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Human well-being in the Anthropocene: limits to growth

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Non-technical summary. Transformation of the world towards sustainability in line with the 2030 Agenda requires progress on multiple dimensions of human well-being. We track development of relevant indicators for Sustainable Development Goals (SDGs) 1–7 against gross domestic product (GDP) per person in seven world regions and the world as a whole. Across the regions, we find uniform development patterns where SDGs 1–7 – and therefore main human needs – are achieved at around US$15,000 measured in 2011 US$ purchasing power parity (PPP).
Technical summary. How does GDP per person relate to the achievement of well-being as targeted by the 2030 Agenda? The 2030 Agenda includes global ambitions to meet human needs and aspirations. However, these need to be met within planetary boundaries. In nascent world-earth modelling, human well-being as well as global environmental impacts are linked through economic production, which is tracked by GDP. We examined historic developments on 5-year intervals, 1980–2015, between average income and the advancement on indicators of SDGs 1–7. This was done for both seven world regions and the world as a whole. We find uniform patterns of saturation for all regions above an income threshold somewhere around US$15,000 measured in 2011 US$ PPP. At this level, main human needs and capabilities are met. The level is also consistent with studies of life satisfaction and the Easterlin paradox. We observe stark differences with respect to scale: the patterns of the world as an aggregated whole develop differently from all its seven regions, with implications for world-earth model construction – and sustainability transformations.
Social media summary. Reaching human well-being #SDGs takes GDP levels of $15k. This may help shape transformation to a world that respects #PlanetaryBoundaries.

1. Introduction

The global community has adopted the United Nations 2030 Agenda challenge to achieve the 17 Sustainable Development Goals (SDGs) by 2030 (United Nations, 2015). However, global advances on human well-being SDGs in the context of the conventional gross domestic product (GDP)-based growth paradigm could generate systemic deterioration of the biophysical environment (O'Neill et al., 2018; Wiedmann et al., 2020) or even trigger shifts in large-scale Earth system regime (Steffen et al., 2018). This prospect would undermine social gains made under the 2030 Agenda and hinder future development. To avoid these risks, human development would have to take place within the biophysical constraints of the planetary 'safe operating space' (Raworth, 2012; Rockström et al., 2009; Steffen et al., 2015). But is this at all possible?

We previously developed a highly aggregated quantitative simulation model, *Earth3*, that allows transparent exploration of pathways of future regional and global development (Randers et al., 2018; 2019; Goluke et al., 2018; Collste et al., 2018). *Earth3* builds on insights gained from earlier global system modelling endeavours (including Meadows et al., 1972, 2004; Randers, 2013; Randers et al., 2016) to simulate linked socio-economic and environmental developments over time towards 2050, taking the 17 SDGs and nine planetary boundaries into consideration. The *Earth3* model provided the backbone for the *Transformation is feasible* report that was submitted to the Club of Rome for its 50th anniversary (Randers et al., 2018). The report raised five key transformations for shifting global development onto a sustainable path: (1) rapid increase in renewable energy, (2) shift to sustainable food chains, (3) new development models, (4) inequality reduction and (5) investments in education, gender equality, health and family planning. These transformations are further explained in Randers et al. (2018) and are being further explored in the Earth4All project (https://www.earth4all.life).

Our model makes assessments for seven world regions and for the world as a whole (Randers et al., 2019). *Earth3*'s causal structure and parametrization provide insights into the patterns of regional achievements on human well-being goals in the global context.

Regional analysis can provide insights into generalizable policies that are also relevant for national decision-makers, while remaining closer to representation of globally systemic relationships, such as tracking how global well-being goals influence pressures on the planetary boundaries. The regions that we have chosen for this paper and the wider *Earth3* analyses are based mainly on total population sizes (people), income per person and sizes of the economies (in purchasing power parity (PPP)-adjusted GDP US$ 2011).

