Economics
The Open-Access, Open-Assessment E-Journal

Discussion Paper
No. 2017-28 | June 08, 2017 | http://www.economics-ejournal.org/economics/discussionpapers/2017-28

The Sustainable Development Goals and the systems approach to sustainability

Edward B. Barbier and Joanne C. Burgess

Abstract

The authors explore the link between the systems approach to sustainability and the 17 Sustainable Development Goals (SDGs), which were formally adopted by the UN in 2015. The systems approach depicts sustainable development as the intersection of the goals attributed to three interlinked systems: environmental (or ecological), economic and social. The authors illustrate how each of the 17 SDGs can be characterized as a goal primarily attributed either to the environmental, economic or social system, and as suggested by the systems approach, there may be important tradeoffs in attempting to attain all these goals simultaneously. By adopting standard methods of the theory of choice and welfare under imposed quantities, the authors show that is possible to measure the welfare effects of an increase in the indicator level for one SDG by identifying the tradeoffs that occur with achieving another goal. They present a quantitative assessment of current progress and tradeoffs among the 17 SDGs, using a representative indicator for each goal. They then conduct a preliminary welfare analysis of these tradeoffs through employing the approach developed in this paper. Although this analysis focuses on the potential tradeoffs among SDGs, the approach could also be applied to show complementarities, or "win-wins", in simultaneous progress among two or more SDGs. Such an analysis can help in the design of appropriate policy interventions to achieve specific SDGs, minimizing the potentially negative knock-on effects on some goals whilst capitalizing on the positive win-win impacts on other SDGs.

(Published in Special Issue The Sustainable Development Goals—Assessing interlinkages, trade-offs and synergies for policy design)

JEL Q01 O20 D61 Q56
Keywords Sustainable development; Sustainable Development Goals; systems approach; tradeoffs; United Nations

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Citation Edward B. Barbier and Joanne C. Burgess (2017). The Sustainable Development Goals and the systems approach to sustainability. Economics Discussion Papers, No 2017-28, Kiel Institute for the World Economy. http://www.economics-ejournal.org/economics/discussionpapers/2017-28

Received May 30, 2017 **Accepted as Economics Discussion Paper** June 1, 2017
Published June 8, 2017

Introduction

Economic interpretations of sustainability usually take as their starting point the consensus reached by the World Commission on Environment and Development (WCED 1987), which defined sustainable development as:

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

But despite the universal approval of the WCED definition of sustainability, opinions still diverge on how this goal can be attained. One of the first attempts in economics was the *systems approach*, which characterizes sustainability as the maximization of goals across environmental, economic and social systems (Barbier 1987; Barbier and Markandya 2012; Ekins 1994; Elliott 2006; Holmberg and Sandbrook 1992; Pezzey and Toman 2002). This approach is attributed to Barbier (1987), who first identifies three systems as basic to any process of development: the environmental or ecological system, the economic system and the social system. He then argues that "the general objective of sustainable economic development, then, is to maximize the goals all these systems through an adaptive process of trade-offs" (Barbier 1987, p. 104). This can be represented by a Venn diagram, which depict sustainable development as the intersection of the goals attributed to the environmental, economic and social systems (see Figure 1).

In this paper we explore the link between this systems approach to sustainability and the Sustainable Development Goals (SDGs), which were formally adopted in 2015 by the General Assembly of the United Nations (UN) as its 2030 agenda for sustainable development (UN 2015). The 17 SDGs that comprise this objective are a complex system comprising 169 targets and currently about 230 indicators. The UN agenda emphasizes that the interlinkages and integrated nature of the SDGs are of crucial importance in ensuring that sustainable development is realized. As we show here, each SDG can in fact be identified as primarily an economic, environmental, or social system goal. Thus, collectively the UN's SDG targets can be considered a representation of the systems approach to sustainable economic development.

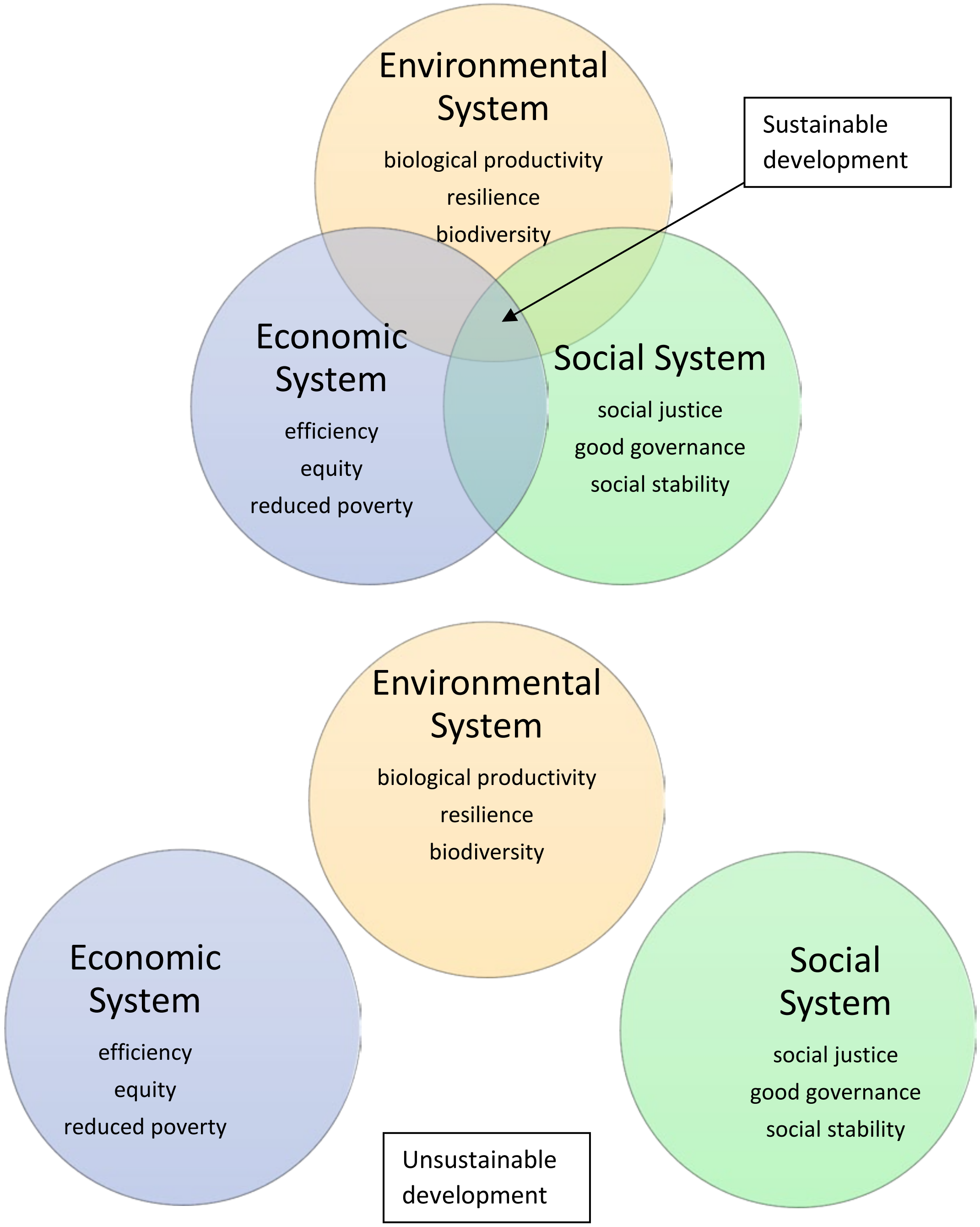
To show this, we first describe and discuss in more detail the systems approach and its relation to the UN SDGs. We illustrate how each of the 17 SDGs can be characterized as a goal primarily attributed either to the environmental, economic or social system, and as suggested by the systems approach, there may be important tradeoffs in attempting to attain all these goals simultaneously. However, to date, a key limitation to the systems approach to sustainability is that "there is no guidance as to how the tradeoffs among the goals of the various systems should be made" (Barbier and Markandya 2012, p. 38). By adopting standard theoretical methods of the theory of choice and welfare under imposed quantities (Freeman 2003; Lankford 1988), we show that is possible to measure the welfare effects of an increase in the indicator level for one SDG by identifying the tradeoffs that occur with achieving another goal. Such an approach could be applied to assessing recent progress in attaining the UN SDGs. Although there is currently insufficient data to employ such a comprehensive and explicit welfare measurement, we present a quantitative assessment of current progress for each of the 17 SDGs, using a representative indicator for each goal. The assessment not only provides a useful summary of the current state of the UN's 2030 sustainability agenda but also helps identify the likely tradeoffs among the SDGs that need further consideration. We then conduct a preliminary assessment of these tradeoffs through employing the welfare analysis approach developed in this paper. Although this analysis focuses on the potential tradeoffs among SDGs, our approach could also be applied to show complementarities, or "win-wins", in simultaneous progress among two or more SDGs.

