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THE AIR WE BREATHE: ESTIMATES OF AIR POLLUTION EXTENDED GENUINE SAVINGS FOR EUROPE

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This paper constructs measures of Genuine Savings (GS), the leading economic indicator of sustainable development, for 28 European economies from 1990 to 2016. The World Bank publishes GS estimates for most countries in the world. The World Bank's estimates are extended to include local air pollutants (sulfur dioxide, non-metallic volatile organic compounds, nitrogen oxides and ammonia), on a country-specific basis. The extended pollution damages have a sizeable impact, even for highly developed economies. As many as 11 member states signaled persistent unsustainable development compared with just two in the equivalent World Bank dataset. Overall, it appears economies with higher levels of per capita national income and those more open to trade tend to hold higher savings rates. Findings of negative savings, an indicator of unsustainable development, were concentrated in the former communist regimes of Eastern Europe.

JEL Codes: E01, Q01, Q56

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1. Introduction

Environmental economists offer what is arguably the most internally consistent theory of sustainable development (Pearce *et al.*, 1996). Within the economic literature, a development path that ensures the maintenance of "comprehensive" wealth has been shown, theoretically, to maintain well-being opportunities for future generations (Arrow *et al.*, 2012). In this context, comprehensive wealth comprises all assets that is, capital stocks from which individuals obtain well-being, either directly or indirectly. The concept of comprehensive wealth thus forces the conception of capital to be broadened beyond physical capital (machines and infrastructure), and to include human capital (education and skills), natural capital (natural resources, ecosystems and the atmosphere) and social/institutional capital (culture and trust).[1] The "green" accounting literature has demonstrated a clear link between changes (net investments) in comprehensive wealth—the so-called "genuine savings" (GS)—and changes in future well-being. Declining wealth

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[1]Institutional/social capital represent key components but data limitations mean the literature focuses on the other assets.

(negative GS) provides a signal of unsustainable development as this implies capital stocks and thus future well-being opportunities are diminished, even if Gross Domestic Product (GDP) per capita is rising in the short-term (Dasgupta and Mäler, 2000). Empirical applications have shown GS to be a good forward-looking indicator of well-being (Greasley *et al*., 2014; Hanley *et al*., 2015).

There is broad agreement within the economic literature that to achieve sustainable development some form of wealth maintenance is necessary but a debate over "weak" versus "strong" forms continues. Solow (1991) explains weak sustainability as a requirement not to conserve any specific resource, but instead only to ensure that sufficient (broadly defined) capital resources exist that allow future generations to have the opportunity to create living standards at least as good as the present generation.[2] Achieving weak sustainability requires total aggregate wealth/capital to be maintained and depends on one or more of the following assumptions holding; natural resources are superabundant, all capital forms are sufficiently substitutable with each other and/or that technological progression makes this substitution a moot point. Strong sustainability requires an additional stronger constraint of non-declining natural wealth as proponents view natural resources as non-substitutable capital (Costanza *et al*., 1991; Cabeza-Gutés, 1996).

GS has emerged as a leading economic indicator of sustainable development (Hanley *et al*., 2015), gaining international recognition through World Bank publications exploring global wealth measurement (World Bank, 2006; 2011; 2018). The World Bank currently provides empirical estimates of GS for all European Union (EU) member states (and most countries in the world) termed "Adjusted Net Savings" (ANS). Monitoring of the European Union's (EU) progress towards the EU Sustainable Development Strategy (SDS) and the Europe 2020 strategy, aiming for "smart, sustainable, inclusive growth," does not include estimates of GS despite the ANS data for each member state being readily available and updated. The omission of GS may be explained by the well-documented limitations of the World Bank's indicator (Ferreira and Vincent, 2005; Pillarisetti, 2005; Dietz and Neumayer, 2006; Goossens *et al*., 2007; Atkinson and Hamilton, 2007; Stiglitz *et al*., 2009; Neumayer, 2013). This literature has repeatedly acknowledged the omission of local air pollutants as a key concern, particularly for the EU (Goossens *et al*., 2007; Stiglitz *et al*., 2009). Some research suggests omitted air pollution may considerably bias the European ANS estimates upwards (Hamilton and Atkinson, 1996; Pearce, 2001a; Ferreira and Moro, 2011; McGrath *et al*., 2019; McGrath *et al*., 2020). Others are skeptical of the impact of additional air pollutants on developed economies (Neumayer, 2013).

This paper contributes to the literature by addressing the limited coverage of air pollutants contained in World Bank's GS indicator. At present, the World Bank accounts for carbon dioxide (CO_2) and particulate matter (PM) damages. This paper extends the World Bank's approach to account for the EU's most important

[2]Interestingly, Hayek (1960) although rejecting the notion of a common unit of measurement for a "national" aggregate capital stock (Hayek, 1941), makes an almost identical argument at the individual/entrepreneurial level *"Any natural resource represents just one item of our total endowment…our problem is not to preserve this stock in any particular form, but always to maintain it in a form that will make the most desirable contribution to total income. The existence of a particular natural resource merely means… its temporary contribution to our income will help us to create new ones..."*

air pollutants (EEA, 2018). The key innovation is the inclusion of a range of country-specific damage costs for sulfur dioxide (SO_2), nitrogen oxides (NO_X), ammonia (NH_3) and non-metallic volatile organic compounds (NMVOC) across 28 European economies from 1990 to 2016. [3] Empirical GS exercises based on highly aggregated data across a large panel of countries, may be inferior to a smaller sample that employs more comprehensive and consistent data.[4] With consistency in mind, our methods retain a key strength of the World Bank indicator, namely its "league table" comparability. The results demonstrate pollution damages can result in substantial adjustments, even for well-developed economies and highlights the potential benefits achieved from market incentives, technological advancements and sensible environmental policy.

The remainder of the paper is structured as follows: Section 2 presents the theoretical framework of GS. In section 3, the methodology detailing the adjustments to the World Bank's GS estimates is described. The results are presented in section 4, where the limitations of the ANS indicator are discussed and ways forward are suggested. Section 5 provides concluding remarks.

2. Theoretical Framework

Seminal contributions during the 1970s (Solow, 1974; Dasgupta and Heal, 1974; Stiglitz, 1974a, 1974b; Weitzman, 1976; Hartwick, 1977) provided a natural framework for the economics of sustainable development to emerge. The literature was built on the foundation of the Hicksian income concept that, in essence, has sustainability built in (Hicks, 1939) and is grounded in optimal growth theory. [5] Weitzman (2017) refers to the underlying theorethical model as the "pure theory of perfectly complete national income accounting". Within this generalized model of economic growth, the present value of future consumption changes equals the value of net investments in the broadly defined capital stocks that is, GS (Dasgupta, 2009; Weitzman, 2017).[6] The model thus provides a remarkable result, in a world (even an imperfect one) where there is complete accounting, the level of GS corresponds to variations in inter-generational well-being, as measured by consumption changes. However, the model contains a demanding assumption of perfectly complete accounting where all well-being relevant items are included in the consumption bundle and all well-being relevant assets are captured in the capital stocks and everything is evaluated at the correct shadow prices.

[3]PM causes cardiovascular disease and cancers. Primary PM is emitted directly, secondary PM forms following the release of precursor gases (SO_2, NOx, NH_3 and some NMVOCs). NOx contributes to acidification and eutrophication of water and soils, is an O3 precursor and affects health. SO2 contributes to acidification and negatively affect health. NH_3 contributes to both eutrophication and acidification. NMVOCs, are O3 precursors and some are directly hazardous to health.

[4]We thank an anonymous reviewer for this point.

[5]Although sustainable development is now generally considered a *normative* goal El Serafy (1996) argues weak sustainability is concerned with proper national income measurement and consequently can be defended on *positive* grounds.

[6]Where all well-being/utility relevant assets are included as capital and all well-being/utility relevant items are captured in the consumption bundle. Furthermore, GS and consumption are evaluated using the correct shadow prices.