This paper was written in conjunction with the development of the *Earth3* model, and the findings set out here have supported its parametrizations. Here, we discuss insights from the model's causal structure and parametrization with the aim to maximize transparency about the socio-economic features of the model, both for users of the model outputs in policy and practice and for model developers who may view *Earth3* as a prototype or skeleton for new-generation integrated world-earth models that connect human and Earth system dynamics (Donges et al., 2017, 2020). Analysis and quantitative exploration of this paper is based on the different sets of data assembled and transformed in the development of the model, and not on model simulations. A more quantitative analysis, including how model parameters were estimated, can be found in Collste et al. (2018).

2. Materials and methods

2.1 A common tracker for human well-being, consumption and production and social-ecological disruptions

In all global models, the selection of indicators and parametrizations embeds fundamental assumptions and encodes structural accounts of how society works. The diagram of the system in Figure 1 portrays a high-level conceptualization of key feedbacks and influences in world-earth modelling, as implemented in *Earth3* and compatible with understandings of sustainable development as meeting people's needs '(…) while safeguarding Earth's life-support system (…)' (Griggs et al., 2013). The diagram displays how long-term human well-being depends on balancing the reinforcing loop of production (incorporating food, industrial and service systems) against the counteracting loop of social-ecological disruptions. Production and consumption are at the centre of the diagram as it enables the provision of some of people's needs required for human well-being, and it also links to pressures on planetary boundaries through the required material throughput – with the consequent risk of large-scale, abrupt and potentially irreversible social-ecological disruption.

In development policy and in integrated assessment modelling alike, the GDP has long been the most widely used measurement of the value of production and consumption. GDP per person, also referred to as income per person or average income, is also the most widely used indicator of economic progress – and has also been used as a proxy for human well-being (Fanning & O'Neill, 2019; Weil, 2009). An advantage of using GDP and average income in modelling is that they have excellent availability of worldwide data (Feenstra et al., 2015). However, the limitations of using a production metric as a well-being measurement are well-known (GDP was never meant for that purpose (Costanza et al., 2009)). GDP per person does not adjust for the distribution of incomes and wealth within countries, an essential element of well-being (Wilkinson & Pickett, 2009). It only counts activities that pass through official, organized markets (Himmelweit, 2017) and does neither include unpaid domestic work (Himmelweit, 2017) nor leisure time (Costanza et al., 2009) which both clearly contribute to human welfare. It also counts the 'bads' that hamper well-being as well as the socially beneficial 'goods' in economic activity. For instance, polluting activities that harm well-being can be double-counted as GDP measures the clean-up activities (if these are paid for by the government) as well as the activity itself (Costanza et al., 2004; Islam & Clarke, 2002).

Nevertheless, a key question for SDG modelling (and world-earth modelling more generally) is: What are the implications of using GDP per person as the common tracker for well-being? Here, we investigate this question, studying average income in different world regions and its correlation with indicators of human well-being as targeted by SDGs 1–7, in our examination of achievements of the 2030 Agenda (Table 1). Earlier studies, including Lamb and Rao (2015) as well as Steinberger et al. (2020) have looked at the correlations between human development indicators, climate impact and income levels. However, they have not used the plethora of indicators that overlap SDGs as well as human well-being frameworks in their studies.

2.2 The basis of well-being in SDG modelling

The 2030 Agenda resolution calls for shifting the world on to a 'sustainable and resilient path' where 'all human beings can fulfil their potential in dignity and equality and in a healthy environment' (United Nations, 2015). Representation of SDGs 1–7 in world-earth modelling thus requires sustainability measures and frameworks that go beyond preference satisfaction theories of conventional welfare economics (Penz, 1986), but that can still be linked to measures of production and average income. In preference satisfaction theory, individual preferences and well-being are best judged by individuals themselves, and people are primarily seen as self-interested and rational. In these lines, objective monetary measures such as average income are useful as all well-being satisfaction options are seen as interchangeable. Real-world problems with preference satisfaction theory are that preferences often change when available options change (as people become richer they may seek yet higher incomes to satisfy new preferences) (Easterlin, 1974, 2003). It is also impossible to quantify, compare and weight one person's preference satisfaction against others'. In addition, there are limits to knowledge and people oftentimes do not act according to neoclassical economists' account of rationality (Gough, 2015; Kahneman, 2012).