The next section describes in more detail the systems approach to sustainable development. We then discuss the relevance of this approach to the UN SDGs. Next, we show how the theory of choice and welfare under imposed quantities can be adapted to develop an explicit measure of the welfare effects of an improvement in the indicator level of one SDG that also accounts for possible tradeoffs with other SDGs. The subsequent section presents our quantitative assessment of current progress for each of the 17 SDGs specified in UN (2015), which serves as the basis for our preliminary welfare assessment of the tradeoffs among progress toward these goals. We conclude the paper by outlining key areas for further research and policy analysis of the SDGs and the implications for the UN sustainability agenda.

The Systems Approach to Sustainable Development

The systems approach can be captured in a Venn diagram (see Figure 1), which depicts sustainable development as the intersection of the goals attributed to three interlinked systems: environmental (or ecological), economic and social. The Venn diagram representation of sustainability now has many versions, but was first employed by Barbier (1987). One important insight is that attempting to maximize the goals for just one system does not achieve sustainability, because the impacts on the other systems are ignored (Holmberg and Sandbrook 1992). For example, achieving greater efficiency, equity and reduced poverty in economic systems may still generate unintended environmental and social impacts that undermine ecological and social systems. As shown in Figure 1, the latter approach to development fails to recognize that environmental, economic and social systems are interlinked, and that progress solely focused on one system's goals could have consequences for the other systems.

Figure 1. The Systems Approach to Sustainability



Source: Adapted from Barbier (1987), Figure 1 and Holmberg and Sandbrook (1992), Figure 1.1.

Instead, sustainable development can only be achieved by balancing the tradeoffs among the various goals of the three systems.[1] As explained by Barbier (1987, p. 104), although "each system has its own set of human-ascribed goals", attaining "sustainable development involves a *process of trade-offs* among the various goals of the three systems" as "it is not possible to maximize all these objectives all the time". Attempting to maximize the goals for just one system, or even two, does not achieve sustainability either, because the costs imposed on the other systems are not taken into account. For example, an economic system may be efficient, and even equitable, in the allocation of resources but still generate environmental degradation that threatens biological productivity, biodiversity and resilience.[2] Thus, the economic system should strive for efficiency, equity and poverty reduction, but at the same time account for the impacts on biological productivity, biodiversity and ecological resilience as well as the implications for social justice, good governance and social stability. "The general objective of sustainable economic development, then, is to maximize the goals across all these systems through an adaptive process of trade-offs" (Barbier 1987, 104), which is illustrated by the intersection of the environmental, economic and social systems in the Venn diagram of Figure 1.

Although the systems approach to sustainability has conceptual appeal, it does have practical limitations in terms of applicability and guidance for policy (Barbier and Markandya 2012; Pezzey and Toman 2002). In particular, Barbier and Markandya (2012, p. 38) point out that current application of this approach offer "no guidance as to how the tradeoffs among the goals of the various systems should be made. How should we decide to trade off, for example, more economic efficiency for less biodiversity and ecological resilience?" As suggested by Holmberg and Sandbrook (1992, p. 24), "choices must therefore be made as to which goals should receive greater priority. Different development strategies will assign different priorities."

However, to assist policy makers in making these choices among sustainability goals, it is necessary to know what are the gains and losses – i.e. the different welfare implications – of such choices. That is, if we decide to prioritize improvements towards one goal or set of goals, and there are consequences for achieving another goal, is there likely to be a net gain in welfare from this choice? Later in this paper, we show how such welfare effects and tradeoffs can be

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[1] Although Figure 1 and the original development of the systems approach to sustainability by Barbier (1987) emphasizes the possibility of tradeoffs among the various economic, environmental and social system goals, the interlinkages could be could be positive as well as negative. For example, there could be a positive impact of an improvement in the efficiency in terms of improving the protection of biological productivity and biodiversity in the environmental system. Therefore, as well as taking account of trade-offs, one should look to capitalize on any positive interaction effects across system goals when they arise. In our analysis, potential trade-offs may be lessened by such positive interlinkages, which may also arise across the 17 SDGs identified by the UN (2015).

[2] The term *ecological resilience* usually refers to an ecosystem's ability to absorb large shocks or sustained disturbances and still maintain internal integrity and functioning. This concept of resilience is usually attributable to Holling (1973), who maintains that ecosystems are characterized by multiple locally stable equilibria, or different *ecological regimes*. Hence, a *regime shift* can occur if the ecosystem undergoes a sudden change from one stable equilibrium to another. The resilience of an ecosystem can therefore be thought of the extent to which it can sustain shocks or disturbances before the ecosystem "flips" to an alternative stable state, or ecological regime.

measured explicitly. First, we explore further the link between this systems approach to sustainability and the Sustainable Development Goals (SDGs)

The UN Sustainable Development Goals (SDGs)

In 2015, the General Assembly of the United Nations (UN) adopted 17 sustainable development goals (SDGs). The aim of these goals is to set attainable targets that can achieved as a 2030 agenda for sustainable development; e.g., "the goals and targets will stimulate action over the next 15 years in areas for critical importance for humanity and the planet" (UN 2015, p. 5). The SDGs are further decomposed into 169 targets, and there are currently about 230 indicators that have been proposed for realizing these targets.

The SDG approach adopted by the UN fits well within the systems approach to sustainable development discussed previously. First, the 2030 agenda emphasizes that the SDGs are interlinked, and that ensuring integration across all 17 goals is critical to achieving sustainable development. Second, each of the SDGs can be characterized as a goal primarily attributed either to the economic, environmental or social system.

