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Spaiser, V orcid.org/0000-0002-5892-245X, Scott, K orcid.org/0000-0001-7952-0348, Owen, A orcid.org/0000-0002-3872-9900 et al. (1 more author) (2019) Consumption-based accounting of CO2 emissions in the sustainable development Goals Agenda. International Journal of Sustainable Development and World Ecology, 26 (4). pp. 282-289. ISSN 1350-4509

https://doi.org/10.1080/13504509.2018.1559252

SHORT RESEARCH PAPER

Consumption-based accounting of CO2 emissions in the Sustainable Development Goals Agenda

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ABSTRACT
In 2017 the paper "The Sustainable Development Oxymoron: Quantifying and Modelling the Incompatibility of Sustainable Development Goals" (Spaiser et al. 2017) was published, showing that there is a conflict between socio-economic development goals and ecological sustainability goals using cross-country time-series data. The authors looked at production-based CO2 emissions to measure and model the 13th SDG goal addressing climate change. Their models showed that production-based CO2 emissions were stalling or even decreasing in rich countries, which suggests that other countries are also likely to see stalling and decrease in their CO2 emissions once they become rich. However, this conclusion can be challenged when accounting for consumption-based CO2 emissions rather than production-based CO2 emissions. In this follow-up paper, we re-run some of the analyses performed in the original paper making use of consumption-based CO2 emissions. The analysis confirms the inherent SDG conflict between socio-economic and ecological SDGs. But, this new analysis demonstrates that from a consumption perspective the trend of stalling or decreasing CO2 emissions is reversed, with natural depletion costs being exported to poorer countries. Despite this new perspective on CO2 emissions, the conflict between SDG goals can still be avoided by making investments in public health, education and renewable energy, as suggested in the original paper.

KEYWORDS
Sustainable Development Goals; consumption-based CO2 emissions; production-based CO2 emissions; climate change; dynamical systems modelling; feature selection

1. Introduction

In 2015 UN member countries adopted a set of 17 goals to end poverty, protect the planet and ensure prosperity and inclusion for all, known as the New Sustainable Development Agenda. These goals are to be achieved globally over the next 15 years. In their paper "The Sustainable Development Oxymoron: Quantifying and Modelling the Incompatibility of Sustainable Development Goals" Spaiser et al. (2017) argue, that there is a conflict between socio-economic development goals and ecological sustainability goals outlined in the New Sustainable Development Agenda, using cross-country time-series data. They use machine learning and dynamic systems modelling to explore the reasons for the conflict and to indicate how this inherent conflict between fighting poverty and exclusion on the one hand, and protecting the environment could be avoided.

Sustainable Development Goals (SDGs) are highly interconnected with global climate

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policy and von Stechow et al. (2016) show how alternative mitigation pathways strongly affect the prospects of meeting numerous other SDGs other than the one on climate change and vice versa. Progress towards meeting climate targets is generally measured as a reduction in emissions produced within a country. In their analyses Spaiser et al. (2017) used production-based CO2 measures with respect to the 13th SDG concerning the climate. However, it has been argued that this measure is not accurate, because it does not account for the fact that particularly rich countries tend to turn to service- and knowledge-based economies that do not tend to produce as much CO2 emissions as industry- and agriculture-based economies (Peters et al. 2011; Jiborn et al. 2018; Baker 2018). And while wealthier countries largely consume the goods produced and manufactured in poorer countries, the CO2 emissions that result from these productions and manufacturing are accredited to the poorer, producing countries (Peters and Hertwich 2008; Scott and Barrett 2015). Consequently, it may appear that rich countries are reducing their CO2 emissions, as predicted the increasingly challenged environmental Kuznets curve (Stern et al. 1996), when instead they are meeting their increased consumption from industries abroad, known as weak carbon leakage (Davis and Caldeira 2010; Hertwich and Peters 2009). Including emissions embodied in consumption challenges the Kuznets curve that says that emissions start to decline when a certain income is reached. Instead of an inverted-U shape, consumption emissions are not necessarily observed to be decoupling from income (Steinberger et al., 2013). For this reason consumption based accounting tools, and the perspective that they provide, are seen as increasingly important for understanding consumer responsibility as they explicitly recognize the global nature of supply chains and hence emissions (Krey et al. 2014; Peters and Hertwich 2008).