The life satisfaction approach has been proposed as an alternative basis (Diener, 1994; Layard, 2005), where well-being is measured subjectively by the extent to which people are happy with their lives. Easterlin (Easterlin, 1974, 2003; Easterlin et al., 2010) argues that income supports life satisfaction only up to a certain level. The Easterlin paradox is the observation that while there is a clear positive correlation between average incomes and life satisfaction within a population, the same pattern does not hold over time as these incomes increase beyond a given threshold. At lower levels, income has a strong effect on life satisfaction as it may mediate the satisfaction of '…the most basic of physiological needs' (Howell & Howell, 2008, p. 538). Frey and Stutzer (2010) argue that the relationship between income and life satisfaction levels off somewhere around US$15,000 of average income per person per year (converted to PPP, constant 2011 US$, as used in previous *Earth3* studies and in all the following discussion). At this level, the correlation between average income and measures of life satisfaction breaks down. Others have however argued that the positive correlation between life satisfaction and

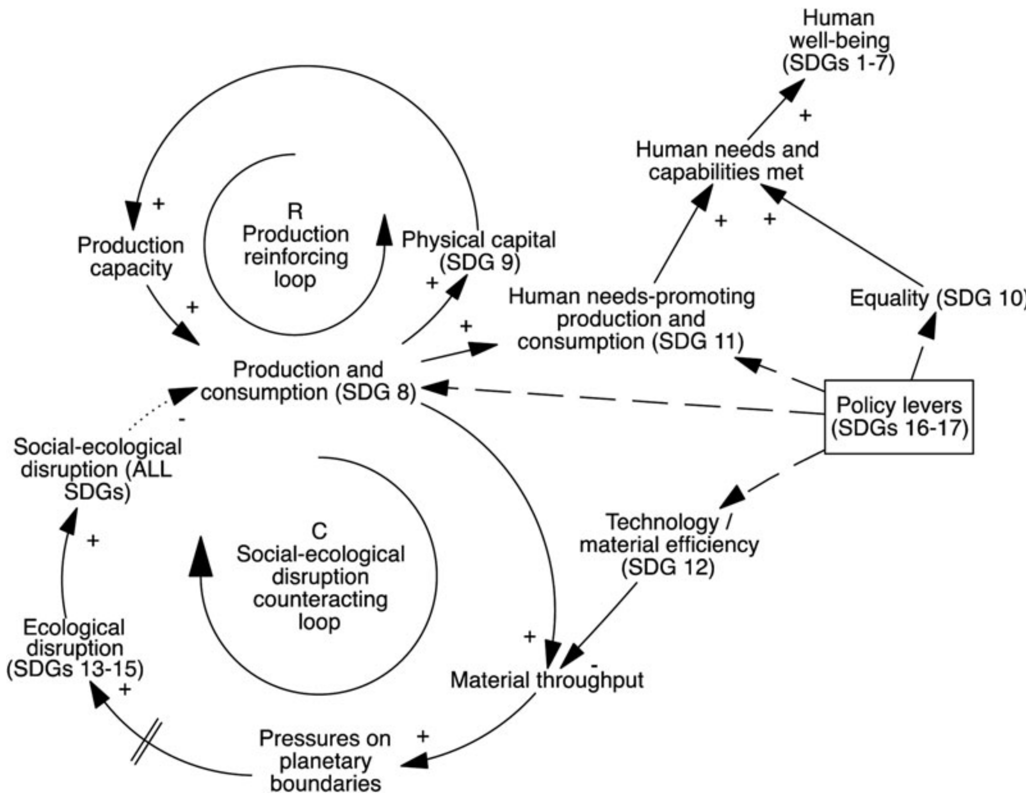

Figure 1. Conceptual sketch of two global feedbacks and influences in world-earth modelling within the Earth3 model representing SDGs within planetary boundaries. Each arrow represents a causal relationship. The '+' signs at the arrowhead indicate that the effect is positively related to the cause (e.g. an increase in production causes the material throughput to rise above what it otherwise would have been). The '–' signs at the arrowhead indicate that the effect is negatively related to the cause (e.g. a social-ecological disruption causes production to fall below what it otherwise would have been). The top loop is self-reinforcing, hence the loop polarity identifier R; the bottom loop in counteracting, hence the loop polarity identifier C. The two lines on the link going from 'Pressures on planetary boundaries' to 'Ecological disruption (SDGs 13–15)' is a delay mark representing that there are important delays here. The dashed lines from 'Policy levers (SDGs 16–17)' indicate that different policies can be analysed in the model environment. These may however both be positive or negative as it depends on which policy is analysed (hence no '+' or '–'). The dotted line between 'Social-ecological disruption (ALL SDGs)' and 'Production and consumption (SDG 8)' indicates that this feedback was not incorporated into the Earth3 model at the point of the study. GDP per capita is represented by production and consumption (SDG 8) at the centre of the diagram. Further note that this figure serves as a simplification. More comprehensive overviews of the Earth3 model are available in Randers et al. (2018, p. 45, 2019, p. 3). Also note that a more encompassing understanding of key feedbacks may also incorporate positive contributions of nature for human well-being.