Table 1 depicts the 17 SDGs of the 2030 agenda (UN 2015), and indicates the system with which it can be mainly associated. For example, there are seven economic system goals, five environmental system goals, and five social system goals.

Re-arranging the 17 SDGs by system, one obtains a revised and updated version of the Venn diagram of sustainability, where the SDGs are now depicted as the new economic, environmental and social system goals (see Figure 2). Grouped in this way, the 17 SDGs represent the UN's goals for attaining sustainable development across the three interlinked systems. Once again, sustainability can only be achieved by balancing the tradeoffs among the various goals of the three systems, and what is required is an analytical approach for estimating these potential tradeoffs to show the gains and losses involved.

Table 1. The 17 Sustainable Development Goals

1. No Poverty: End poverty in all its forms, everywhere (*Economic*)

2. Zero Hunger: End hunger, achieve food security and improved nutrition and promote sustainable agriculture (*Economic*)

3. Good Health and Well Being: Ensure healthy lives and promote well-being for all at all ages (*Economic*)

4. Quality Education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all (*Social*)

5. Gender Equality: Achieve gender equality and empower all women and girls (*Social*)

6. Clean Water and Sanitation: Ensure available and sustainable management of water and sanitation for all (*Economic*)

7. Affordable and Clean Energy: Ensure access to affordable, reliable, sustainable and modern energy for all (*Economic*)

8. Good Jobs and Economic Growth: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (*Economic*)

9. Industry, Innovation and Infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation (*Economic*)

10. Reduced Inequalities: Reduce inequality within and among countries (*Social*)

11. Sustainable Cities and Communities: Make cities and human settlements inclusive, safe, resilient and sustainable (*Environment*)

12. Responsible Consumption and Production: Ensure sustainable consumption and production patterns (*Environment*)

13.Climate Action: Take urgent action to combat climate change and its impacts (*Environment*)

14. Life Below Water: Conserve and sustainably use the oceans, seas and marine resources for sustainable development (*Environment*)

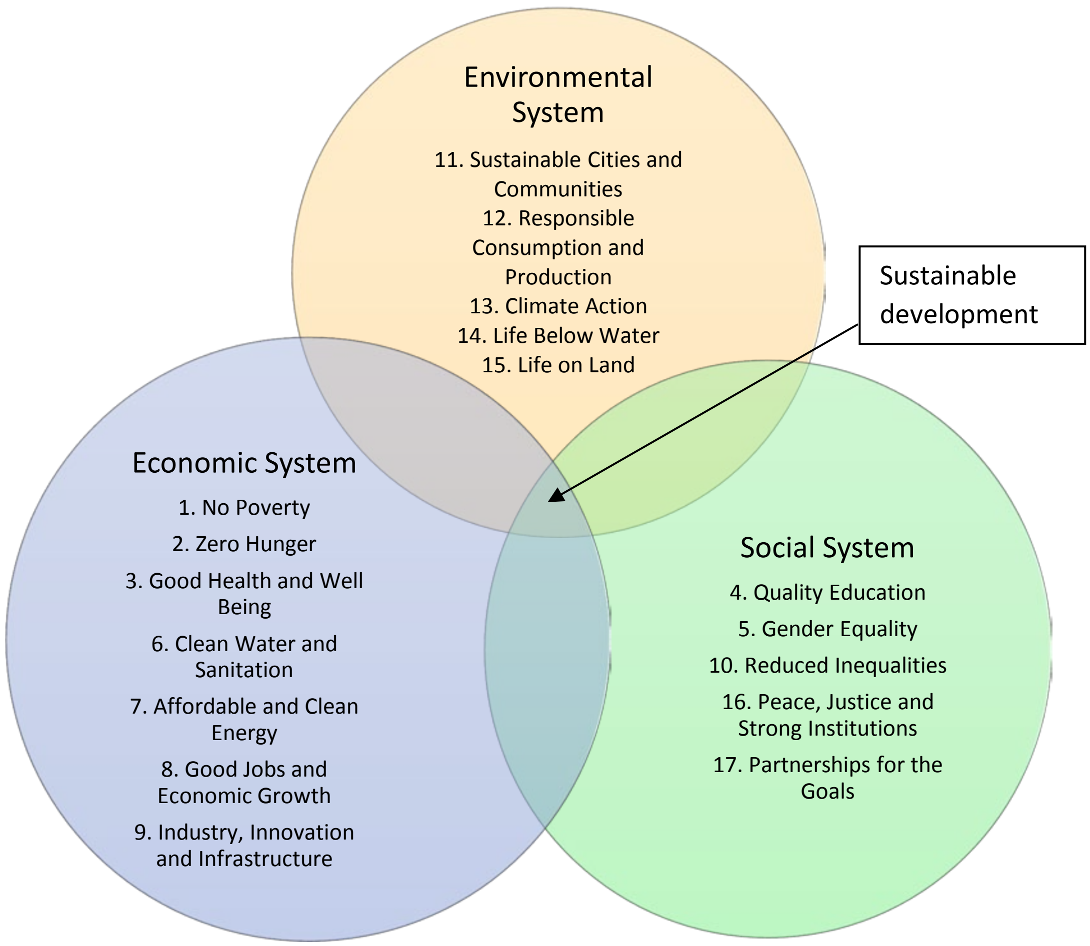
15. Life on Land: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (*Environment*)

16. Peace, Justice and Strong Institutions: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels (*Social*)

17. Partnerships for the Goals: A successful sustainable development agenda requires partnerships between governments, the private sector and civil society. These inclusive partnerships built upon principles and values, a shared vision, and shared goals that place people and the planet at the center, are needed at the global, regional, national and local level (*Social*)

Source: United Nations. *Sustainable Development Goals: 17 Goals to Transform our World*. Available at http://www.un.org/sustainabledevelopment/sustainable-development-goals/ Accessed May 26, 2017.

Figure 2. The Systems Approach to Sustainability Applied to the 17 SDGs



The Welfare Effects of Improvement towards a SDG

Each of the UN's Sustainable Development Goals (SDGs) indicated in Table 1 and Figure 2 represent a fixed endpoint that is achieved through improvement in some measure or indicator to achieve that goal over a given period of time, *T*. For example, the first goal of "No Poverty" presumes that there exists an acceptable indicator of poverty comparable across countries, such as a poverty headcount ratio measured at an international poverty line, and the UN target is to ensure that this ratio is effectively zero for all countries by 2030. However as Table 1 also shows there are different goals, and thus indicators, for each of the three systems of interest – the ecological, economic and social systems. Although it may be possible to make progress across all these goals by 2030, it is more likely that attaining improvement toward one SDG by 2030 may come at the expense of another. For example, we may have achieved progress in reducing poverty over recent years, but over the same time period, the way in which this progress has been achieved – e.g. through economic expansion and industrial growth – may have come at the cost of declines in achieving some environmental or social goals, such as Climate Action or Reduced Inequalities.