Given this debate the question arises whether the results reported in Spaiser et al. (2017) would change if consumption-based CO2 emissions are used in the analysis instead of the production-based CO2 emissions. For instance, would we still see the stalling and possible reduction of CO2 emissions once countries have achieved a certain level of prosperity, reported in the paper (Spaiser et al. 2017) and predicted by the environmental Kuznets curve? In order to investigate this question, some of the analyses in Spaiser et al. (2017) have been repeated with consumption-based CO2 emissions, leaving everything else the same. Results of the following research questions are reported and discussed in this paper:

(1) Will the same conflicts between the environment and development prevail?
(2) Will the main predictors of sustainable development change?
(3) How will the model that best describes changes in CO2 emissions change using a consumption-based measure?

2. Data and Methods

To test, quantify and model the alleged inconsistency of the SDGs, we used the same data as used in the original paper, i.e. cross-countries time-series data provided by the World Bank for the period 1980-2014 (World Bank 2014), datasets from Polity IV (Marshall et al. 2014), CIRI Human Rights Data Project (Cingranelli et al. 2013), Centre for Systemic Peace data (Marshall 2014; Marshall and Cole 2014), the Freedom House data (Freedom House 2014a,b) and the Heritage Foundation/Wall Street Journal data (Miller et al. 2014). To this data on consumption-based CO2 emissions was added from the Eora multi-regional input-output (MRIO) model version 199.82 (http://www.worldmrio.com/footprints/ carbon). Eora is a macro-economic model capable of reallocating industrial emissions to products bought by final demand consumers in each country by understanding the contributions each industry makes to a products supply chain. Eora is the largest and most comprehensive of the state-of-the-art MRIO models (Inomata and Owen 2014) comprising data for 189 countries for a time series from 1980-2013 (Lenzen et al. 2012) to match the time-series of the original data in Spaiser et al. (2017).

The Eora model requires data on the economic structure of a country – which includes information on how industries trade with each other, import from abroad, and produce goods for exports – and data on the demand for goods and services by households and government. Final demand is part of the calculation used for GDP and is available for all nations. Economic structure data is more difficult to obtain. For 74 countries, the economic structure data is found in the 'input-output' tables produced by national statistical offices. For the remaining countries, national level data on industrial output is applied to a proxy input-output template based on the average of the Australian, Japanese and United States tables (Lenzen et al. 2012). The 74 countries where input-output data is available include the 34 nations in the OECD, the BRICS nations and other large developing nations such as Ecuador, Indonesia and Vietnam. Nations that rely on a proxy structure tend to be smaller economies, particularly in the African continent. Clearly there is uncertainty in the consumption-based accounts calculated with proxy economic structures. However, recent work (Owen et al., 2014) has shown that the most important elements in calculating a consumption-based account are the emissions intensity of industry and the final demand data, which are known for each nation.

The analyses were conducted using identical methods as in Spaiser et al. (2017), i.e. Confirmatory and Exploratory Factor Analyses (Principal Component Analysis) to test and quantify the inconsistency of the SDGs, Feature Selection to preselect best predictors from the large set of potential predictors and Dynamical Systems Models (Ranganathan et al. 2014) with the preselected predictors to model potentially non-linear, coupling and feedback effects and dynamics of social, economic and ecological change. The variables that appear in the models below are presented in Table 1. The methods used in this paper as well as in the original paper do not distinguish between large and small countries, every country observation is treated equally, hence the impact of large countries may be under-estimated, on the other hand most measures are per capita or percentage measures and hence account for population size.

To exclude the possibility that changes in the models and results reported here are due to a different data source for CO2 emissions rather than the difference between consumption-based and production-based CO2 emissions, we also re-run the respective analyses in Spaiser et al. (2017) with Eora production-based CO2 emissions data. The models and results reported in Spaiser et al. (2017) remained essentially unchanged.