income is still positive beyond this level, although the relationship is weaker (Deaton, 2008).

The capabilities approach sees freedom to achieve well-being as society's primary goal and focuses on people's capabilities to achieve outcomes that they themselves value and 'have reasons to value' (Sen, 2001, p. 291). This resonates with the text of the 2030 Agenda resolution: 'a world […] of equal opportunity permitting the full realization of human potential and contributing to shared prosperity' (United Nations, 2015). However, the operability of this approach in world-earth modelling is limited. Although 'core capabilities' have been defined (Nussbaum, 2011), measuring them would entail enumerating not just the freedoms that individuals choose but also the almost infinite number of open opportunities they have to choose from (Gough, 2015). Brock (2009) argues that for the basic requirements for a decent life (such as those partly covered under SDGs 1–7), the capabilities approach converges with the human needs approach (Doyal & Gough, 1991; Max-Neef, 1992), which better allows for operationalization. The human needs approach proposes minimum levels of fundamental provisions that should be met for all people, and which can be objectively measured.

In Table 1, we show how SDGs 1–7 relate to some of Doyal and Gough's (Doyal & Gough, 1991; Gough, 2017) indicators for human needs and Nussbaum's (2011) core capabilities. Doyal and Gough's list of prerequisite basic needs, and indicators for intermediate need-satisfaction, converges well with the indicators for the well-being SDGs that we have chosen for inclusion in *Earth3* (see Table 1). In other words, the objective indicators for SDGs 1–7 used in our study have many overlaps with both a human needs framework and the capabilities approach.

3. Results

The graphs presented in Figure 2 show the observed historic relationships between average income and the respective human well-being SDG indicators over 5-year intervals, from 1980 to 2015.

The *regional* data in Figure 2 indicate clear saturation levels and patterns of diminishing returns, where income per person levels off with respect to progress on the seven SDGs. Poverty (SDG 1) reaches levels under 2% at average income per person around $15,000, and undernourishment (SDG 2) gets under the 7% threshold between $10,000 and $15,000. Effects on health (SDG 3) are reached between $10,000 and $15,000, with life

Table 1. Indicators and threshold values for the UN Sustainable Development Goals 1–7 used in *Earth3*, and how they relate to Doyal and Gough's (Doyal & Gough, 1991; Gough, 2017) indicators for human needs and Nussbaum's (2011) core capabilities