As noted previously, one of the major weaknesses of the systems approach to sustainable development is that it has offered "no guidance as to how the tradeoffs among the goals of the various systems should be made" Barbier and Markandya (2012, p. 38). Here, we adopt standard theoretical methods of the theory of choice and welfare under imposed quantities (Freeman 2003; Lankford 1988) to show that is possible to measure the welfare effects of an increase in one SDG that takes into account any tradeoffs with another goal.

Assume that there are a large number of individuals in an economy, and each individual consumes a single composite good *x* that has a market price *p*. A representative individual will choose to allocate his or her income *M* to purchase this marketed good. Suppose that, at the time of the individual's allocation decision, the economy has achieved predetermined indicator levels for *n* different SDGs. For example, in the case of the "No Poverty" SDG example, the indicator level would be the prevailing level of poverty headcount ratio in the economy. Although the welfare of the individual is affected by the economy-wide initial SDG indicator levels, from the individual's point of view, the most important characteristic of these SDG levels is that they are available only in fixed, unalterable quantities. The individual may be able to choose how much of the marketed good to consume but not the SDG indicator levels of the entire economy.

The utility function of the representative individual is therefore

$$u = u\left(x; s\right),\ s = s_1, \ldots s_i, s_j\left(s_i\right), \ldots s_n,\ u_z > 0,\ u_{zz} \leq 0,\ z = x, \mathrm{s},\ \frac{\partial s}{\partial s_i} > 0,\ \frac{\partial s_j}{\partial s_i} \leq 0, \qquad (1)$$

where the vector $s = s_1, \ldots s_i, s_j\left(s_i\right), \ldots s_n$ represents the currently attained indicator levels of the *n* SDGs, and the utility function has the normal concave properties with respect to its main arguments *x* and *s*. The condition $\partial s/\partial s_i > 0$ indicates that an increase in the indicator level of the i^{th} SDG will have a direct beneficial effect on the utility of the representative individual.

However, the condition $\partial s_j / \partial s_i \leq 0$ implies that there may also be a tradeoff between increasing the indicator level of the i^{th} goal in terms of reducing the level of the j^{th} SDG.

The representative individual will choose the amount of *x* to consume that minimizes total expenditure $px = M$ subject to the constraint that utility (1) is equal to or exceeds a given initial level u^0. From the standpoint of the individual, as the vector *s* is constant, then the first-order condition $u(x; s) = u^0$ is sufficient to solve for the optimal compensated demand for the marketed good $x^* = x^*(s, u^0)$, which is conditioned on the initial indicator levels of all SDGs as represented by *s*. Substituting the latter expression into the expenditure function *px* yields the corresponding conditional expenditure function

$$E^* = E^*(p, s, u^0),\ s = s_1, \ldots s_i, s_j(s_i), \ldots s_n,\ \frac{\partial s}{\partial s_i} > 0,\ \frac{\partial s_j}{\partial s_i} \leq 0. \tag{2}$$

Suppose that there is small increase in the level of the i^{th} SDG. The marginal value of this increase in s_i is the reduction in the expenditures on *x* that the individual must make that is just sufficient to maintain utility at the initial level u^0. However, this willingness to pay *w* for the increase in s_i must be net of any tradeoff in terms of lowering any other SDG level s_j. That is, from (2), the exact measure of this welfare change is

$$w = -\frac{\partial E^*(p, s, \mathrm{u}^0)}{\partial s}\left[\frac{\partial s}{\partial s_i} + \frac{\partial s}{\partial s_j}\frac{\partial s_j}{\partial s_i}\right],\ \frac{\partial s}{\partial s_i} > 0,\ \frac{\partial s_j}{\partial s_i} \leq 0\ . \tag{3}$$

If $\partial s_j / \partial s_i < 0$, then the gain in welfare from an increase in s_i is offset by tradeoff from declining s_j. As long the latter effect is not too large, then there will be a net welfare gain for the individual as long as $\frac{\partial s}{\partial s_i} > -\frac{\partial s}{\partial s_j}\frac{\partial s_j}{\partial s_i}$. However, if $\partial s_j / \partial s_i = 0$ there are no tradeoffs with another SDG, then the welfare change of an increase in s_i is simply $w = -\frac{\partial E^*(p, s, \mathrm{u}^0)}{\partial s}\frac{\partial s}{\partial s_i}$.

For a non-marginal change in s_i, from an initial level s_i^0 to some final level s_i^1, the welfare change is the total amount of expenditure on *x* that the individual is willing to pay for this improvement in the SDG indicator level. This compensating surplus (CS) measure of the welfare gain to the individual is the integral of (3) taken over the relevant range in s_i

$$CS = -\int_{s_i^0}^{s_i^1} \frac{\partial E^*(p, s, \mathrm{u}^0)}{\partial s}\left[\frac{\partial s}{\partial s_i} + \frac{\partial s}{\partial s_j}\frac{\partial s_j}{\partial s_i}\right] ds_i \tag{4}$$

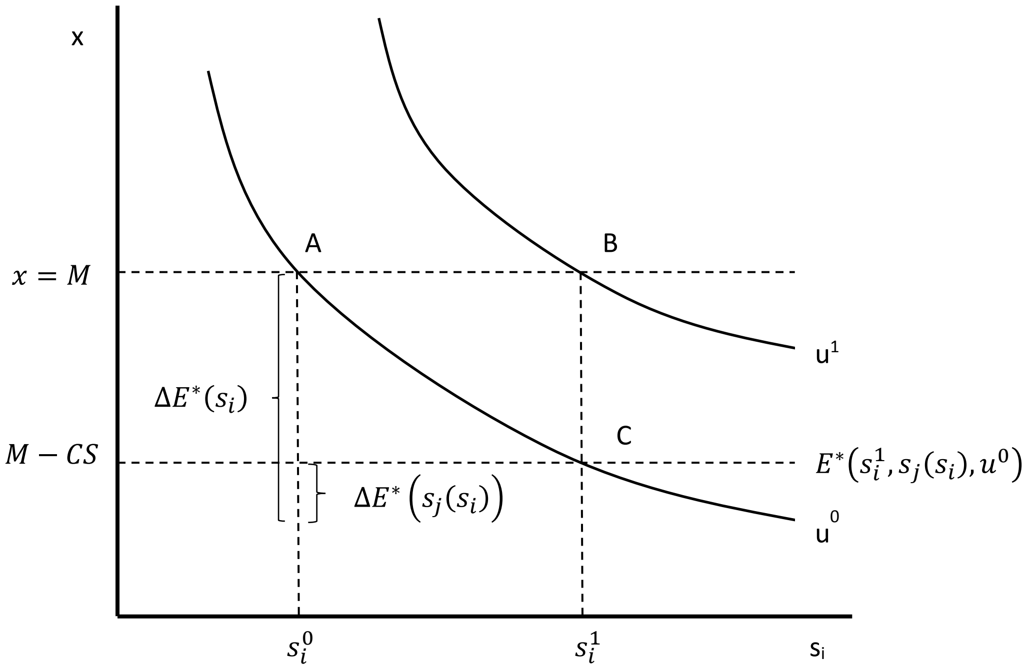
Another way of measuring this compensating surplus is through the effects of non-marginal changes in the levels of s_i on the conditional expenditure function in (2)