Table 1. Variables used in the reported models

Variable	**Abbreviation**	**Note**
	Dependent variables	
consumption-based CO2 emissions per capita	$CO2_c$	New variable, as described above
production-based CO2 emissions per capita	$CO2_p$	CO2 emissions measure used in the original paper
Child Mortality	C_m	Number of children under five dying per 1000 births
Education	E_d	Percentage of children getting secondary school education, this variable was reverse coded, i.e. throughout the analysis it represents the percentage of children excluded from secondary school education
Sustainable Development Latent Variable	L	Factor scores from Factor Analysis with Child Mortality, Education and consumption-based CO2 emissions (this paper) / production-based CO2 emissions (original paper)

Predictors from original paper		
GDP per capita	G	Gross Domestic Product per capita
Final Consumption Expenditure	C	Sum of household, private and government expenditures
Adjusted savings: natural resources depletion	N_d	Sum costs of the net forest depletion, energy depletion, and mineral depletion that would be deduced from the adjusted net savings of a country, which measures the value of a specified set of assets, excluding capital gains
Net foreign assets	D	Sum of foreign assets held by monetary authorities and deposit money banks, less their foreign liabilities, essentially a measure of the indebtedness of a country
Fertility rate	F_r	Births per woman
Women's Economic Rights	R_f	Degree to which government laws and practices ensure women’s free choice of profession, the right to gainful employment, equality in hiring and promotion, etc.
Independence of the Judiciary System	J	Degree of independence of the judicial system from influences of the government, individuals, or companies
Combustible renewables and waste	E_r	Extent to which biomass is used for energy production.
Particulate Emission Damage	E_m	Adjusted savings: particulate emission damage: productivity losses in the workforce due to premature death and illness
Measles Immunization	M	% of children aged 12-23 months
Trade freedom	T_f	Composite measure of the absence of tariff and non-tariff barriers that affect imports and exports of goods and services
Government spending	W_g	General government expenditure as a percentage of GDP at all levels of government such as federal, state, and local
New predictors		
Mortality rate	D_r	the total number of deaths per year per 1000 people
Tertiary education rate	T	School enrollment, tertiary (% gross)
Service Economy	S	Services, value added (% of GDP)
Credit	C_r	Domestic credit to private sector by banks (% of GDP)
Education Expenditure	E_e	Adjusted savings: education expenditure

3. Testing the Consistency of Sustainable Development with Consumption-based CO2 emissions

We tested the consistency of the SDGs using Exploratory (EFA) and Confirmatory Factor Analysis (CFA). As in Spaiser et al. (2017), three main indicators representing the three dimensions of the SDGs, i.e. protecting environment, reducing poverty and socio-economic inclusion were used, only replacing the original CO2 emissions measure with consumption-based CO2 emissions. Figure 1(a) clearly shows there is an inherent conflict between reducing poverty (represented by reducing child mortality) and increasing socio-economic inclusion (represented by increasing secondary education rates) on the one hand and protecting environment (represented by consumption-based CO2 emissions). This outcome confirms the results in Spaiser et al. (2017). Including one indicator for each SDG confirms this contradiction (see Figure 1(b)). This suggests, pursuing classical development goals usually results in straining the environment, irrespectively of how CO2 emissions are measured. Hence, it is not enough for countries to turn down their industrial and agricultural production and focus on service or knowledge economy. These changes are likely to lead to greater overall wealth but they will not contribute to greater sustainability as predicted by the environmental Kuznets curve (Stern et al. 1996) as long as the consumption patterns, which are still based on fossil fuel economy and other environmentally damaging productions, do not change.