SDG	Indicator for SDG achievement	Earth3 target (green shade in Figure 2)	Earth3 half-way target (yellow shade in Figure 2)	Indicator for human need (Doyal & Gough, 1991)	As referred to in core capabilities (Nussbaum, 2011)
1. No poverty	Fraction of population living below $1.90 per day (%)	Less than 2%	Less than 13%	Economic security, '% in absolute poverty' under indicators for intermediate need-satisfaction, p. 190	Central Capability 10. Control over one's environment (…) (B) Material. Being able to hold property (both land and movable goods), and having property rights on an equal basis with others; having the right to seek employment on an equal basis with others
2. Zero hunger	Fraction of population undernourished (%)	Less than 7%	Less than 15%	Appropriate nutritional intake, 'Calorie consumption below FAO/WHO requirements', p. 219	'to be adequately nourished' under Central Capability 2. Bodily health. p. 33
3. Good health	Life expectancy at birth (years)	More than 75 years	More than 70 years	Physical health, mental health and appropriate healthcare 'Life expectancy at various ages', p. 190	'Being able to live to the end of a human life of normal length', under Central Capability 1. Life. p. 33
4. Quality education	School life expectancy (years)	More than 12 years	More than 10 years	Appropriate education and cultural understanding/teachers 'Years of formal study', p. 220	'adequate education', under Central Capability 4. Senses, imagination, and thought. p. 33
5. Gender equality	Gender parity in schooling (1): the ratio between expected schooling for boys and girls respectively	More than 0.95 (1.0 implies perfect equality in expected years of schooling between women and men)	More than 0.80 (1.0 implies perfect equality in expected years of schooling between women and men)	Procedural, material and distributional preconditions 'Gender differences in need satisfaction', p. 267	'provisions of nondiscrimination on the basis of (…) sex' under Central Capability 7 Affiliation, and 'seek employment on an equal basis with others' under Central Capability 10. Control over one's environment. p. 34
6. Safe water	Fraction of population with access to safe water (%)	More than 98%	More than 80%	Clean water '% lacking access to adequate safe water', p. 219	'to be adequately nourished' under Central Capability 2. Bodily health. p. 33
7. Enough energy	Fraction of population with access to electricity (%)	More than 98%	More than 80%	Procedural, material and distributional preconditions 'Energy consumption per capita', p. 261	Not included as a Central Capability

More details are available in the Supplementary information.