$$CS = E^*\left(p, s_i^0, s_j\left(s_i^0\right), u^0\right) - E^*\left(p, s_i^1, s_j\left(s_i^1\right), u^0\right)$$
$$= M - E^*\left(p, s_i^1, s_j\left(s_i^1\right), u^0\right) = \Delta E^*\left(s_i\right) - \Delta E^*\left(s_j\left(s_i\right)\right), \quad (5)$$

where $\Delta E^*\left(s_i\right) = E^*\left(p, s_i^0, u^0\right) - E^*\left(p, s_i^1, u^0\right)$ is the reduction in expenditure on x to compensate for an increase in s_i and $\Delta E^*\left(s_j\left(s_i\right)\right) = E^*\left(p, s_j\left(s_i^0\right), u^0\right) - E^*\left(p, s_j\left(s_i^1\right), u^0\right)$ is the additional expenditure on the marketed good that is necessary to compensate for the tradeoff between s_i and s_j, i.e. $\partial s_j / \partial s_i < 0$. In this case, the true welfare gain is found by deducting from $\Delta E^*\left(s_i\right)$ an amount equal to the unavoidable increase in expenditure from the decline in any other SDG level $\Delta E^*\left(s_j\left(s_i\right)\right)$.

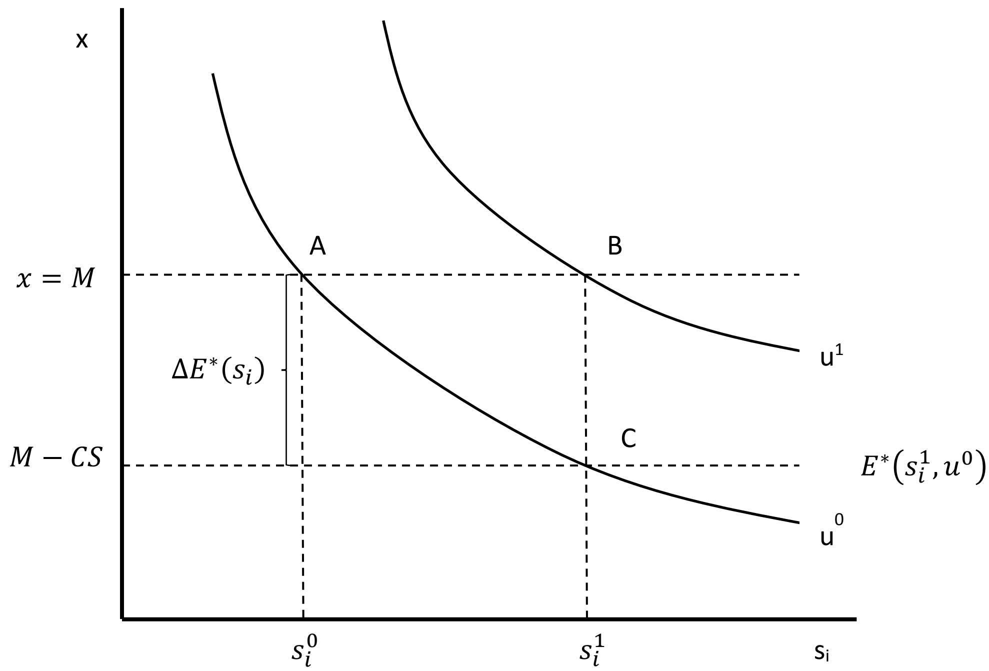
Figure 3 illustrates graphically this exact welfare measure where there is a tradeoff in the increase in one SDG indicator at the expense of another. The figure is drawn with the assumption that the price of the marketed good x is normalized to one ($p = 1$). Point A represents the initial starting point before the change in the i^{th} SDG. An increase in the level of s_i leads to a rise in the individual's utility to u^1 (point B). Because there is a tradeoff with another goal s_j, the reduction in expenditures (income) necessary to compensate for the rise in s_i overstates the welfare gain. The true welfare gain is thus net of this tradeoff, and is represented by distance *BC* in Figure 3.

Figure 3. The Welfare Effects with Tradeoffs in SDGs



In contrast, as shown in Figure 4, if the rise in the indicator level of one SDG does not affect the attainment of any other goals, then only the direct welfare effect of an improvement in s_i matters, i.e. $\Delta E^*(s_i)$ in (5). That is, the reduction in expenditures (income) necessary to compensate for the rise in s_i no longer overstates the welfare gain, which is again is distance *BC*.

Figure 4. The Welfare Effects with No Tradeoffs in SDGs



Quantitative Assessment of Progress in Attaining SDGs

Table 2 presents our quantitative assessment of current progress for each of the 17 SDGs, using a representative indicator for each goal. Although UN (2015) lists several possible indicators for each SDG, as far as possible, we have chosen the primary indicator listed for each goal. The indicator levels are global, and not for any individual country. As indicated in the table, most of the data for the indicators are from the World Bank Sustainable Development Goals and World Development Indicators databases, three are from the Millennium Development Goal Indicators, and one from the Credit Suisse Global Wealth Report 2016.

As before, the 17 SDGs in Table 2 have been re-grouped under the three types of systems – economic, environmental and social. The time period of assessment for each goal is 2000 to 2015, unless otherwise specified. In addition, for each indicator, the levels have been transformed into a percentage index (0 to 100%), so as to show more clearly whether the indicator level has been improving or declining over the 2000-2015 period, where 100% represents full attainment of that specific SDG.[3]

Overall, the indicator levels associated with most of the SDGs have improved. However, seven indicators have declined. These include the indicators for two economic system goals (8. Good Jobs and Economic Growth and 9. Industry, Innovation and Infrastructure), three environmental system goals (13. Climate Action, 14. Life Below Water and 15. Life on Land), and two social system goals (10. Reduced Inequalities and 17. Partnership for the Goals).

Figure 5 depicts the changes in indicators associated with the 17 SDGs in a radar graph comparing levels in 2000 to 2015. The graph shows the considerable progress that has been made in achieving some goals. For example, the No Poverty goal went from around 73% completion in 2000 to 89% in 2015, Clean Water and Sanitation was 82% attained in 2000 and 91% in 2015, and Quality Education increased from 75% to 84%. For other goals, there has been improvement over 2000-2015, but the attainment levels are still low. Examples include Sustainable Cities and Communities, which was only 8% complete in 2015, Responsible Consumption and Production 12% attained in 2015, and Gender Equality 23% reached in 2015.

Of particular concern are SDGs that were far from complete in 2000, and have shown further deterioration in progress since. For example, the indicator for Good Jobs and Economic Growth more than halved over the assessment period, and stands only at 11% in 2015. Climate Action has decreased from 60% to 50% complete from 2000 to 2015. The indicator for Life on Land also declined slightly over the 2000-2015 assessment period, and is now below 31%. Life Below Water was over 80% attained in 2000, but in 2015 fell to only 70% complete. The indicator for Industry, Innovation and Infrastructure also declined from 19% in 2000 to 15% in 2015.

[3] Note that some SDGs do not specify an exact target, and thus it is difficult to determine what 100% attainment implies for these SDGs. Rather than specify arbitrarily a target for such cases, we have opted instead to convert the actual value of the relevant indicator for the SDG to a (0 to 100%) scale, and then use that scale to show the extent of improvement or decline in the indicator over the 2000 to 2015 assessment period.