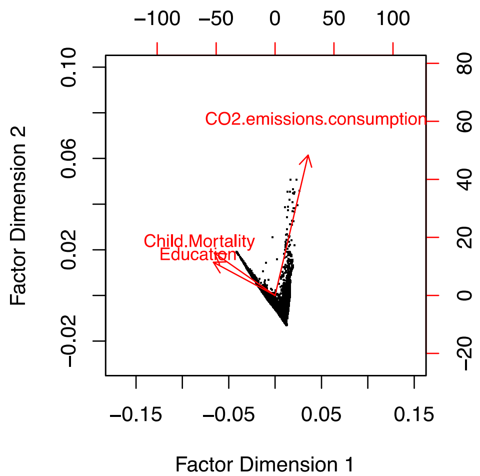
To replicate the results in the original paper and to investigate what these inconsistencies mean for the SDGs, we chose the three above-mentioned indicators, namely Child Mortality, Education and consumption-based CO2 emissions, and used the CFA factor scores to create the latent variable L representing sustainable development. We then used Feature Selection to scan through the large number of potential indicators in our data set to find the most relevant predictors for changes in the latent variable L. These indicators were then used to fit a large range of dynamical system model for changes in L. The best model predicting changes in L is

$$0.35C + 0.21D_r + 0.31T^2 - 0.01G^2 - 0.09\frac{R_f}{J} - 1.86\ \frac{G}{N_d}. \tag{1}$$

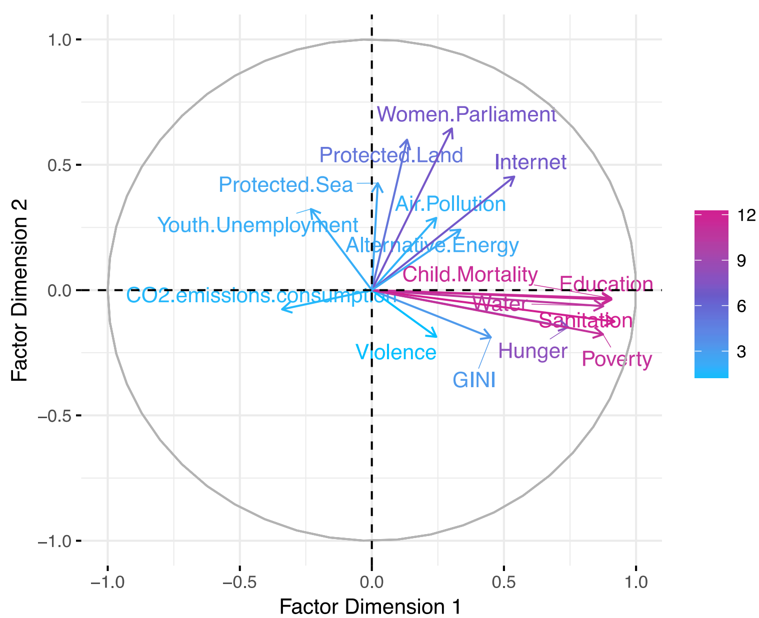
This model differs from the original model in Spaiser et al. (2017), which was

$$0.46\frac{D}{G} + 0.002G^3\ - 0.02G^2 - 0.01DF_r - 0.06\frac{R_f}{J} - 0.002N_d^2\ . \tag{2}$$

The two terms that appear in both models are the squared GDP per capita (G) and the fraction with women's economic rights (R_f) and independence of the judicial institutions (J). Specifically, the fourth term in equation 1 with GDP per capita, indicates that once countries have reached a certain level of GDP per capita they can reduce L and they can do it faster the higher the GDP is. That is, higher GDP per capita helps to reduce poverty and promote socio-economic inclusion. The fifth term in equation 1 reflects that women's economic rights are positively associated with socio-economic development, particularly in countries with weak judicial institutions. Other terms in equation 1 are different. The last term for instance reinforces what has already been said with respect to the GDP per capita effect, however, it seems that too high environmental costs, i.e. high natural depletion costs (N_d), a predictor that also appears in equation 2, may limit to some extent the positive effect GDP has on socio-economic development. The other three terms with final consumption expenditure (C), mortality rate (D_r), and tertiary education rates (T) also indicate that the decrease in L (i.e. decreases in poverty and socio-economic exclusion) is limited. Rich, highly developed countries, i.e. countries with high final consumption expenditure (C) and tertiary education rates (T) have to a great extent overcome extreme poverty and extreme socio-economic exclusion and further improvements in these countries are harder to achieve, in fact, we may expect that poverty and socio-economic exclusion may rise again in highly developed countries.