There are two slightly different main definitions of sustainable development in the literature. One postulates that development at a particular moment is sustainable if current consumption can be maintained forever (Pezzey, 2004), while the other assumes that development is sustainable if well-being is not decreasing (e.g. Arrow *et al.*, 2012). In both cases, negative GS signals that development is unsustainable. However, having positive GS does not guarantee that consumption will not decrease at some period in the future (Asheim, 1994; Pezzey, 2004). In this sense, GS might be considered as an unsustainability indicator. For real-world GS applications Hamilton and Clemens (1999) built on Pearce and Atkinson (1993) to provide a methodology that underpins the World Bank's GS indicator termed Adjusted Net Savings (ANS) and outlined in Eq. 1. See World Bank (2018) for a detailed methodology.

$$\text{(1)} \qquad Genuine\ Savings = GNS - D_K - D_S - D_E + A_H$$

Starting from Gross National Savings (GNS), as reported in the system of national accounts (SNA), deductions are made for the depreciation of the physical capital stock (D_K), the depletion of the natural capital stock that consists of subsoil assets (D_S) and environmental degradation (D_E) and finally, the addition of human capital accumulation (A_H).[7] The World Bank's GS indicator (ANS) includes only CO_2 and Particulate Matter less than two microns in diameter (PM 2.5) within the environmental degradation estimates, due to data constraints. Human capital accumulation is proxied using education spending.

Two important theoretical issues omitted from the World Bank approach and the pollution extended GS estimates presented in this paper, are population growth and technological progress. With a growing population, per capita wealth rather than total wealth should be sustained (Neumayer, 2013).[8] However, the appropriate accounting for population growth is not straightforward. A growing population raises available human capital but also places a strain on wealth.[9] Hamilton and Atkinson (2006) recommend dividing GS by total population, and then deducting a so-called Malthusian correction term that multiplies total comprehensive wealth per capita by the population growth rate. Insufficient data on total comprehensive wealth limits the practical application of this correction term.[10]

Technical progress can be viewed as another capital stock or the "value of time passing". Weitzman (1997) was the first to examine exogenous technical change in this context and suggested an upward adjustment of 40 percent of GNI. Many have argued for the inclusion of exogenous technological progress within the GS model (Pemberton and Ulph, 2001; Pezzey, 2004; Pezzey *et al.*, 2006; Mota *et al.*, 2010; Greasley *et al.*, 2014; Hanley *et al.*, 2016; Blum *et al.*, 2017; Lindmark

[7]A formal derivation of GS can be found in Hamilton and Clemens (1999) see A1 in the appendix for the key results.

[8]When population growth is exponential the sustainability criteria should be considered in per capita term (Arrow et al., 2003). Asheim (2007) show population growth must be quasi-arithmetic to be compatible with sustainability in a competitive framework. Li and Löfgren (2013) show a term reflecting the welfare loss from risk aversion should be subtracted

[9]The thesis of Simon (1981) is that population growth is the "ultimate resource."

[10]This obstacle may be overcome in future given the World Bank already produces point estimates of comprehensive wealth for 1995, 2000, 2005, 2010 and 2015.

et al., 2018).[11] However, the inclusion of exogenous technical progress is more practical when analyzing a long time series of historical data. In this regard, some studies have included exogenous technical progress within the GS model by estimating the present value of the Solow residual that is, Total Factor Productivity (TFP) in long time series' of data (Greasley *et al.*, 2014; Hanley *et al.*, 2016, Blum *et al.*, 2017; Lindmark *et al.*, 2018). It is difficult to provide estimates of unknown future technical progress within current GS estimates. In this context, it is important to note that a finding of negative savings where exogenous technical progress is omitted provides a warning of potentially unsustainable development but that these negative savings may be overcome by future technological progress.

3. Methodology

World Bank (2018) provides the detailed methodology used to calculate each of the components of Eq. 1. The methods employed for the estimation of the change in mineral and energy resources are briefly described below, as well as the adjustments for physical and human capital and then, go into detail regarding the adjustments for environmental degradation as this is the focus of this study. For a more in-depth discussion on the estimation of the change in mineral and energy resources the interested reader should consult World Bank (2018), as well as the succinct discussion contained in Ch. 5 of Neumayer (2013).

3.1. *Gross National Savings (GNS) and Physical Capital Depreciation (D_K)*

Gross national savings (GNS), as reported within the SNA, represent the traditional measure of national savings (gross national income less total consumption, plus net transfers). The rationale behind "green" adjustments to GNS is to move towards measuring changes in *comprehensive* wealth. Another standard item in the SNA is the consumption of fixed capital (CFC) which captures the depreciation of human-made capital (D_K). Subtracting CFC from GNS equates Net National Savings (NNS) and signifies net investments of physical capital.

3.2. *Human Capital*

Within the wealth accounting approach, there have been a number of methods used to estimate human capital accumulation such as expenditures on education, or as a rate of return on time spent in education, or as a measure of discounted lifetime earnings by skill level (Greasley *et al.*, 2014). The World Bank employ the education

[11]Although not directly comparable due to differences in truncation and discounting, Blum et al (2017) finds the following average annual rates of the PV of TFP from 1990–2000; Britain 23 percent, Germany 38 percent, US 24 percent, Australia 18 percent, France 27 percent, Switzerland 28 percent, Argentina 10 percent, Brazil 22 percent, Chile 5 percent, Columbia 2 percent and Mexico 7 percent. Greasley et al. (2014) find the average annual PV of TFP to be 22 percent of GDP in Britain from 1950–1999. Hanley et al. (2015) find average annual rates of 26, 19, and 34 percent of GDP for US, Britain and Germany, respectively, from 1870–1990. However, there are a number of reasons to doubt these magnitudes. First, TFP is related to innovativeness, intangible assets and social capital. Consequently, adding TFP risks significant "double-counting" (Hamilton, 2012). Finally, there is no inclusion of "green capital" (see Mota and Domingos, 2013).

expenditure method. The expenditure approach requires a strong assumption that every euro spent on public education yields exactly one euro in additional human capital formation. Consequently, the expenditure method has attracted much criticism (Schultz, 1988; Jorgenson and Fraumeni, 1992). In defense of the expenditure method the World Bank argues that public spending education corrects for the misallocation of investment expenditures as consumption within the SNA and can be interpreted as a lower bound estimate for the change in the human capital stock (Hamilton and Clemens, 1999). An alternative view offered is that education spending may be an overestimate due to a lack of depreciation (Dasgupta, 2001) or the ineffectiveness of public schooling (Caplan, 2018). The GS estimates presented in this paper follow the expenditure method given the level of data demanded to undertake alternative methods across many countries over a long time period.

3.3. *Natural capital (Sub-Soil Assets)*

For non-renewable mineral and energy resources (oil, natural gas, and coal, bauxite, copper, gold, iron ore, lead, nickel, phosphate, silver, tin, and zinc) depreciation equates the ratio of the present value of rents, discounted at 4 percent, to the exhaustion time of the resource.[12] One renewable resource, forestry, is included and calculated as a one-sided adjustment of the extraction of timber beyond natural regeneration rates. For economies where increment exceeds wood extraction, no adjustment is made.

3.4. *Natural Capital (Environmental Degradation)*

The external damages emanating from pollution can be considered a form of negative natural capital (Atkinson and Hamilton, 2007; Nordhaus, 2008). One should ensure pollutants included in the empirical measurement of GS are consistent with its theoretical framework. GS refers to changes in the productive capacity of the economy. Thus, it seems obvious that greenhouse gases (GHGs) be included as, by their very nature, they cause damage as a stock pollutant. Other non-stock pollutants that damage productive stocks (e.g. particulate matter (PM) affecting human capital through increased morbidity and mortality) should also be included in GS estimates (Hamilton and Atkinson, 1996; Pearce and Atkinson, 1998; Atkinson and Hamilton, 2007).

Alternative environmentally adjusted macro aggregates such as the Index of Sustainable Economic Welfare (ISEW) and Genuine Progress Indicator (GPI) often suffer from a lack of theoretical rigor. For example, ISEW and GPI applications sometimes include damages arising from noise pollution (Cobb and Cobb, 1994). The inclusion of these so-called “pure flow” pollutants is theoretically inconsistent with GS. A pure flow pollutant (e.g. noise or odor) reduces the current utility of those directly affected and thus reduces current well-being (the focus of current well-being measurement) but this damage, in general, largely ceases with exposure and thus does not inhibit the economy’s future production and consequently

[12]See https://datacatalog.worldbank.org/dataset/adjusted-net-savings for detailed methodology. World Bank (2011) limited the lifetimes of all resources to 25 years before World Bank (2018) attempted country-specific estimates.

future well-being, possibilities (the focus of sustainable development measurement). Pollution damages should be estimated at society's marginal willingness to pay (WTP) to reduce emissions and reflect the present value of future impacts (Hamilton, 1996; Hamilton and Clemens, 1999; Dasgupta, 2001). Some applications of the GPI and ISEW value pollution damages using marginal damage costs but then permit the damages to accumulate over time. Accumulating marginal damages amounts to multiple counting as the marginal damages already reflect long-term damage (Neumayer, 1999).