Table 2. Indicators of Progress in Attaining the Sustainable Development Goals, 2000-2015

Sustainable Development Goal	Indicator	Actual Value 2000	Actual Value 2015	Index (%) 2000	Index (%) 2015	Outcome
Economic System						
1. No Poverty	Poverty headcount ratio at $1.90 a day (% of population, 2011 PPP), 2000-2013	26.7	11.0	73.3	89.0	Improving
2. Zero Hunger	Prevalence of undernourishment (% of population)	15.0	10.8	85.0	89.2	Improving
3. Good Health and Well Being	Births attended by skilled health staff (% of total), 2000-2012	59.9	76.5	59.9	76.5	Improving
6. Clean Water and Sanitation	Improved water source (% of population with access)	82.5	91.0	82.5	91.0	Improving
7. Affordable and Clean Energy	Access to clean fuels and technologies for cooking (% of population), 2000-2014	50.6	57.6	50.6	57.6	Improving
8. Good Jobs and Economic Growth	Adjusted net national income per capita (annual % growth)	25.0	11.0	25.0	11.0	Declining
9. Industry, Innovation and Infrastructure	Manufacturing, value added (% of GDP), 2000-2014	19.1	14.9	19.1	14.9	Declining
Environmental System						
11. Sustainable Cities and Communities	PM2.5 air pollution, population exposed to levels exceeding WHO guideline value (% of total)	95.1	91.8	4.9	8.2	Improving
12. Responsible Consumption and Production	Adjusted net savings, excluding particulate emission damage (% of GNI)	10.9	11.9	10.9	11.9	Improving
13. Climate Action	CO_2 emissions per capita (metric tons*10), 2000-2013	40.0	50.0	60.0	50.0	Declining
14. Life Below Water	Proportion of fish stocks within safe biological limits (%), non-fully exploited, 1990-2009[a/]	18.6	29.9	81.4	70.1	Declining
15. Life on Land	Proportion of terrestrial area protected (% of total surface area), 1990-2014	31.3	30.8	31.3	30.8	Declining
Social System						
4. Quality Education	Adolescents out of school (% of lower secondary school age), 2000-2014	25.2	16.0	74.8	84.0	Improving
5. Gender Equality	Proportion of seats held by women in national parliaments (%)	13.9	22.9	13.9	22.9	Improving
10. Reduced Inequalities	Top 1% share of global household wealth, 2000-2016[b/]	49.6	50.8	50.4	49.2	Declining
16. Peace, Justice and Strong Institutions	Proportion ODA to basic social services (%), 2000-2013[a/]	14.0	18.0	14.0	18.0	Improving
17. Partnerships for the Goals	Net Share of OECD/DAC donors' GNI (%*100), 1990-2013 [a/]	32.0	30.0	32.0	30.0	Declining

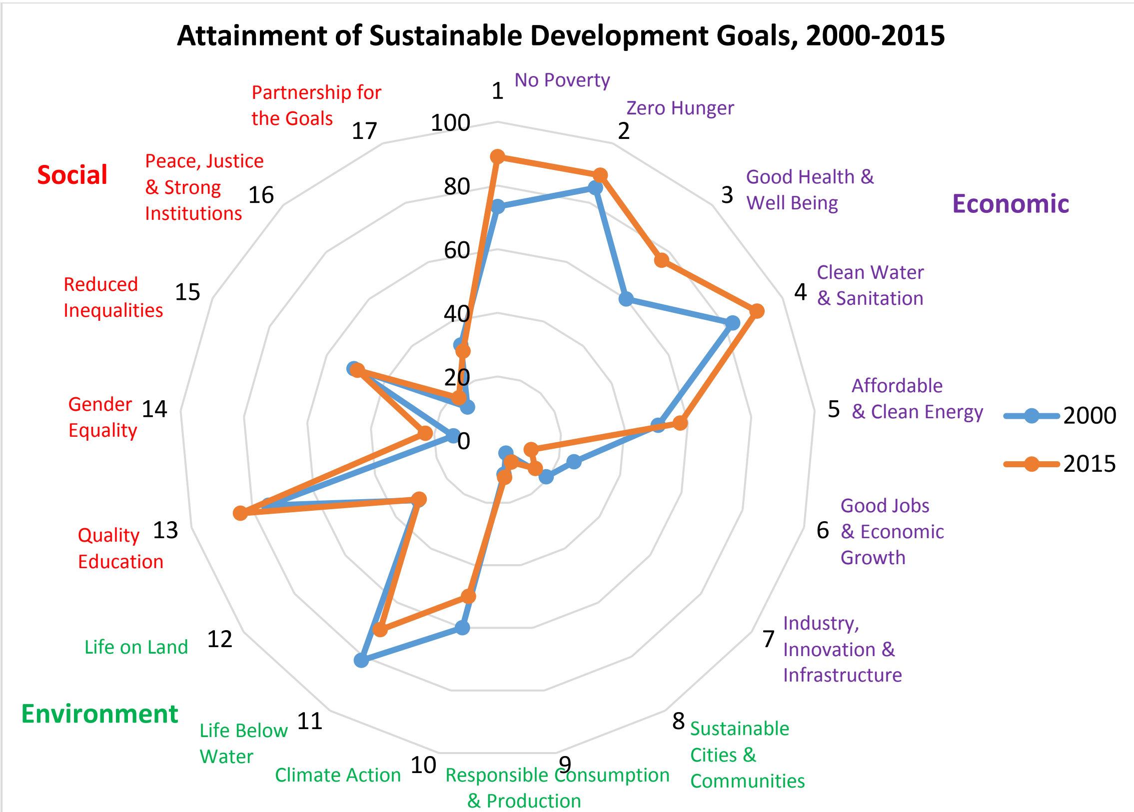
From World Bank Sustainable Development Goals and World Development Indicators. Available at http://databank.worldbank.org/data/. Accessed May 26, 2017.

[a/] From Millennium Development Goal Indicators. Available at https://unstats.un.org/unsd/mdg. Accessed May 18, 2017

[b/] From Credit Suisse Global Wealth Report 2016. Available at https://www.credit-suisse.com/us/en/about-us/research/research-institute/global-wealth-report.html Accessed May 26, 2017.

Actual values have been converted to a positive index scale showing percentage attainment of Sustainable Development Goals, where appropriate.