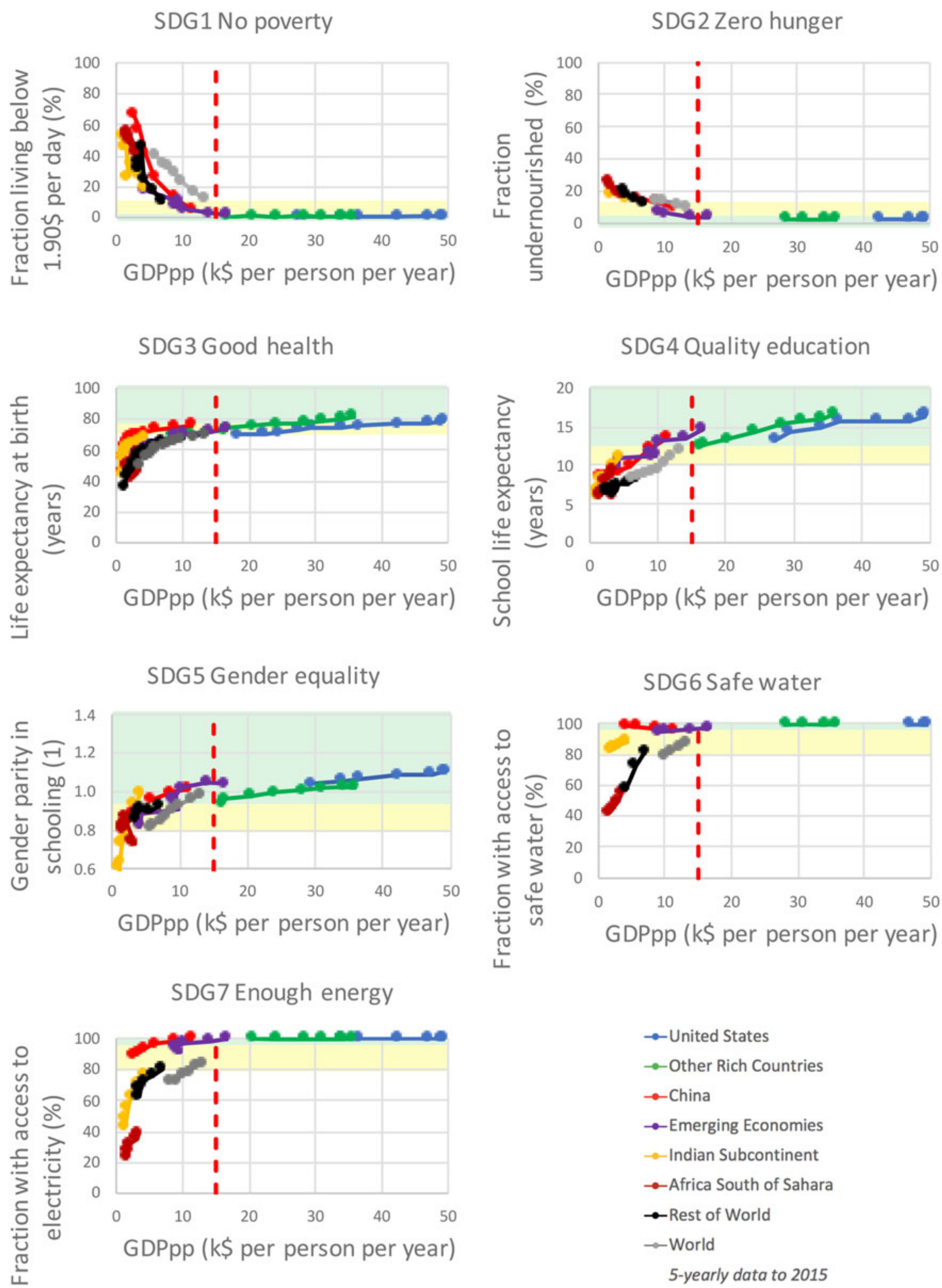

Figure 2. All regions develop to increased GDP per person (GDPpp, measured in constant 2011 US$ PPP). For data time range, see Supplementary information. Vertical line represents GDPpp at $15k, related to Frey and Stutzer (2010). Data sources: adapted from World Development Indicators, The World Bank, World Bank EdStats, UN Population statistics and Penn world tables (Feenstra et al., 2015).

expectancy passing the 75 years threshold. Educational attainment (SDG 4) above 12 years of expected schooling is reached between $10,000 and $15,000. Gender equality in expected years of schooling (SDG 5) is associated with a GDP per person of less than $10,000 for China and the Indian subcontinent. Africa South of Sahara and rest of the world can be assumed to reach gender equality in expected schooling at similar income levels, if we assume that the trends depicted in the graph continue. For widespread (more than 98%) access to safe water (SDG 6), the patterns are not as uniform, and saturation patterns not as clear. Note that for safe water as well as undernourishment, the earliest data point is 2000 which impairs tracing longer-term trends and the patterns are therefore not as clear as for the other indicators. However, trends seem to suggest that access to safe water is correlated with a GDP level of around $15,000. Finally, the electricity access threshold (more than 98%, SDG 7) is associated with GDP levels of less than $10,000 for all regions.

From the data portrayed in Figure 2, we can derive three main insights: there is a comparatively consistent level of average incomes above which the seven SDGs are met; scale differences are apparent when comparing world data with regional data and regions differ from each other. We elaborated on each of these points below.

3.1 The well-being–production relationship

Our observations indicate the levels of average income per person at which the seven SDGs are met. In the graphs of Figure 2, we have indicated by red dashed lines where the relationship between income and life satisfaction levels off, according to Frey and Stutzer (2010). The 'levelling-off point' around US$15,000 was achieved in the United States before 1965, in other rich countries around 1975 and in emerging economies in 2010. It lies above the most recent income data for China ($11,370 for 2015), and just above the world average ($13,130 in 2015).