(a) EFA-Biplot with Factor Dimension 1 having a proportion of explained variance of 65.97 % and Factor Dimension 2 of 28.65 %. The EFA suggests a single factor solution. A CFA for this factor, comprising of consumption-based CO2 emissions (factor loading: -0.356), Child Mortality (factor loading: 0.656) and Education (reverse coded, factor loading: 0.665) has acceptable Model Fits: CFI: 0.95, TLI: 0.91, RMSEA: 0.05, SRMR: 0.07.



(b) PCA Factor Map of 16 SDG indicators with Factor Dimension 1 having a proportion of explained variance of 34.9 % and Factor Dimension 2 of 9.8 %. The axes depict standardized factor loadings. The color shows the contribution of each indicator to the factor solution: indicators in red contribute strongly, those in blue weakly.

Figure 1. Inconsistency of the Sustainable Development Goals Agenda

Similar conclusions were drawn in the original model, albeit based on different terms and hence with a slightly different focus. Finally, the term with mortality rate D_r, indicates that countries with high mortality rates do not tend to prosper. To some extent this is the limitation of L reduction from the other side; extremely poor countries (high mortality rates due to diseases, malnutrition etc.) and/or countries experiencing violent conflicts, are not able to develop on their own and poverty and socio-economic exclusion tends to get even worse in these countries. Note moreover, due to the inherent conflict between the SDGs outlined above, positive development in terms of reducing poverty and socio-economic exclusion usually means negative impact on the environment and particularly on the climate.

4. Modeling changes in consumption-based CO2 emissions

In Spaiser et al. (2017), the authors looked in the next step at the three indicators comprising L separately. Changes in CO2 emissions were best predicted in Spaiser et al. (2017) by

$$0.00002\frac{N_d}{E_r} - 0.0004G^3 + 0.11GE_m - 0.11CE_m + 0.004GC - 0.003\frac{C}{E_m}. \quad (3)$$

As Spaiser et al. (2017) write: "The equation combines several non-linear terms, involving natural depletion costs (N_d), renewable energy production (E_r), log GDP per capita (G), particulate emission damage (E_m) and final consumption expenditure (C). The model is highly complex and shows how the various factors interact in various non-linear ways. Combined, these terms show that poor countries have low CO2 emissions, that then rise with growing economy and consumption until countries have reached very high wealth levels, at which point CO2 emissions can be expected to stall, though at this stage the CO2 emissions levels of a country will be already unsustainably high. CO2 emissions are proportional to overall natural depletion costs per unit of energy produced through biomass and they are coupled with particulate emission damage, thus with detrimental effects of environmental pollution on human health." (p. 463).

Using changes in consumption-based CO2-emissions as dependent variable instead, results in the following best-fit model:

$$4.8\frac{C}{S} + 0.005C^2 - 0.015SE_e - 0.002E_e^3 + 0.02GC_r - 0.0003\frac{N_d}{E_r}. \quad (4)$$

R-Square for this model is 0.5907. There are some new predictors in this equation, i.e. S measuring service economy, C_r measuring domestic credits given to private sector by banks and E_e measuring the costs of education expenditure. The predictors natural depletion costs (N_d), renewable energy production (E_r), log GDP per capita (G) and final consumption expenditure (C) are the same as in the original equation 3. The first difference we note here comparing the two equations 3 and 4 is that consumption-based CO2 emissions are clearly rising the richer a country gets and there is no leveling-off, i.e. stalling, as in the model for production-based CO2 emissions. In fact the quadratic term with C indicates, that rising in consumption-based CO2 emissions takes off once a country has reached a certain level of wealth. And further growth in wealth is then rapidly accelerating the increase in the consumption-based CO2 emissions. This growth in consumption-based CO2 emissions is only limited to some extent by education expenditure and expansion of service economy, though these limiting effects are non-linear. The cubic term with E_e means that consumption-based CO2 emissions are decreasing (or low) where education expenditure is low or very high, while it is increasing in countries with moderate, average education expenditure. This does not mean that average higher education in the population translates into lower consumption-based CO2 emissions. The focus is on education expenditure. It is also important to remember that the negative terms here are rather limiting factors, that make sure the growth in consumption-based CO2 emissions is not escalating, rather than terms that actually lead to decreases in consumption-based CO2 emissions. Finally, it is worth noting, that the last term in equation 4 is the same as the first term in equation 3 but with a different sign. In the original model (equation 3) the natural depletion costs are rising proportionally with CO2 emissions. In the model for consumption-based CO2 emissions (equation 4), they are decreasing. What this may mean, if we consider the two models together, is that natural depletion costs are exported to poorer countries where consumption-based CO2 emissions are low but natural depletion costs are high. Renewable energy production is weakening this effect.