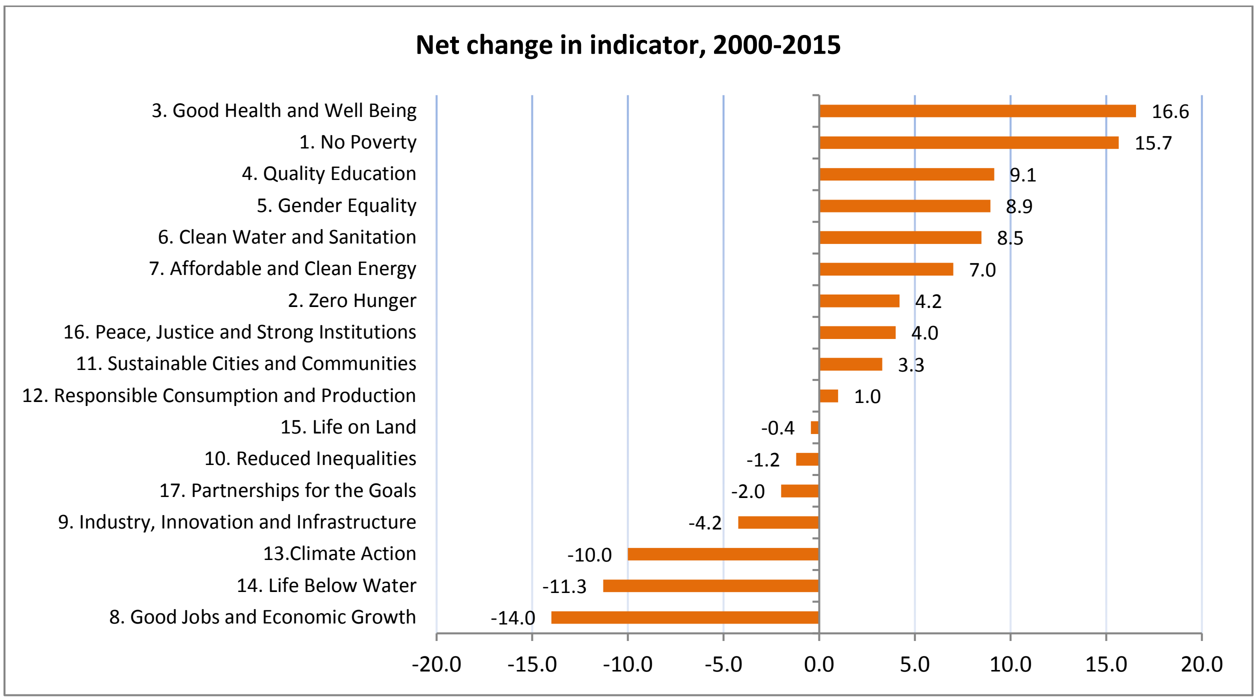
Figure 5. Changes in SDG Indicator Levels, 2000 to 2015



Based on Table 2.

The bar graph in Figure 6 ranks the net change in SDG indicator levels over 2000 to 2015, from the largest gains to the biggest declines. As the graph indicates, it is mainly the economic system goals that have had the largest positive gain, led by Good Health and Well Being (16.6%) and No Poverty (15.7%). In contrast, two of the biggest falls have been for the environmental system, Life Below Water (-11.3%) and Climate Action (-10.0%), although the largest decline has been for the economic system goal Good Jobs and Economic Growth (-14.0%).

Figure 6. Net Change in SDG Indicators, 2000-2015



Economic Goals: 1,2,3,6,7,8,9

Environmental Goals: 11,12,13,14,15

Social Goals: 4,5,10,16,17

Based on Table 2.

Preliminary Welfare Analysis of SDG Tradeoffs

We use our quantitative assessment of the net change in SDG indicators over 2000 to 2015 presented in Table 2 to illustrate the welfare analysis of potential tradeoffs in attaining these goals that we developed earlier. This analysis is preliminary, and its purpose is purely illustrative. We want to show that it is possible to use the method devised here to measure the welfare effects of an increase in the indicator level for one SDG that takes into account any tradeoffs with achieving another goal.

We select as our example the No Poverty goal, which is the first SDG listed in Agenda 2030 (see Table 1). As shown in Table 2, the indicator for this goal is the poverty headcount ratio at $1.90 per day (% of population, 2011 PPP). Our estimates suggest that this indicator level improved globally by 15.7% between 2000 and 2015, thus suggesting significant progress in attaining this SDG. However, over this same period, the indicators for several other SDGs fell. Figure 6 depicts the latter SDGs, from smallest to largest declines, as 15. Life on Land (environmental system, -0.4%), 10. Reduced inequalities (social system, -1.2%), 17. Partnership for the Goals (social system, -2.0%), 9. Industry, Innovation and Infrastructure (economic system, -4.2%), 13. Climate Action (-10.0%), 1.4 Life Below Water (-11.3%), and 8. Good Jobs and Economic Growth (-14.0%). Other SDG indicators improved during this period, such as Good Health and Well Being and Quality Education, reflecting potentially positive interaction with reduced poverty. Here we focus on the tradeoffs.

Thus, through some simplifying assumptions, we can apply our compensating surplus measure (5) to estimate the willingness to pay for the improvement in the No Poverty SDG indicator from 2000 to 2015. First, assuming no tradeoffs with any other SDGs, we can adapt $\Delta E^*\left(s_i\right)$ in (5) to measure the reduction in expenditures (income) necessary to compensate for the rise in s_i. Second, taking into account a possible tradeoff between attaining the No Poverty goal and each of the other SDGs showing decline over 2000-2015, we can adapt $\Delta E^*\left(s_i\right) - \Delta E^*\left(s_j\left(s_i\right)\right)$ in (5) to account for this tradeoff effect, which is the additional expenditure (income) that is necessary to compensate for the tradeoff between two different SDGs, s_i and s_j.

We choose the world's adjusted net national income (ANNI) per capita in 2000 (constant 2010 US$) as a proxy for the (Hicksian) income necessary to compensate the average individual in the global economy for a change in the indicator level of any SDG. As shown by Arrow et al. (2012), national income that accounts for the net depreciation of an economy's natural, human and reproducible capital is a measure of the sustainable income generated each year by the economy. In the World Development Indicators, adjusted net national income is gross national income (GNI) minus consumption of fixed capital and net depletion of natural resources. Although it does not include net changes in human capital, ANNI serves as an approximate measure of sustainable income that the average individual would be willing to pay for an improvement in the level of any SDG.

Using world ANNI per capita in 2000 as our numeraire allows us to assume that an individual would be willing to compensate $1 of this sustainable income for a 1% improvement in the indicator for the No Poverty goal from 2000 to 2015, and equally, would accept an additional $1 ANNI to compensate for the tradeoff of a 1% loss in the indicator level of any other SDG. That is, equation (5) simplifies to $CS = \Delta E^{*}(s_i) - \Delta E^{*}(s_j(s_i)) = (\Delta s_i - \Delta s_j)E^{*}$, where Δs_i is the percentage gain in the indicator level for the No Poverty Goal over 2000-2015, Δs_j is the percentage loss in the indicator level of any other SDG adversely affected over 2000-2015, and E^{*} is the numeraire of world ANNI per capita in 2000.

Table 3 depicts the results of this preliminary welfare analysis. The first row shows that, in the absence of tradeoffs with attaining any other SDG, the willingness to pay for the reduction in poverty in the world economy that occurred over 2000 to 2015 in accordance with the No Poverty goal was $1,122 per person. However, this welfare gain may be diminished, depending on whether there is a perceived tradeoff with the declines over the same period in the indicator levels associated with other SDGs. For example, if in improving progress towards the No Poverty Goal there is concern that the goal of Reduced Inequalities has become less attainable, then the net gain from reducing poverty over 2000 to 2015 is $1,036. If the tradeoff is with Climate Action, then the net welfare gain from improvement towards the No Poverty Goal is $406 per person. Finally, there may be a tradeoff even with another economic goal – Good Jobs and Economic Growth – in which case the net benefit of progress over 2000-2015 towards the No Poverty SDG is only $119.