GS is grounded in theory to serve as a sustainable development measure while the ISEW is an attempt to "correct" certain perceived limitations of GDP. The ISEW tries to address both current well-being and sustainable development measurement but these two concepts can conflict.[13] Consequently, the ISEW/GPI arguably fails to address either by meshing current well-being and sustainable development together in one index (Neumayer, 1999).[14] Alternatively, one could interpret the ISEW/GPI loosely as a modified version of green Net National income (gNNI). gNNI is derived from the same theoretical model as GS and is defined as comprehensive consumption (inclusive of all well-being/utility relevant items) plus GS (Hamilton and Clemens, 1999). The interpretation of gNNI in terms of sustainability assessment is less straightforward than GS and is a key reason that GS is preferred (Dasgupta, 2009).[15] Lawn (2003) argues for a different theoretical interpretation of ISEW/GPI based not on the Hicksian income concept but on Irving Fisher's concepts of capital and income but as McGrath *et al*. (2020) argue, this appears to miss the point as Weitzman (2017) shows that the Hicks, Fisher and Lindhal conceptions of income are all equivalent within the "pure theory of perfectly complete national income accounting."

The World Bank ANS indicator includes damages from the stock pollutant carbon dioxide (CO_2) and the non-stock pollutant particulate matter (PM). The World Bank includes CO_2 damages by employing the polluter pays principle and as such, each nation is notionally charged for its contribution to global damages.[16] To place a monetary value on CO_2 one must choose an appropriate social cost of carbon (SCC). The SCC represents the present value of the expected future damages to the world economy caused by an additional ton of carbon emitted into the atmosphere. One must also deal with the fact that the SCC is often reported in a contemporary base year price. An overview of approaches to estimate historical CO_2 damage costs can be found in Kunnas *et al*. (2014). It has been argued that, for historical estimates, one should consider two price movements. The first is general

[13]Suppose income inequality boosts capital accumulation, a boon for sustainability but a potential a drag on current welfare.

[14]Pezzey (2004) shows the conceptual difference between GS and its theoretically related welfare indicator Green NNI as the effects of current period economic activity on current utility or welfare and thus implies that while "pure flow" pollutants are relevant for measures of Green NNI they should be removed from GS.

[15]See Hanley et al., 2015 for a discussion. Under some certain assumptions preventing gNNI from falling is equivalent to preventing GS from becoming negative.

[16]The theoretical rationale for applying the polluter pays principle stems from Hamilton and Clemens (1999) where they internalized the stock-pollutant externality within a theoretical GS model by applying the optimal Pigouvian tax Arrow et al. (2012) argue in favor of an alternative method that accounts only for direct damages to each country. See Kunnas et al. (2014) for a thorough defense of the polluter pays approach.

inflation and can be dealt with using an output deflator such as the GNI-deflator. The second relates to the variation of damage costs with atmospheric concentrations of CO_2 over time. The second effect implies that damage costs should be discounted to account for the fact that the damages emanating from emissions in the past were expected to occur further into the future as compared with the contemporary base-year. The World Bank employs a social cost of carbon (SCC) of US$30/t$CO_2$ emitted in 2015 (year 2014 prices) and deal with the first effect using the GDP deflator. To address the second effect the SCC is discounted at 3 percent per year. At this rate, the cost per ton CO_2 emitted in 1990 was $14/t CO_2 (year 2014 prices). Lindmark and Acar (2013; 2014; 2019) use the discount rate from the original damage cost assessment to estimate the second effect.[17] The main results presented in this paper follow the World Bank approach. Within Section 4.3 the impact of applying a much larger SCC is analyzed.

The World Bank incorporates the damages to public health from non-stock local air pollution in the form of PM damages. A forgone labor approach is used to obtain an estimate of the monetary losses associated with premature mortality due to PM exposure. Under the forgone labor approach, the financial cost of PM damage is equated with the income that an individual would have earned over their remaining working life, discounted to the present year, had they not died prematurely from an illness caused by PM exposure. Losses are estimated per 5-year age group for premature mortality suffered among individuals under the age of 80. The approach is described in detail in World Bank (2018).

There is by now a large literature critically appraising the World Bank's GS calculations with repeated calls to expand the coverage of pollutants (Ferreira and Vincent, 2005; Pillarisetti, 2005; Dietz and Neumayer, 2006; Atkinson and Hamilton, 2007; Neumayer, 2013; Hanley *et al.*, 2015). Goossens *et al.* (2007) analyzed several alternative progress indicators, including the World Bank GS indicator, in the context of the EU using Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. Goossens *et al.* (2007) found a key limitation was that "*the amount of industrial pollution generated by EU Member States might not be sufficiently reflected*." In an attempt to improve the accuracy of the measurement of GS rates across the EU the ANS estimates are extended for 28 EU member states. Country-specific damage costs are included for sulphur dioxide (SO_2), nitrogen oxide (NOx), non-metallic volatile organic compounds (NMVOC) and ammonia (NH_3).[18]

Emissions data are available for each pollutant from Eurostat back to 1990.[19] Given the uncertainty surrounding estimated marginal damage estimates the advice of Atkinson and Hamilton (2007) is followed by presenting a range of estimates. For SO_2, NOx, NMVOC and NH_3 a range of country-specific damage costs are provided by the European Environment Agency (EEA, 2014a). By obtaining country-specific damage costs from a single source one of the key strengths of the

[17]We thank an anonymous reviewer for this point.

[18]We argue these pollutants cannot be considered "pure flow" due to their effects on other productive stocks and because of their role as indirect GHGs, SO_2, NOx & NMVOC are considered indirect GHGs by the UNFCCC. Other authors have assumed these pollutants affect only current utility and thus represent "pure flow" pollutants (e.g. Mota and Domingos, 2013; Pezzey et al., 2006).

[19]https://ec.europa.eu/eurostat/statistics-explained/index.php/Air_pollution_statistics_-_emission_inventories

TABLE 1
Average Marginal Damage Costs Employed Across Each Genuine Savings Scenario (in 2005 Prices)

Pollutants	GSAP1	GSAP2	EU-wide Emissions 1990	EU-wide Emissions 2016	% Change in Emissions 1990–2016
SO_2	€32,754/t	€11,168/t	20mt	2mt	−90%
NOx	€12,586/t	€4,665/t	18mt	8mt	−56%
NH_3	€27,238/t	€10,859/t	18mt	7mt	−61%
NMVOC	€3,574/t	€1,369/t	5mt	4mt	−20%

SO_2 = sulfur dioxide, NOx = nitrogen oxides, NH_3 = ammonia, CO = carbon monoxide, NMVOC = non-metallic volatile organic compounds, t = tons, mt = mega tons.

indictor is retained by keeping the comparable "league table" aspect intact. As pointed out by Hanley *et al.* (2015) comparability is often lost when country-specific GS studies are undertaken.

EEA (2014a) assesses damages caused by air pollution by industrial facilities in the EU, Norway, and Switzerland by quantifying the health effects of primary PM as well as SO_2, NOx, NH_3 and NMVOCs resulting from the formation of secondary PM and ozone through chemical reactions in the atmosphere. EEA (2014a) also incorporates damages by the main air pollutants to crop and building material damage and includes country-specific damages costs for each country in 2005 prices.[20] Two measures of pollution extended GS estimates are constructed, "*GS Additional Pollutants 1*" (*GSAP1*) and "*GS Additional Pollutants 2*" (*GSAP2*) and compared with the World Bank's ANS estimates. EEA (2014a) provides a lower bound damage cost estimate obtained using the value of a life year (VOLY), and an upper-bound estimate using the value of statistical life (VSL). In this paper, GSAP1 takes the upper-bound estimate from the EEA (2014a) for each pollutant and GSAP2 takes the lower-bound estimate.[21] All other GS components are common across the estimates. Table 1 illustrates the average marginal damage costs for the base year in each of the extended pollutants in 2005 prices.