The human well-being trends evident in our data can be related to what Max-Neef (1995) has referred to as a threshold beyond which economic growth does not bring about significantly more life quality but may even begin to deteriorate. In his data, this threshold lies between $15,000 and $25,000 translated to 2011 US$ PPP. The related concept of genuine progress indicator (GPI) for measuring economic welfare has been argued to peak at around $8000 (Kubiszewski et al., 2013).

3.2 Differences between scales

For the world as a whole (grey in the graphs of Figure 2), progress on the seven SDGs instead appears to be linear with respect to income per person, with no indication of saturation at higher rates of income per person. Why does the world data not indicate the same pattern of saturation as the regional data depict? It is likely that inequality plays a major role here. That is, although the high incomes of the minority living predominantly in USA and other rich countries affect the income per person in the aggregated world data, rich regions have already reached the human well-being SDGs and hence increases in incomes in rich regions do not directly affect the attainment of aggregated human well-being SDGs. An increased size of the world economy may thus not significantly affect the achievement of human well-being SDGs, unless it is due to higher incomes in poorer regions. This finding also highlights the need for regional disaggregation when drawing policy conclusions from world-earth models. Besides, the world data's highest level of income per person is the most recent data point for 2015 at US$13,130 – and the saturation effect is seen only at yet higher levels. The world data do therefore not indicate any level of income per person for which human well-being SDGs are attained. A similar scale effect would likely be observed if we zoomed in further and looked at the national and local levels.

3.3 Regional differences

Finally, despite the uniformity discussed in Section 3.1, regions differ in human well-being SDG performance per unit of GDP per person (a related concept is the environmental efficiency of well-being, see Knight & Rosa, 2011). For example, while in our data China reaches the target level on SDG 3 good health (i.e. a life expectancy of 75 years) at around US$8000, India reaches the target level only at a level of US$14,000. Further analysis of these kinds of regional differences may give hints on how human well-being can be reached at lower levels of income. Scale does also play out in the data: the regions differ in population size and number of countries that are included (see Supplementary information).

3.4 Trade-off between human well-being and a flourishing planet?

Figure 1 presents the postulation that production and consumption systems are needed to provide for human needs and capabilities. Simultaneously, production and consumption require material throughput that risks causing pressures on planetary boundaries (note that these pressures can be traced by referring to environmental indicators, as included in the wider *Earth3* modelling project, see Randers et al., 2018, 2019). The causal representation in Figure 1 indicates that there are trade-offs between increasing human well-being (especially when GDP per person is used to indicate production and consumption levels) and staying within planetary boundaries. For a sustainable system, the two loops in Figure 1 have to be better balanced against each other.

If human well-being is based on a more inclusive framework, such as the life satisfaction approach, human needs or capabilities, then the levelling-off portrayed in Figure 2 can be seen as an argument for sufficiency. Above a sufficiency threshold, additional income becomes unnecessary to achieve human well-being (see, e.g. Hickel, 2020). The levelling-off in the human well-being SDGs traced in our study would suggest not to focus on GDP per person as a measure for delivery of human well-being SDGs, especially not beyond the indicated threshold. Instead, a focus on life satisfaction, human needs or capabilities can help in finding inclusive sustainability pathways that provide for human well-being while limiting pressures on planetary boundaries. This reasoning however contradicts achievements of SDG 8 that incorporates a focus on economic growth. The contradiction between SDG 8 and achievements of other SDGs has been highlighted elsewhere, notably by Hickel (2019).