As emphasized previously, this welfare analysis is preliminary and only indicative; the WTP amounts indicated in Table 3 should not be considered to be accurate estimates. Nevertheless, the analysis is a useful exercise as it shows that it is possible to measure the welfare effects of possible tradeoffs among achieving more than one SDG, when such goals are considered to be interlinked and essential to achieving sustainable development. Developing such an analysis is the first step in helping policy makers prioritize improvements towards one goal or set of goals, and above all, to show explicitly that there are consequences in terms of net gains and losses for achieving one goal at the possible expense of others.

For example, one surprising outcome of the preliminary welfare analysis depicted in Table 3 is the potentially large tradeoffs over 2000-2015 between attaining two economic system goals: the positive gains in poverty reduction versus the world economy becoming less successful in providing Good Jobs and Economic Growth. It appears that we are making good progress in attaining the No Poverty Goal, but ironically, it may be coming at the expense of making the global economy less sustainable.

Finally, although this preliminary welfare analysis focused on the tradeoffs between progress towards the No Poverty goal and improving indictors associated with other SDGs, the analysis could also be applied to show complementarities, or "win-wins", in simultaneous progress among two or more SDGs. For example, the net gains in the indicators for No Poverty, Clean Water and Sanitation, and Zero Hunger over 2000-2015 may be strongly interlinked and mutually reinforcing. In which case, the net welfare gains from reducing poverty depicted in Table 3 might be further boosted from the additional positive gains from simultaneous improvements in the indicators for the other two related SDGs.

Table Welfare Analysis of SDG Tradeoffs: Reduction in Poverty, 2000-2015

Sustainable Development Goal	Indicator	Net change (%) in indicator 2000-2015	Net WTP ($) per capita
1. No Poverty	Poverty headcount ratio at $1.90 a day (% of population, 2011 PPP)	15.7	1,122
Tradeoff with			
15. Life on Land	Forest area (% of land area)	-0.4	1,091
10. Reduced Inequalities	Top 1% share of global household wealth	-1.2	1,036
17. Partnerships for the Goals	Net share of OECD/DAC donors' GNI (%*100)	-2.0	979
9. Industry, Innovation and Infrastructure	Manufacturing, value added (% of GDP)	-4.2	819
13.Climate Action	CO_2 emissions per capita (metric tons*10)	-10.0	406
14. Life Below Water	Proportion of fish stocks overexploited (%)	-11.3	312
8. Good Jobs and Economic Growth	Adjusted net national income per capita (annual % growth)	-14.0	119
Numeraire:			
Adjusted net national income per capita (constant 2010 US$), 2000			7,164

WTP = Willingness to pay

Adjusted net national income is gross national income (GNI) minus consumption of fixed capital and net depletion of natural resources, from World Development Indicators. Available at http://databank.worldbank.org/data/. Accessed May 27, 2017.

Conclusion

One of the first attempts in economics to explain sustainable development was the *systems approach*, which suggests that sustainability can only be achieved by balancing the tradeoffs among the various goals across environmental, economic and social systems (Barbier 1987; Barbier and Markandya 2012; Ekins 1994; Elliott 2006; Holmberg and Sandbrook 1992; Pezzey and Toman 2002). Although conceptually appealing and easy to depict visually (see Figure 1), this approach has provided little policy guidance on how to assess the tradeoffs among various system goals or how to determine the welfare implications of such choices. The purpose of this paper has been to show that it is possible to develop the systems approach to sustainability to make such welfare assessments, and more importantly, such an approach is directly relevant to the 2030 Sustainable Development Agenda of the United Nations (UN 2015).

For example, we illustrate how each of the 17 Sustainable Development Goals (SDGs) can be characterized as a goal primarily attributed either to the environmental, economic or social system, and as suggested by the systems approach, there may be important tradeoffs in attempting to attain all these goals simultaneously. By adopting standard theoretical methods of the theory of choice and welfare under imposed quantities (Freeman 2003; Lankford 1988), we show that is possible to measure the welfare effects of an increase in the indicator level for one SDG that takes into account any tradeoffs with achieving another goal. We then conduct a quantitative assessment of progress over 2000-2015 for each of the 17 SDGs, using a representative indicator for each goal. Overall, the indicator levels associated with most of the SDGs have improved. However, seven indicators have declined. These include the indicators for two economic system goals (Good Jobs and Economic Growth and Industry, Innovation and Infrastructure), three environmental system goals (Climate Action, Life Below Water and Life on Land), and two social system goals (Reduced Inequalities and Partnership for the Goals).

The first SDG listed by UN (2015) is No Poverty, and the indicator for this goal has shown considerable progress between 2000 and 2015. We therefore employed our welfare analysis to estimate preliminary welfare effects of the increase in the indicator level for the No Poverty goal, both without and with possible tradeoffs with indicators for other SDGs that have declined over 2000-2015. Our results, depicted in Table 3, indicate that such an analysis can help policy makers prioritize improvements towards one goal or set of goals, and above all, to show explicitly that there are consequences in terms of net gains and losses for achieving one goal at the possible expense of others. For example, one of the surprising outcomes of our analysis is that reducing poverty over 2000-2015 may have come at the expense of making our economies less sustainable. On the other hand, the estimated net welfare gains from reducing poverty might be further boosted from the additional positive gains from simultaneous improvements in the indicators for two other related SDGs, Clean Water and Sanitation and Zero Hunger.

Overall, our paper suggests that, despite its practical limitations, the systems approach has made an important contribution to sustainable development by emphasizing that environmental, economic and social systems are interlinked, and that progress solely focused on one system's goals could have consequences for the other systems. As shown in this paper, this approach is directly relevant to the 17 SDGs, as each one of these goals can be attributed to economic, environmental and systems and there are clear tradeoffs in attempting to attain progress across these goals. By developing an explicit approach for measuring the welfare effects of these potential tradeoffs, this paper will hopefully point to an important area for future research in assessing progress and policy analysis of the SDGs. Specifically, what is need is more economic analysis of the net welfare impacts for achieving one goal at the possible expense of others, and equally, to show the "win-win" gains that occur when there is complementary progress between two or more goals. Such an analysis can help in the design of appropriate policy interventions to achieve specific SDGs, minimizing the potentially negative knock-on effects on some goals whilst capitalizing on the positive win-win impacts on other SDGs.

Finally, the type of welfare analysis across interlinking goals and impacts developed here may be applicable to other policy areas. There is a growing scientific literature emphasizing that human populations and economic activity are rapidly exceeding "planetary boundaries", which could lead to abrupt phase changes, or "tipping points" (Lenton et al. 2008; Röckstrom et al. 2009; Steffen et al. 2015). To date, this literature has focused on characterizing boundaries rather than suggesting "how to maneuver within the safe operating space in the quest for global sustainability" (Steffen et al. 2015). However, increasingly economists have argued that recognition of the joint interaction of economic and environmental systems in determining market and nonmarket outcomes is essential to developing models that inform stewardship of this "safe operating space" (Smith 2017). Improved welfare analysis of the tradeoffs among system goals will be even more critical for the policy choices needed for such stewardship within critical and binding constraints.

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