There are important methodological challenges one confronts when expressing the social cost of pollutants over time. EEA (2014a) reports the unit damage costs for each country and each pollutant in contemporary unit costs (€/ton in 2005 prices) and explicitly warns that the marginal damage costs will vary through time and should not be held constant (fixed prices). Non-constant marginal damages for each of the extended pollutants are assumed and deflated with country-specific GNI deflators.[22] Other studies have constructed pollution-specific deflators, based on weighted asset prices (actual or shadow prices) for those assets degraded by the pollutant (Lindmark and Acar, 2014). The European aggregate results obtained using fixed prices, are included in Figure 5 within the appendix.[23]

[20]GS is interested in asset declines thus there is a strong argument that damages to crops should be removed from the analysis if soil damages affect only current output although the analysis is less straightforward if damages affect future output. It is not easy to exclude the crop damages from the damage estimates thus we include them in the analysis however it should be noted that the damage costs are likely to be underestimated as negative impacts on ecosystem services are unquantified. Depreciation effects (e.g. acid rain damaging buildings and machinery), should be captured but in practice, the SNA is not sophisticated enough (Atkinson and Hamilton, 2007). In these scenarios asset value declines should be also be costed.

[21]Table 4 in the appendix provides the marginal damage costs for each Member state as reported by EEA (2014a).

[22]While assuming fixed prices for the pollutants through time is unsatisfactory, the choice of deflator is not inconsequential as Lindmark and Acar (2013) demonstrate. The authors use a simple example of a pollutant that impacts only human health. In this simplified scenario, the damage cost in 1990 requires that the 2005 unit cost be deflated with a wage index that proxies expected lifetime incomes. If wages rose faster than the GNI deflator since 1990, deflation with the GNI deflator would exaggerate the historical social cost and vice versa. In the absence of country-specific wage deflators and given that not only human health will be affected by the extended pollutants in the study we chose to use the GNI deflator as a more accurate measure than fixed prices.

[23]With fixed prices the trends do not change, however GS rates are considerably lower in the early 90s (environmental damages are larger). The gap tightens until 2005 when damages are equivalent then GS rates are slightly higher from 2006 before converging at the end of the period. Taking the extremes, with fixed prices the average GSAP1 rate in Bulgaria is −76 percent of GNI compared with −61 percent with non-constant damages, for Sweden there is no difference.

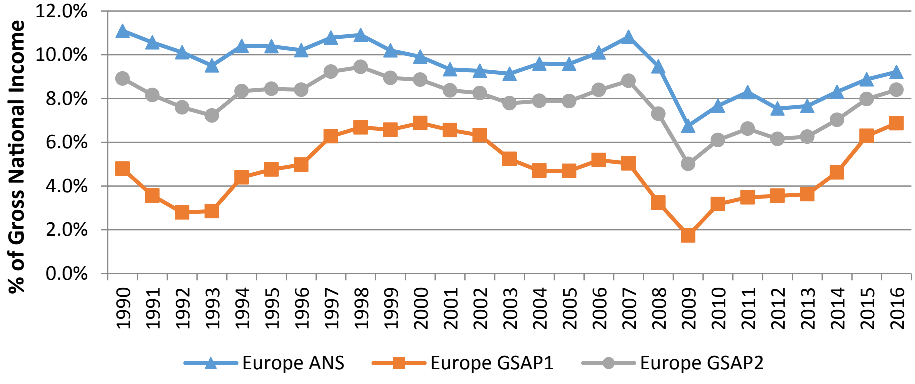

Figure 1. European aggregate GS indicators 1990–2016.
Note: GSAP1 takes the upper bound environmental damage estimates from EEA (2014a), GSAP2 the lower bound. All other components are common across the estimates [Colour figure can be viewed at wileyonlinelibrary.com]

4. Results

4.1. *European Aggregate Genuine Savings 1990-2016*

Figure 1 illustrates the European aggregate savings rates across each GS measure and Figure 2 provides a breakdown of the components of the GS indicators. Initially, savings rates declined prior to the establishment of the single market in 1993. European wealth grew at slower rates due to high pollution damages and falling net physical capital investment. During this period, the inclusion of local air pollutants had the largest impact on estimated wealth formation, as large as 7 percent of GNI, a similar adjustment, in the opposite direction though, to net physical capital investments (7 percent of GNI). Only education spending (5 percent of GNI) prevented negative savings rates in 1992 and 1993 in the GSAP1 measure. The extended pollution damages accounted for 2–5 percent of GNI, on average compared with the combined CO_2 and PM2.5 damages contained within the ANS estimates of 0.5 percent of GNI. The mid-90s saw Europe become more tightly integrated and this coincided with increased traditional investment and large declines in environmental damages; both factors contributed to European wealth increasing at faster rates. During that period, an important driver was that the Eastern European transition economies began to find their feet following the collapse of communism. As discussed in Section 4.2, savings rates were severely negative or close to zero in those transition economies during the early 1990s but rose considerably following structural reforms. By the mid-90s, ten ex-communist regimes had entered into Association Agreements with the EU that provided for increased trade liberalization, support for institutions more conducive to a market-based economy and policy support in areas such as democratization, the environment and transport (Hare, 2001). European aggregate savings rates were stable or rising until the financial crisis hit the global economy in September 2008. The resultant collapse in NNS lead to new troughs recorded in all three GS measures in 2009. From 2008 to 2011 only sustained education expenditures prevented negative GS. Savings rates rebounded from 2010.

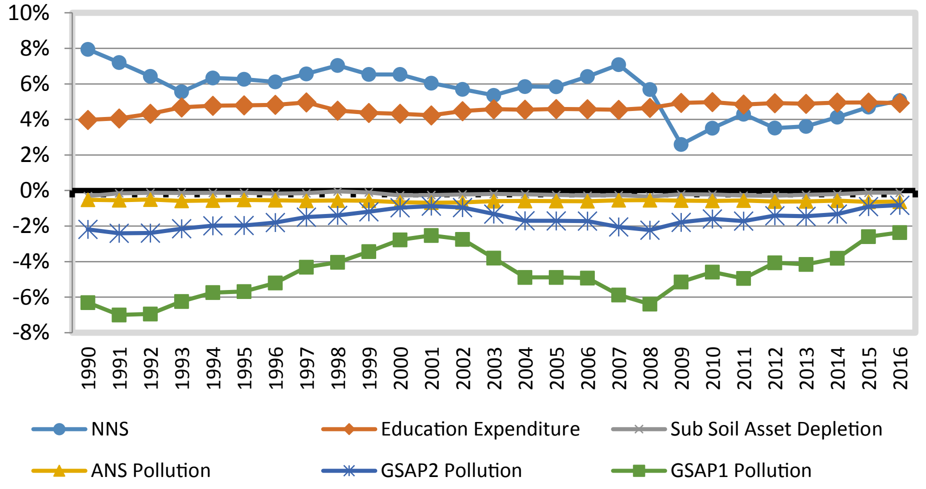

Figure 2. Components of GS estimates from 1990–2016
[Colour figure can be viewed at wileyonlinelibrary.com]

Figure 3 provides a breakdown of the external costs of environmental damage, by pollutant and Table 1 indicates the substantial reductions in emissions across each of the four extended air pollutants. EU-28 emissions of SO_2, NOx, NMVOC and NH_3 declined throughout 2002–2008 but damages increased as the reductions did not keep pace with rising marginal damage costs, highlighting a principal issue with physical indicators without reference to monetary valuation. This relationship is most clear with CO_2 and NH_3 damages which were actually larger in 2016 than in 1990 despite sizeable emissions reductions over that period. The total emissions of each pollutant as well as the annual damages of all but CO_2 and NH_3 have declined since 1990. SO_2 has been the key determinant of the total damages and has also seen the starkest decline, both in terms of emissions and damages.[24]

Extended environmental damages as a share of GNI peaked in 1991. Figure 4 illustrates a counterfactual scenario, for GSAP1, where the relationship between environmental damages and GNI had remained fixed at the 1991 peak levels. Savings rates would have been negative or less than 1 percent of GNI in 4 years (2009, 2010, 2012 and 2013), averaged 2.5 percent of GNI over the entire period and 1 percent of GNI from 2008 to 2016. In this counterfactual scenario, excluding education expenditure (EE) would have resulted in negative savings rates in every year except 1990. These findings suggest the potentially sizeable benefits that can

[24]EU-28 SO_2 emissions fell from 20 million tons (mt) in 1990 to 2.4mt in 2016 and largely attributable to fuel-switching in energy sectors, technological development in industrial facilities and the impact of EU directives (EEA, 2018). NOx emissions fell from 18.1mt to 7.6mt largely a result of legislative standards in transport and technological advancement in the energy sector (e.g. low-NOx burners). NMVOC fell from 17.5mt to 6.7mt largely due to changes industrial processes and product use. NH3 emissions reduced from 5.1 to 3.9mt, reductions have been achieved through manure management (EEA, 2018).

