{9}	4.26×10^{11}	2.49×10^{11}	4.71×10^{10}	1.16×10^{11}	1.89×10^{10}	2.52×10^{10}	4.08×10^{10}	2.59×10^{10}	5.15×10^{10}	1.26×10^{11}
E	−	Mineral depletion	2.52×10^{10}	2.19×10^{10}	1.28×10^{11}	2.31×10^{9}	309,967	8.69×10^{9}	5.3×10^{9}	6.05×10^{8}	7.10×10^{9}	1.48×10^{9}	5.72×10^{9}	1.15×10^{9}	8.93×10^{9}	1.94×10^{8}	1.48×10^{9}
F	−	Energy depletion	4.14×10^{10}	1.92×10^{8}	2.53×10^{11}	3.13×10^{10}	5.53×10^{8}	3.56×10^{10}	3.34×10^{10}	2.38×10^{10}	7.18×10^{10}	1.29×10^{7}	8.50×10^{8}	2.63×10^{9}	8.04×10^{9}	1.38×10^{10}	1.18×10^{9}
G	−	Forest depletion	1.8×10^{10}	0	4.16×10^{9}	5.95×10^{7}	0	2.26×10^{10}	1.86×10^{9}	0	0	3.32×10^{7}	6.33×10^{8}	1.06×10^{9}	2.38×10^{8}	3.08×10^{9}	0
H	−	Damage from CO_2 emissions	4.56×10^{9}	8.57×10^{8}	1.07×10^{11}	8.98×10^{8}	5.26×10^{8}	2.46×10^{10}	5.31×10^{9}	2.58×10^{9}	4.96×10^{9}	5.82×10^{8}	9.89×10^{8}	3.51×10^{9}	5.07×10^{9}	3.31×10^{9}	3.52×10^{9}
		Population	2×10^{8}	1.76×10^{7}	1.36×10^{9}	4.83×10^{7}	9.89×10^{6}	1.25×10^{9}	2.5×10^{8}	2.97×10^{7}	1.22×10^{8}	3.30×10^{7}	9.84×10^{7}	3.85×10^{7}	5.32×10^{7}	6.70×10^{7}	7.49×10^{7}
		ISEW per capita	3875.67	5991.26	3227.52	2589.60	5841.45	541.36	1566.52	3848.00	4224.09	1580.22	905.03	7077.49	1512.61	2521.57	6516.55
		GDP per capita	11,208.08	15,732.31	6807.43	7831.22	13,485.47	1497.55	3475.25	10,538.06	10,307.28	3145.76	2765.08	13,653.72	6886.29	5778.98	10,971.66

As far as Hungary is concerned, albeit support exists for the neutrality hypothesis in an energy-GDP growth context, the growth hypothesis appears to be the case when sustainable economic welfare is considered. Noteworthy is the fact that Hungary yields some of the lowest differences between the sustainable economic welfare and GDP. Also, it appears that a small difference in the measure of welfare leads to a completely different conclusion as to which hypothesis is supported. Energy consumption tends to not promote GDP growth but it does support ISEW growth. Given that the Hungarian energy sector is highly dependent on fossil fuel, we have results suggesting that increasing the use of fossil fuels supports the more "sustainable" features of economic welfare even though it does not support the growth of GDP, itself. However, this finding needs additional research in the future.

As far as Poland is concerned, it appears to be experiencing a growth hypothesis supporting phase in 1995–2013 when the measures of GDP and BISEW are used, but when the SISEW is used, there is support for the neutrality hypothesis instead. The latter is a positive finding, since energy conservation measures will not harm sustainable economic welfare growth in Poland if what government seeks, is sustainable economic growth and not mere GDP growth or BISEW growth. In both Poland and South Africa, causality results that are observed within a GDP framework coincide with BISEW, but not the SISEW. In one sense the results about Poland are what one would intuitively expect, i.e. that an increase in energy consumption corresponds to an increase in GDP and BISEW. The SISEW is not supposed to increase in this case since the use of fossil energy tends to decrease the value of environmental parameters contained therein. Overall, this country has one of the highest differences between sustainable economic welfare and GDP and this should be taken into account for further research.

In order to interpret the available results, each time, we should take into account the components that build each version of ISEW. For example the "SISEW", besides the economy components, contains negative environmental items that are bound to reduce the ISEW. On the other hand, "BISEW" is centered on private consumption (adjusted for several parameters) which is then added to parameters that generally increase the ISEW. Although, this is a point for our future research, we understand that the addition or subtraction of components creates a new context on which the economy must base its conservation, growth, feedback, and neutrality hypothesis. Of course, a more definite picture will be obtained only when all theoretic components would be in place (the objective ones too).

Since not all possible environmental parameters have been included in the "SISEW", this entails that we may have omitted serious environmental problems existent in one country but non-existent in the other. For example, water pollution may be at very high level in one country, let's say country "x". The fact that we have been unable to find appropriate data to enrich our ISEW with water pollution data, gives the "x" country an inaccurately high SISEW. Suppose that we have another country "z" which suffers from a high level of CO_2 emissions. The fact that our ISEW contains this parameter though, gives this country a SISEW which is lower that the SISEW in country "x". Therefore, our conclusions are applicable strictly at a "ceteris paribus" context.

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