3.5 Contribution to integrated systems modelling

Although current integrated modelling frameworks can provide valuable insights into the social, environmental and economic implications of pursuing multiple SDGs (Costanza et al., 2016; Hughes, 2019), they are not constructed and configured to deal with systemic interactions among all the SDGs (van Soest et al., 2019). Nor are these models constrained within the comparatively stable and predictable Earth system conditions of the Holocene highlighted by the planetary boundaries framework (Rockström et al., 2009; Steffen et al., 2015). There is, furthermore, a paucity of models with bidirectionally integrated social-ecological components (Costanza et al., 2007; Hughes, 2019; Verburg et al., 2016). Zimm et al. (2018) and van Soest et al. (2019) have therefore called for integrated assessment models that meaningfully cover more human dimensions of the SDGs.

The SDGs starkly expose the gap between models appropriate for global policy contexts (energy/economy and climate-focused integrated assessment models are well-established examples), and models informing decisions at the national level of policy makers' typical scope and influence (Collste et al., 2017; Hughes, 2019; Pedercini et al., 2019). National actions taken independently may not add up to desired global outcomes, and 'problem shifting' and spillovers to other sectors and locations are recognized as a global implementation weakness (Engström et al., 2021).

Our insights from building the *Earth3* model contribute to a simple and straight-forward yet useful way to link human well-being SDG performance to income levels. As a consequence of the analysis of data presented in this paper, GDP per capita has been kept as a key driver in the Earth3 model. However, the thresholds discussed have been incorporated so that increases in GDP per capita only affect the simulated performance of the human well-being SDGs at lower income levels, and with decreasing marginal effects.

This can be used to further develop integrated social-ecological model components for world-earth modelling, and is currently being further explored in the context of the Earth4All project (https://www.earth4all.life).

4. Conclusions

With regards to the development of our set of indicators of human well-being SDGs 1–7, data patterns are strikingly uniform across regions. In addition to assisting us in building a more robust model (see Randers et al., 2019), this analysis has yielded some insights that should be taken into account in future global sustainability modelling. Analyses at the regional level can facilitate bridging national policy making with the planetary scale of the 2030 Agenda's ambitions and of the shifting Earth's system dynamics of the Anthropocene. The ways that societies react to emerging problems vary among the world's regions; hence, we have traced trends in indicators of the human well-being SDGs by region. The observed patterns give an indication of the 'business as usual' relationship between income per person and the respective human well-being SDG indicators. Through correlation analysis of these trends, we have obtained parameters for both the seven regions and for the world as a whole, that are used in the Earth3 model (see Collste et al., 2018 for a further explanation of the correlation analysis).

Below the identified income level of around US$15,000 (measured in 2011 US$ PPP), growth is associated with achievements of well-being SDGs for the indicators we use. Above this level, the data indicate limits to the well-being gains from economic growth. As income increases above US$15,000, these data are not associated with considerably better achievement of well-being SDGs. This observation holds across all studied SDGs and regions, and our identified well-being SDG threshold income level is similar to levels presented with regards to the life satisfaction approach as the level where national income increases is no longer strongly associated with higher life satisfaction.

The functional patterns are also sensitive to scale. That is, the degree of aggregation hides differences and inequalities between regions as well as countries. Thereby, the story of the relationship between per person incomes and attainment of SDGs 1–7 differs if we look at the world level or at regional levels. Linear relationships emerge for the aggregated world level, while the relationships seem exponential for the regions.

In the current situation of mankind in which critical planetary boundaries are being transgressed, societies must accelerate sustainability transformations for an equitable future on a finite planet. Although ecological limits to growth have been repeatedly emphasized (including by Meadows et al., 1972, 2004), our analysis contributes to the literature on the limits of growth in providing human well-being above a certain income threshold.

There is a rapidly growing consensus that it is time to shift the world's focus away from maximizing material production to assuring human well-being in a flourishing environment (including, e.g. Jackson, 2011; Maxton and Randers, 2016; O'Neill et al., 2018; Raworth, 2017; Stoknes, 2021; Trebeck and Williams, 2019; Victor, 2019). In the context of Earth3, this has been framed as achieving the SDGs within planetary boundaries. A future in which SDGs have been achieved with limited pressures on planetary boundaries is possible, but we do not have much time.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/sus.2021.26.

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