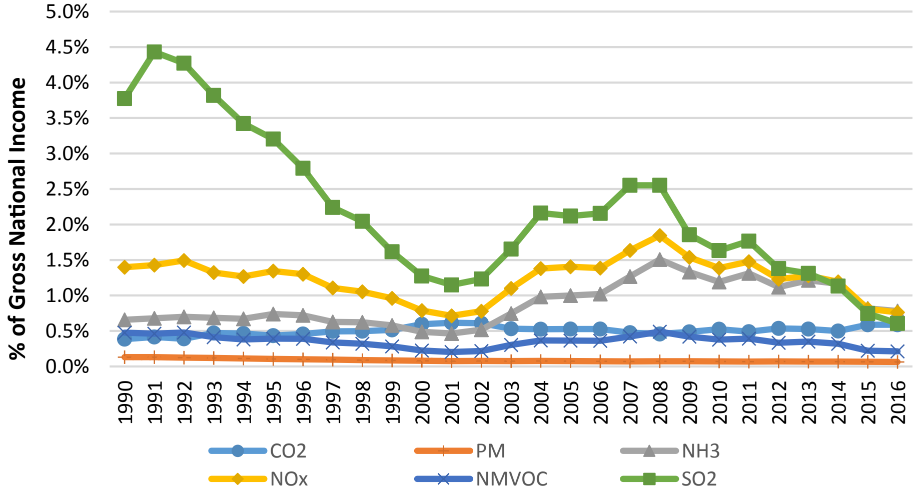

Figure 3. Breakdown of pollution damages as a % of GNI [Colour figure can be viewed at wileyonlinelibrary.com]

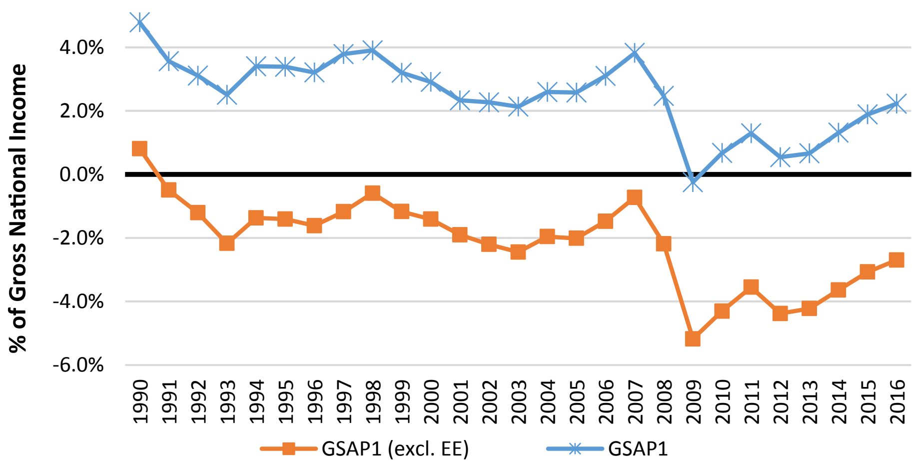

Figure 4. Counterfactual GSAP1 scenario [Colour figure can be viewed at wileyonlinelibrary.com]

be achieved through market incentives, technological advancements, and sensible environmental policy

4.2. *Development Paths of European Economies*

Table 2 presents the mean savings rates for each of the individual economies across each observed period. Column (1) presents the ANS results from the World Bank where only two economies exhibited an average negative ANS rate (Latvia and Romania). The sustainability message differs considerably when the extended air pollutants are accounted for. Eleven member states were found to have held

TABLE 2
Average Genuine Savings Rates (all figures in percentages)

Country	Time Period	(1) ANS	(2) GSASP1	(3) GSAP2
Austria	2005–2016	13	10	12
Belgium	2002–2015	12	8	10
Bulgaria	1990–2016	3	(−61)	(−18)
Cyprus	1990–2016	10	9	10
Czech Republic	1993–2013	7	(−18)	(0)
Germany	1991–2016	11	6	9
Denmark	1990–2016	15	12	14
Estonia	2000–2015	13	(−4)	7
Spain	1990–2016	10	6	9
Finland	1990–2016	12	11	12
France	1990–2016	10	7	9
Greece	1990–2015	3	(−1)	1
Croatia	1995–2016	7	(−6)	3
Hungary	1993–2015	5	(−9)	1
Ireland	2005–2016	14	11	12
Italy	1990–2016	8	2	6
Lithuania	2004–2016	19	11	16
Luxembourg	1999–2016	23	18	22
Latvia	1995–2016	(−3)	(−12)	(−6)
Malta	2000–2016	11	9	10
Netherlands	1990–2016	15	12	14
Poland	2004–2016	8	(−15)	(0)
Portugal	1990–2016	6	3	5
Romania	1990–2016	(−3)	(−32)	(−13)
Sweden	1990–2016	18	17	18
Slovenia	2004–2015	10	(−3)	5
Slovakia	2004–2015	4	(−8)	(0)
United Kingdom	1990–2016	5	2	4

Note: GSAP1 takes the upper bound environmental damage estimates from EEA (2014a), GSAP2 the lower bound.

negative average GSAP1 rates, where the upper limits of the country-specific damage costs from EEA (2014a) were incorporated. Six member states exhibited average GSAP2 rates that were negative or 0 percent of GNI. A further two economies held average rates of 1 percent of GNI. It is striking that the findings of negative savings, an indicator of unsustainable development, were concentrated in the former communist regimes. Of the 11 member states where at least one GS measure showed persistent negative savings, all were ex-communist except Greece. As discussed below, the dynamics differ in the Greek case where negative average savings were driven by negative NNS during the financial crisis, whereas the others were driven by pollution damages.

By employing the range of estimated marginal pollution damages from EEA (2014a) a natural sensitivity analysis is undertaken but clearly these estimated damages contain a high degree of uncertainty. A more robust sensitivity analysis is provided in Table 6 within the appendix. Hypothetical marginal damage costs are examined by scaling up or down the estimated damages from EEA (2014a) under an "optimistic sensitivity" and "pessimistic sensitivity" analysis for each member state. The optimistic sensitivity analysis examines how high could environmental damages be relative to the EEA (2014a) estimates and still yield positive savings rates in each year observed. The pessimistic sensitivity analysis uncovers how low could the environmental damages be relative to EEA (2014a) estimates and yet still yield negative savings rates in each year observed.

The findings contrast with the GS literature that has consistently shown developed economies to consistently hold sizeable and positive savings rates (Pearce and Atkinson, 1993; Hamilton and Clemens, 1999; Arrow *et al.*, 2012; World Bank, 2018). The results indicate that environmental externalities drove negative savings rates for many European member states, from 1990 to 2016. It should be noted that unsustainable development may be overcome through exogenous future technical progress. However, the magnitude of the negative savings rates in Bulgaria and Romania, in particular, suggest that even accounting for rapid technological change, signals of unsustainable development would in all likelihood persist.

The individual economies can be categorized into 4 broad groups. Group 1 (Latvia and Romania) consists of those economies with persistent negative savings rates across all 3 GS indicators (ANS, GSAP1, and GSAP2) thus providing a strong signal of unsustainable development. Both nations experienced large negative NNS during much of the observed period and high levels of pollution damage. Both countries also experienced types of Environmental Kuznets Curve (EKC) effects during periods of robust economic growth. Latvia experienced a strong reduction in local air pollution as was common across the EU and this led to a sharp increase in savings rates throughout the period although savings remained negative in most years. Romania experienced a sharp decline in carbon emissions, largely a result of social and political change following the restructuring of the economy during the early 1990s. For example, there was a sharp decline in the energy-inefficient heavy industry that had prevailed prior to Romanian liberalization (EEA, 2008). Local air pollution increased during the period that carbon damages declined and resulted in a fall in GSAP1 and GSAP2 savings rates from 2002, an upward trend emerged from 2008.