We also looked into models that include production-based CO2 emissions $CO2_p$ as a predictor for changes in consumption-based CO2 emissions, to see the relation between the two. The following model was suggested by the model selection procedure:

$$4.14\frac{C}{S} + 0.035C^2 - 0.012SE_e - 0.06CO2_p + 0.01GC_r - 0.0002\frac{N_d}{E_r}. \qquad (5)$$

In this model the production-based CO2 emissions $CO2_p$ replace the E^3_e term and R-Square increases to 0.6258. The new term shows that the higher production-based CO2 emissions the lower the consumption-based CO2 emissions and vice versa. So indeed, countries that were able to reduce their production-based CO2 emissions usually experience increases in consumption-based CO2 emissions and these are typically wealthy countries.

5. Implications for the Sustainable Development Agenda

In Spaiser et al. (2017) the authors finally looked at all the equations, i.e. equation (2) predicting changes in sustainable development latent factor L, the equation for changes in CO2 emissions (3) and the two equations for predicting changes in child mortality (6) and education (7), i.e.

$$-0.03T_fG + 0.86M - 6.4\frac{M}{G} - 0.001F_r^3, \qquad (6)$$

$$-0.01G - 0.03W_g^2 + 0.001CG + 0.16\frac{W_g}{C}, \qquad (7)$$

in order to find some explanation for the inconsistency of sustainable development. In the original paper all models include GDP per capita, which has overall a positive effect on reducing poverty (equation 2, 6) and increasing socio-economic inclusion (equation 2, 7), but a mainly negative effect on reducing CO2 emissions (equation 3). The same can be observed when comparing equations 1 (for changes in latent factor L with consumption-based CO2 emissions), 4, 5 (for changes in consumption-based CO2-emissions), 6 and 7. Hence, as in the original paper, we conclude, that it is the current economic system that is based on economic growth and consumption (C in equation 1, 3, 4, 5 and 7) that makes some of the SDGs incompatible. “As every nation seeks to increase economic growth to meet the rising standard of living expectations of its population, nature is under-prioritized”, Spaiser et al. 2017 note (p.463). But as in the original paper, the models also reveal factors (indicators unique to equations 6, 7 and 4 or with specific opposite effects) that have beneficial effects on one goal, without having simultaneously adverse effects on other goals. These include as in the original paper extensive health programs for reducing child mortality, government spending, for instance on education (further supported by the negative effect of education expenditure on consumption-based CO2 emissions in 4) to increase socio-economic inclusion, and renewable energy production for reducing CO2 emissions. These results suggest again: “we should shift our focus from a consumption-based economic growth to investment in human well-being (health, education) and environment-friendly technologies." (Spaiser et al. 2017, p.463).