Group 2 (Bulgaria, Czech Republic, Slovakia, and Poland) contains economies where the sustainability message derived from *both* of the augmented GS estimates (GSAP1 and GSAP2) “disagree” with the World Bank’s. Bulgarians faced the highest local air pollution damages in Europe, at an average of 21–64 percent of GNI, annually. Damages from the burning of coal at large industrial power plants explain much of the pollution (EEA, 2014b). Bulgarian GSAP2 turned positive from 2015, following a strong economic recovery from the recession. Interestingly, the Czech Statistical Office includes the time-series of the World Bank’s ANS indicator as part of their “Green Growth” environmental indicators publications (CZSO, 2011 and 2014). The addition of local air pollution changes the sustainability signal completely for the Czech Republic and highlights the importance of acknowledging and addressing the limitations of the ANS measure before making policy decisions. Slovakian GSAP1 was negative in all years but the trend in savings rates was upwards. GSAP2 was positive from 2012. As in the Latvian case, the period of strong economic growth, prior to the economic downturn, coincided with reductions in total environmental damages in Slovakia. Poland was one of the early reformers under the Environmental Action Plan in the 1990s and managed to reduce emissions of many local air pollutants, mainly due to reforms in energy and heavy industry (World Bank, 2019). GSAP2 turned positive from 2011 and GSAP1 increased from −20 percent of GNI in 2004 to −0.3 percent of GNI in 2016. Remarkably, the Polish economy achieved strong real GNI growth (4 percent per year from 2004 to 2016) throughout the global recession indicating a strong EKC relationship between growth and local air pollution.

Group 3 (Hungary, Estonia, Croatia, Slovenia & Greece) comprises those economies exhibiting persistent signals of unsustainability but only when employing the upper limits of environmental damages. Hungary and Slovenia both followed the general EU trend of declining environmental damages and exhibited a trend of increased savings rates. Hungarian and Slovenian GSAP1 was negative on average but turned positive in both nations from 2015. Estonia experienced rapid economic growth from 2001 to 2007 (real GNI grew 7 percent per year) and as in Romania and Bulgaria this growth translated into large levels of conventional investment and a decline in CO_2 damages. However, local air pollution damages rose during the economic expansion. The increase in local air pollution was due to an increase in oil shale consumption likely driven by increased electricity demand. Interestingly, the Estonian economy contracted significantly from 2008 to 2010 (GNI contracted −6 percent per year) but de-growth did not lead to any significant decline in local air pollution. In fact, SO_2 emissions rose sharply from 2009 to 2010 following a large increase in oil shale consumption (OECD, 2017). When growth re-emerged from 2011, Estonian GSAP1 turned positive. For Croatia, GSAP1 and GSAP2 both rose consistently up to 2003, as pollutant damages fell, before stagnant SO_2 and NOx emissions lead to rising pollution damages. Croatia experienced de-growth from 2009 and unlike in Estonia de-growth coincided with strong reductions in total pollution damages. However, it is not until the Croatian economy returned to growth (from 2014) that GSAP1 turned positive. For Greece, NNS were the biggest driver of Greek savings rates. The collapse in the Greek economy during the great recession resulted in double digit negative NNS. Local air pollution damage in Greece was actually below the European aggregate (Figure 1) but were large enough to push GSAP1 negative on average.

Group 4 (Austria, Belgium, Cyprus, Denmark, Finalnd, France, Germany, Ireland, Italy, Lithuania, Luxembourg, Malta, Netherlands, Portugal, Spain. Sweden and the United Kingdom) contains those economies where all three GS measures were positive over each observed period. Group 4 contains those economies that hold comparatively high levels of national income per capita, and appear more open to trade. Further research examining the determinants of European ANS as well as the more comprehensive GSAP rates would be worthwhile. Lithuania is an anomaly in terms of the ex-communist countries. From independence Lithuania immediately began radical market reforms (Černiauskas and Dobravolskas, 2011). Using GDP as a well-being measure, Černiauskas and Dobravolskas (2011) compare Lithuania to Latvia and find Latvia to have had relatively greater development from 1990, but the authors argue GDP understates economic development in Lithuania. The broader development measures presented in this stufy show Lithuania to have fared much better and this was due to sizeable investments in human capital that averaged 16 percent of GNI, annually. Even within Group 4, the extended pollution damages had a considerable impact. For some economies savings rates were even negative or less than 1 percent of GNI in certain years. These negative or low savings were generally confined to GSAP1 and resulted from a collapse in NNS during the financial crisis (Italy, Cyprus, Portugal), high levels of local air pollution during the early 1990s (Italy, UK), or falling NNS in the early 1990s (Finland).[25] From 1990 to 1995 extended environmental damages were as large as 9 percent of GNI for Germany and Luxembourg, 8 percent of GNI for Italy and the UK and 5 percent of GNI in France, Denmark, and the Netherlands. Overall, the findings suggest that accounting for additional pollutants can have a large impact on European GS.

4.3. *Weaknesses and Limitations of the ANS indicator*

An evaluation of the strengths and weaknesses of the World Bank's GS indicator, explicitly in relation to the EU, can be found in Goossens *et al*. (2007) and Stiglitz *et al*. (2009). Goossens *et al*. (2007) were requested by the European Parliament's Committee on the Environment, Public Health and Food Safety to assess the limitations of the World Bank's GS indicator and analyze alternative indicators to GDP, in the context of measuring sustainable development across the EU. As shown in Table 3, the authors identified six limitations but highlighted two in particular—limited capital asset coverage and the valuation of net investments. Stiglitz *et al*. (2009) also identified these two limitations but added a third, the question of scale. The scale issue is returned to after analyzing the weaknesses identified by Goossens *et al*. (2007) and the progress since the publication of that study. Table 3 provides the limitations identified along with the authors' rationale in each case.

Regarding the first limitation identified (1), a limited coverage of natural capital assets is a well-established limitation of empirial GS applications (Ferreira and Vincent, 2005; Pillarisetti, 2005; Dietz and Neumayer, 2006; Atkinson and Hamilton, 2007; Stiglitz *et al*., 2009; Neumayer, 2013; Hanley *et al*., 2015) and a key motivation for this paper. Limitation (2), the valuation of human capital accumulation, is debated, as outlined in 3.2, but this is materially the same weakness identified in (3) and (4), namely the valuation of the net investments and their conformity (or lack thereof) to the theoretical framework. Regarding (3), that net investments do not account for efficiency merely their value, seems odd and there is little clarification offered by the authors. To be clear, the (potentially large) assumption underpinning the estimated net investments is that they are valued by the "correct" shadow prices reflecting their marginal contributions to utility in consumption and marginal rate of substitution in production (Pearce and Atkinson, 1998). The limitation of using market prices and estimated marginal pollution damages, in contrast to these "correct" shadow prices, is widely cited and discussed

Correct valuation is also the essence of (4) as the theory does not imply that GS must be lower than NNS. It is entirely plausible within GS theory that GS could be found to be higher than NNS. As long as the components of GS are

[25]UK GSAP1 was negative or < 1 percent of GNI from 1990–95, and averaged 1 percent of GNI from 2008–10. Portuguese ANS and GSAP1 was negative or < 1 percent of GNI from 2004–16 and GSAP2 from 2005–12 and 2015–16. Italian GSAP1 was < 1percent of GNI from 1991–93 and 2008–15. Finland GSAP1 was < 1 percent of GNI in 1992, All 3 Cypriot savings rates were negative < 1 percent from 2013–15.

TABLE 3
Limitations of the World Bank GS Indicator Identified by Goossens *et al.* (2007)

Weakness/Limitation	Goossens *et al.* (2007) Rationale
1. Data unavailability means excluding natural and intangible capital	Important capital assets such as water, fish, local air pollution and soil are missing due to data constraints
2. Exclusion of loss of human capital through death or knowledge obsolescence	The human capital proxy is a gross measure there is no provision for depreciation.
3. Does not account for the efficiency of investments made	The efficiency of investments are not considered merely the monetary value is included
4. Debated methodology for monetization	The social cost of carbon is debated and resource depletion is currently valued as "market price minus costs of production"
5. Potential for wrong conclusions: positive genuine saving rates may distract attention from unsustainable trends	Within the EU, ANS rates are higher than NNS, which may lead to wrong conclusions due to missing capital assets, in particular water and local air pollution
6. Aggregation into a single indicator assumes "perfect substitutability" of capital stocks.	Aggregation masks complex socio-economic and ecological interlinkages

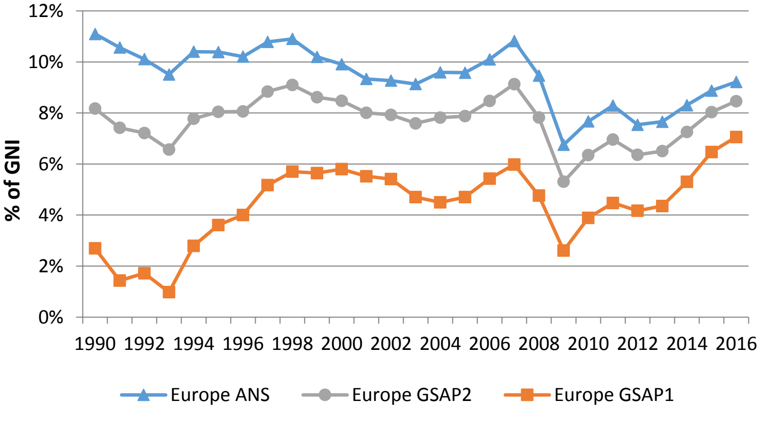

Figure 5. European aggregate GS indicators with fixed prices for local air pollutants 1990–2016 [Colour figure can be viewed at wileyonlinelibrary.com]

correctly valued then the GS indicator cannot offer incorrect signals. The substance of the authors' valid worry is that the components are incorrectly valued. Limitations (5) and (6) amount to negative criticisms in that they are both a criticism of the substitutability assumption underpinning the conditions for "weak" sustainability. If one questions the validity of the substitutability assumption then one is lead to an assumption of non-substitutability and thus theories surrounding "stronger" forms of sustainability. However, *assertions* of non-substitutability do not constitute evidence of non-substitutability (Pearce and Atkinson, 1998). Weak and strong sustainability are *both* non-falsifiable as they *both* rely on assumptions about the unknown future (Neumayer, 2013). By assuming non-substitutability (strong sustainability), a critique of weak sustainability, for assuming substitutability, commits at least a parallel fallacy (Pearce and Atkinson, 1998).[26] This leaves us with two valid weaknesses, limited capital asset coverage and debate about the correct valuation of net investments.

There has been significant progress in relation to these two limitations. First, as this paper demonstrates, the coverage of air pollutants can be expanded across the EU on a comparable basis. It also seems plausible that further coverage of natural capital may be facilitated through the work on natural capital accounting currently being undertaken across the EU (McGrath and Hynes, 2020).[27] Second, regarding the valuation of net investments, the World Bank has made dramatic progress in moving away from the crude net-price valuation method, for sub-soil assets, towards a country-specific net present value approach to provide much more accurate measurement (Neumayer, 2013).[28] Furthermore, many studies have addressed the debate surrounding the valuation of CO_2 damages and suggest, in a similar vein to this study, to provide a range of estimates. The debate around the social cost of CO_2 also offers insight into the limitation of scale identified by Stiglitz *et al*. (2009).

Stiglitz *et al*. (2009) questioned the policy relevance of the World Bank ANS indicator given it is based on country level assessment and thus may be removed from the global context. Stiglitz *et al*. (2009) note the significant disparity between the "weak" ANS estimates which do not indicate global unsustainability and "strong" indicators such as the ecological footprint which suggest the opposite. Pezzey and Burke (2014) resolve the discrepancy between the strong and weak indicators by analyzing the possible future path of emissions and consequent selection of carbon pricing. If emissions are close to optimally controlled (globally) in the future then the ANS indicator does not indicate global unsustainability but if uncontrolled (business as usual) unsustainable development is signified.

The findings of Pezzey and Burke (2014) coupled with Weitzman (2009), who makes a compelling case for climate policy to consider fat-tailed structural uncertainty along with uncertainty arising from temperature variability, suggests a potential avenue available to mitigate the scale issue. The global context may be factored into national GS estimates by considering much larger (although much less probable) damages, and consequently a much larger marginal damage estimate, to reflect a so called "catastrophic climate change" scenario.

[26]Although GS is commonly referred to as a weak sustainability indicator, Fenichel and Abbott (2014) illustrate how appropriate shadow prices could potentially represent any degree of substitutability.

[27]Member states must take steps toward environmental accounting under regulations (EU) 691/2011 and (EU) 538/2014.

[28]The World Bank now calculates depletion as the ratio of the present value of rents, discounted at 4 percent, to estimated exhaustion time. World Bank (2011) limited resource lifetimes to 25 years then World Bank (2018) attempted country specific estimates.

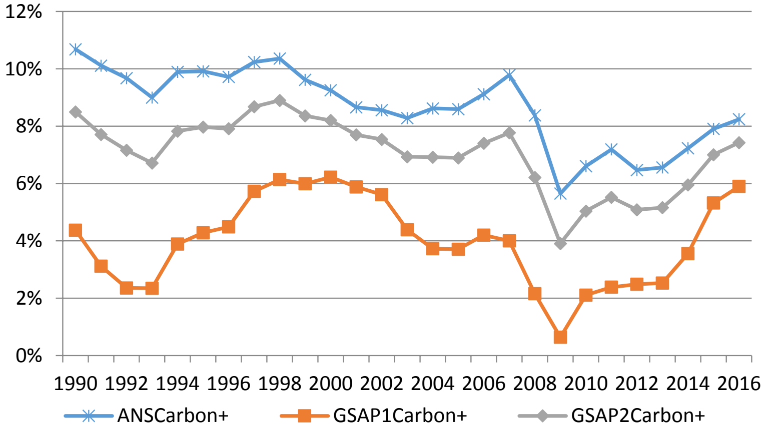

Figure 6. European aggregate GS indicators (non-fixed pollution damages) with Catastrophic Climate damages [Colour figure can be viewed at wileyonlinelibrary.com]

The World Bank employ a Social Cost of Carbon (SCC) of \$30/tCO_2 in 2015 discounted at 3 percent per year (\$14/t in 1990 in real terms) for the computation of ANS. First the SCC is doubled to \$60/tCO_2 (\$28/t in 1990 in real terms) and the subsequent range of European aggregate GS estimates are shown in Figure 6 in the appendix. [29] The inclusion of the larger SCC results in aggregate European GS rates, across all three measures, being reduced by 1 percent of GNI per annum, on average. A 15-fold increase in the marginal damage cost to \$900/tCO_2 (\$3300/tC) in 2015 would be required for ANS to turn negative in all years. A damage cost of \$600/tCO_2 is needed for all years from 2000 to turn negative. GSAP1 would require marginal damages of \$420/tCO_2 (\$1,541/tC), in 2015, for all years to be negative. At \$120/tCO_2, 2009 would turn negative and at \$300/tCO_2 all years from 2004 would turn negative. For GSAP2 \$600/tCO_2 would result in negative savings from 1993 onwards and at \$420/tCO_2 savings rates from 2000 would be negative. On a national basis the impact of the larger SCC is more pronounced where carbon damages were proportionally higher and/or where savings rates were already low. [30] Table 5 in the appendix presents the average GS rates for each member state with the higher SCC.

It is clear that no single indicator can provide an all-encompassing answer to questions surrounding sustainable development (McGrath *et al.*, 2020). However, it is also clear that the current monitoring of the EU sustainable development strategy and Europe 2020 agenda lacks coherence (Goossens *et al.*, 2007) and fails to acknowledge what is arguably the most internally consistent theory of sustainable

[29]A SCC of \$60/tCO_2 represents the upper bound of estimates contained in the review by the IPCC. This is comparable to the \$65/t CO_2, 95th percentile estimate, in 2010 prices contained in who estimates a SCC of \$31/tCO_2 in 2015 (2010 dollars) and a 10th to 90th percentile range of \$7 to \$77/tCO_2.

[30]For example, Bulgarian rates were adjusted by −5 percent of GNI, on average, resulting in 9 additional negative ANS years.