6. Conclusion

In this paper we have investigated whether changing the indicator for climate change addressing SDGs from production-based CO2 emissions to consumption-based CO2 emissions would change the results and conclusions presented in Spaiser et al. (2017). We show that irrespective of how CO2 emissions are measured, the conflict between environmental SDGs and socio-economic SDGs remains the same within the UN Sustainable Development Agenda. However, while the original paper suggested that high GDP per capita would flatten and at some point potentially decrease the CO2 emissions, indicating the conflict between SDGs could be overcome at least in wealthy countries, our analyses here show that this is not the case when looking at consumption-based CO2 emissions. High GDP per capita does not act to limit rising emissions from a consumption perspective; in fact it may even act as an accelerator of consumption-based CO2 emissions further exacerbating the conflict between the SDGs. Hence, the results also show that when measuring CO2 emissions based on consumption, richer countries are not necessarily contributing to a decrease of the overall CO2 emissions, but rather these are exported to poorer countries, who then also have to bear the natural depletion costs. From this perspective, wealthier countries are failing on the 13th SDG goal. Moreover, high depletion costs in poorer countries act to limit the positive effect high GDP per capita has on socio-economic development, the effect of which can be lessened with more renewable energy production. This should be an incentive for wealthier countries to transfer funds to compensate for these additional costs and to invest in renewable energy production nationally and globally.

While Edenhofer et al. (2015) suggest that strong leadership and technology spillover can enable emissions intensive consumer countries to negate additional emissions outside of their political jurisdiction, we need to learn from mistakes made in the Clean Development Mechanism (CDM), which was designed to do just this. Countries with targets in the Kyoto Protocol were able to claim carbon credits to offset their emissions through supporting projects in less developed countries. While sounding attractive in theory, it did not necessarily fulfil its purpose in practice: the benefits to host nations were often overstated; projects have been unevenly distributed across countries; and it is difficult to prove that emissions reductions would not have happened without the CDM (Scott and Barrett 2015). This being said, as both a producer and consumer perspectives result in trade-offs between environmental and socio-economic SDGs, governments, businesses and individuals must acknowledge shared responsibility along global supply chains, both for CO2 emissions and the mechanisms required to reduce them (Lenzen et al. 2007). While complex and subject to criticism, initiatives such as carbon markets and the Clean Development Mechanism provide routes through which transfers of resources can occur in support of sustainable development goals, which could enable richer countries to take on higher emissions reduction targets reflective of their income-driven contribution to climate change (Scott and Barrett 2015; Newell and Bumpus 2012).

Furthermore, despite changes in some of the models, the results confirm the conclusions drawn in Spaiser et al. (2017) as shown in Section 5, i.e. the conflict between various SDGs is mainly due to the fact that the current economic system relies heavily on economic growth and consumption. But, there are ways to avoid the conflict between environmental and socio-economic SDGs when focusing on investments in health programs, education and sustainable technologies (such as renewable energy production) rather than on pure economic growth. However, the results when changing the indicator to consumption-based CO2 emissions provide a vital new perspective that emphasizes the need for international cooperation to develop strategies to achieve the Sustainable Development Goals Agenda. As concluded by Baker (2018) and Lamb et al. (2014), a sustainable transition needs to be a geo-political process that addresses the unequal exchange of emissions and wealth between countries. Countries should not be allowed to improve their climate change balance by outsourcing the environmental problems they create by continuing to consume goods resulting from these environmental problematic productions.

While we have investigated the implications for the UN Sustainable Development Agenda, these are also considerations for global climate policy, due to the interconnected nature of climate policy and sustainable development. Climate policy must consider how alternative mitigation pathways impact SDGs globally. Climate mitigation in one country can affect development prospects in another. In order to reduce CO2 emissions globally, richer countries cannot simply look within their territories to measure progress, and should help poorer countries to adopt cleaner technologies so as not to just offset natural depletion costs to them. However, reducing consumption in itself can also limit the impact GDP per capita has on rising consumption-based emissions, and manage trade-offs between sustainable development goals, as shows in von Stechow et al. (2016). The results in this paper demonstrate that the geographic scope of consumption-based emissions offer advantages towards meeting SDGs, and that SDGs deserve greater consideration in climate policy.

Finally, this analysis shows the importance of what measures are chosen to monitor and assess progress. Switching from production to consumption-based accounts has provided additional insight into the importance of geography and trade, and where fairer responsibilities for climate mitigation could lie. We have also touched upon the inconsistencies between economic growth and sustainability. Using GDP per capita as a measure of growth we could argues does not capture the distribution of wealth within society. These conclusions demonstrate the need to revisit the indices used to measure progress towards SDGs.

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