TABLE 4

Marginal Damage Costs for Each Member State as Reported in EEA

Country	NH_3 Low	NH_3 High	NOx Low	NOx High	NMVOC Low	NMVOC High	SO_2 Low	SO_2 High
€ in 2005 Prices								
Austria	9,914	29,615	8,681	24,442	2,248	6,184	19,651	58,494
Belgium	19,225	57,437	4,152	12,227	2,368	5,750	22,591	66,516
Bulgaria	10,166	33,489	4,588	12,581	912	2,554	6,238	19,696
Cyprus	2,194	4,668	593	1,196	105	237	1,052	2,270
Czech Republic	19,318	56,460	6,420	17,663	2,075	5,518	12,483	36,491
Germany	13,617	41,798	6,817	19,059	1,891	4,772	18,956	57,524
Denmark	4,693	13,944	3,092	8,515	1,156	2,756	11,209	33,200
Estonia	5,017	14,664	2,159	5,566	670	1,723	5,826	16,692
Spain	4,345	12,224	2,241	5,183	1,074	2,690	7,520	21,120
Finland	2,912	8,408	1,481	3,780	599	1,544	4,117	11,867
France	6,258	18,149	5,463	13,951	1,616	4,087	15,875	45,909
Greece	5,085	15,632	1,390	3,142	911	2,386	4,000	11,671
Croatia	10,477	31,786	6,802	18,433	1,542	4,159	10,348	31,348
Hungary	17,191	51,980	7,502	20,354	1,751	4,830	11,821	35,479
Ireland	1,692	5,034	3,736	9,785	1,046	2,647	11,011	32,378
Italy	11,221	35689	7,778	23,029	3,179	8,968	14,729	46,150
Lithuania	4,914	14,479	3,778	9,935	794	2,066	10,106	29,748
Luxembourg	16,125	48,130	6,468	17,974	2,355	5,891	18,763	55,912
Latvia	5,195	15,651	3,021	7.851	866	2,252	8,770	26,175
Malta	4,893	12,756	736	1.696	674	1,651	2,302	6,895
Netherlands	12,199	35,859	4,854	14,770	2,364	5,722	25,209	74,414
Poland	13,435	38,240	5,131	13,840	1,610	4,194	11,802	33,613
Portugal	4,018	11,921	1,805	4,367	628	1,534	5,216	14,949
Romania	11,418	33,832	7,507	20,361	1,159	3,148	10,668	31,439
Sweden	4,017	12,152	2,197	5,662	797	2,038	5,209	15,438
Slovenia	14,343	43,277	9,127	25,992	2,809	7,882	15,774	47,749
Slovakia	20,436	57,719	6,792	17,936	1,442	3,838	10,411	30,093
United Kingdom	9,503	27,790	3,558	9,948	1,450	3,468	14,425	41,861

TABLE 5
Average Genuine Savings Rates with Catastrophic Climate Damages 1990–2016 (all figures in percentages)

Country	Time Period	(1) ANSCarbon+	(2) GSASP1Carbon+	(3) GSAP2Carbon+
Austria	2005–2016	13	9	11
Belgium	2002–2015	11	7	9
Bulgaria	1990–2016	(−2)	(−66)	(−23)
Cyprus	1990–2016	9	8	8
Czech Republic	1993–2013	4	(−15)	(−3)
Germany	1991–2016	10	5	8
Denmark	1990–2016	14	11	13
Estonia	2000–2015	9	(−8)	3
Spain	1990–2016	9	6	8
Finland	1990–2016	11	10	10
France	1990–2016	10	6	8
Greece	1990–2015	2	(−3)	(0)
Croatia	1995–2016	5	(−7)	1
Hungary	1993–2015	3	(−12)	(−1)
Ireland	2005–2016	12	10	11
Italy	1990–2016	7	2	5
Lithuania	2004–2016	18	7	14
Luxembourg	1999–2016	22	17	20
Latvia	1995–2016	(−4)	(−13)	(−7)
Malta	2000–2016	10	7	9
Netherlands	1990–2016	15	11	13
Poland	2004–2016	5	(−18)	(−3)
Portugal	1990–2016	5	2	4
Romania	1990–2016	(−6)	(−35)	(−16)
Sweden	1990–2016	18	17	17
Slovenia	2004–2015	8	(−5)	4
Slovakia	2004–2015	2	(−11)	(−3)
United Kingdom	1990–2016	4	1	3

TABLE 6

Marginal damage cost sensitivity for each Member State, for the extended pollutants (all figures in percentages)

	Optimistic Sensitivity–How High Could Environmental Damages be Relative to EEA (2014a) Estimates and Still Yield Positive Savings Rates in Each Year Observed*		Pessimistic Sensitivity–How Low Could Environmental Damages be Relative to EEA (2014a) Estimates and Still Yield Negative Savings Rates in Each Year Observed*	
Country	GSAP1 optimistic	GSAP2 optimistic	GSAP1 Pessimistic	GSAP2 Pessimistic
Austria	190	730	420	1390
Belgium	440	85	420	1125
Bulgaria	(−97)	(−99)	(−40)	83
Cyprus	310	760	2250	4900
Czech Republic	(−83)	(−52)	(−35)	85
Germany	18	250	440	1470
Denmark	100	470	1820	5300
Estonia	−64	322	4	3
Spain	77	420	460	1500
Finland	(−10)	150	2190	6130
France	107	470	545	1670
Greece	(−34)	86	(−35)	85
Croatia	(−81)	(−29)	55	255
Hungary	(−89)	(−65)	32	360
Ireland	205	750	1570	4480
Italy	−45	−33	220	870
Lithuania	25	250	178	680
Luxembourg	10	210	1000	2100
Latvia	(−90)	(−70)	4	70
Malta	(−20)	130	7201	19080
Netherlands	178	715	903	2829
Poland	−87	−63	−2	175
Portugal	−65	−5	510	1585
Romania	−97	−90	−70	−1
Sweden	690	1800	4170	11700
Slovenia	(−64)	9	13	270
Slovakia	(−88)	(−65)	(−36)	105
United Kingdom	(−45)	50	250	870

*In each year where ANS is at least 1% of GNI.

development (Pearce and Atkinson, 1998). An appropriate measure of GS would offer a clear link between these EU development strategies (Goossens *et al*., 2007). Having said this, we agree with recommendation 3 of Stiglitz *et al*. (2009), "*A monetary index of sustainability has its place in a sustainability dashboard…*" and that this index be based on the concept of comprehensive wealth, which is supported by a strong theoretical framework. McGrath *et al*. (2020) suggest potential paths forward for sustainability policy and assessment that preserve the link with economic theory regardless of what conception of sustainable development is preferred. There has been important progress made on the development of the GS concept in theory and practice and this paper has attempted to provide further progress in relation to measuring European GS.

5. Conclusions

This paper extended the limited coverage of air pollution included in the World Bank GS measure, in the hopes of progressing towards the inclusion of GS in the monitoring of EU economic development strategies and the implementation of the UN Sustainable Development Goals. The results show that augmented pollutant damages can result in substantial downward adjustments to the World Bank's indicator. When taking the upper limits of the estimated marginal social costs of SO_2, NMVOC, NOx and NH_3 emissions, 11 member states exhibited a negative average savings rate, compared with just two in the equivalent World Bank dataset. This is in sharp contrast to the thoughts of Neumayer (2013) who noted *"even comprehensive accounting for pollution is very unlikely to drive down GS rates in developed countries below zero"* and with the GS literature that consistently shows positive savings for developed countries.

On a positive note, it was found that Latvia, Bulgaria, Poland, Hungary and Estonia transitioned away from an unsustainable development path in at least one GS measure and demonstrates the potentially sizeable benefits achieved over this period from structural economic reforms, market incentives, technological advancements, and sensible environmental policy. Overall, those economies that held higher levels of national income per capita, and those more open to trade held higher savings rates. It is striking that the findings of negative savings, an indicator of unsustainable development, were concentrated in the former communist regimes. Further research examining the determinants of European ANS as well as the more comprehensive GSAP rates would be beneficial.

A key policy implication of the work is that policy makers should be cognizant of the theoretical literature that suggests wealth should be the focus of sustainability assessments rather than national income (GDP). The key limitations of the World Bank ANS indicator relate to the limited coverage of capital assets as well as a debate around valuation techniques. This study has attempted to address one of these key limitations by including local air pollution on a comparable basis. Adding local air pollution may be seen as an important, yet preliminary, step in addressing the missing natural assets from the World Bank estimates. However, it seems plausible output from the program of natural capital accounting required to be undertaken by EU member states (Regulations (EU) No 691/2011 and 538/2014) may be integrated with GS measures in the near future and this offers an exciting area for future work. Another area for future work is the development of more refined measures of changes in human capital than the education expenditure approach. Resolving measurement issues remains a formidable task but "*surrendering without a fight to develop the measures [still] seems all to defeatist*" (Pearce, 2001b).

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