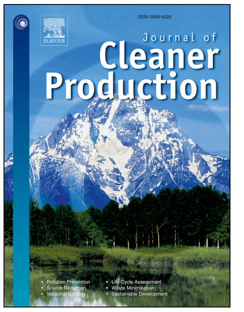

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Abstract

This paper explores the underlying development outcomes and cumulative emissions trajectories of 20 middle-income countries from Eastern Europe, Latin America, North Africa and South Asia. First, it assesses their well-being outcomes, defined in terms of access to education, democratic and legal rights, and the infrastructures that support physical health. Second, it estimates their emissions trajectories to 2050, taking into account current trends in energy consumption and carbon intensity, a likely start-date for stringent climate policy arising from the Paris Agreement (2020), and maximum feasible rates of mitigation. Comparing these estimates to a per capita allocation from the global carbon budget associated with 2^{o}C, ten countries have low-carbon development trends that will not exceed their allocation. Of these, Costa Rica and Uruguay are achieving very high well-being outcomes, while many more are delivering good outcomes in at least two domains of human need. However, most are seriously deficient in terms of social well-being (education, democratic and legal rights). These results call into question the socio-economic convergence of developing countries with industrialised countries; but they also reaffirm the low-emissions cost of extending good infrastructure access and physical health outcomes to all, demonstrated by the existence of multiple countries that continue to avoid carbon-intensive development.

Keywords

Sustainable Development Goals; Human well-being; Cumulative emissions; Climate change; Energy pathways

1. Introduction

Is human well-being compatible with climate change mitigation? Recent research would suggest so: at least a dozen countries have enabled strong health and poverty reduction outcomes, despite very low levels of energy consumption and greenhouse gas emissions (Lamb et al., 2014; Rao et al., 2014; Steinberger and Roberts, 2010; Steinberger et al., 2012). However, many nations in South Asia and Africa still remain below levels of per capita energy consumption necessary for meeting basic human needs (Lamb and Rao, 2015), including many of the aspirational 'Sustainable Development Goals' (SDGs). Reconciling much needed energy growth in these regions with the newly adopted Paris Agreement, which calls for global average temperatures to be held "well below 2^{o}C above pre-industrial levels" (UNFCCC, 2015), is a key challenge in the making of climate policy, particularly as many countries choose to deepen their commitment to carbon-intensive energy sources (Steckel et al., 2015). Yet surprisingly little is known about historical low-carbon pathways of development. Which countries enable high levels of access to household energy services, education, nutrition, health, and democratic rights, at levels of emissions far below the industrial average? This question is the focus of this paper.

Defining low climate impact is of course problematic, since all emissions must ultimately stabilise at zero (or be compensated by negative emissions) to avoid exceeding a temperature target. Similarly, 'high well-being' is an equally contentious phrase. In this paper, we elaborate on an early definition of low-carbon development called 'Goldemberg's Corner' (GC): a domain of relatively low per capita carbon emissions (0 – 3.5 t CO_2), but high levels of achievement in life expectancy (>70 years), comprising about two dozen countries across Eastern Europe, Latin America, North Africa and South Asia (Steinberger and Roberts, 2010). Our contribution is twofold: First, GC countries are examined for their ability to deliver a group of essential household energy and social services in addition to high life expectancy, defined from a human needs perspective, and building on recent literatures critiquing per capita GDP as a poor indicator of development and well-being (Stiglitz et al., 2009). Second, since it is the cumulative emissions that matter for climate impact (Meinshausen et al., 2009), this paper estimates emissions trends and peaking dates for GC countries, comparing these to an allocation from a 2^{o}C global carbon budget to assess the long-term sustainability of their current development pathways. In short, this paper identifies which countries are attaining objectively strong outcomes of human well-being, while continuing to demonstrate emissions trends that are compatible with a 2^{o}C framing of climate change. Accordingly, it argues that such countries may provide a rich source of climate-efficient development policy for those following in their wake, including very large potential emitters such as India, Nigeria and Bangladesh.

This work builds on old and new research investigating well-being in relation to energy consumption (Mazur and Rosa, 1974; Steinberger and Roberts, 2010), territorial emissions (Costa et al., 2011; Steinberger and Roberts, 2010) and consumption-based emissions (Lamb et al., 2014; Steinberger et al., 2012). It is related to research on the links between poverty and greenhouse-gas emissions (Lamb and Rao, 2015; Pachauri et al., 2013; Rao and Baer, 2012; Rao et al., 2014), a stream of work known as the "Carbon Intensity of Well-being" (Dietz et al., 2009; Jorgenson, 2014), and much theoretical and empirical work on the dimensions and determinants of human need (Doyal and Gough, 1991; Gough, 2015; Sen, 1990). Its closest counterpart is a study by Lamb et al. (2014), which investigated the underlying drivers of carbon emissions in Goldemberg's Corner, finding that countries in this domain of low-emissions and high well-being tend to be diverse in their climates, levels of trade, and population growth, but are constrained to low and middle incomes. O'Neill (2015) has also explored countries in the context of their resource consumption, carbon emissions and social performance; while a cumulative emissions framework has been used in Peters et al. (2015) to assess the ambition of mitigation pledges in major emitters.

A number of conceptual and empirical advances are made in this paper. To the author's knowledge, no previous studies have explored the well-being performance of countries from a cumulative emissions framework. In this task, this research builds on recently established consumption-based emissions inventories (Peters et al., 2011), an allocation method to model the persistent short-term emissions growth of countries (Raupach et al., 2014), and carbon emissions budgets of the latest IPCC synthesis report (IPCC, 2014). Furthermore, and in contrast to previous work, it follows a human needs based definition of well-being, moving beyond single-indicator approaches (such as GDP, life expectancy and the human development index) to suggest multiple indicators and thresholds of physical and social need that can be explicitly linked to the Sustainable Development Goals and must be universally enabled to achieve genuine well-being outcomes.

2. Materials and methods

2.1. Country selection

Previous work assessing high-level indicators of human well-being (life expectancy) and environmental impact (energy consumption, carbon emissions) has demonstrated a non-linear relationship: well-being increases with energy consumption (and thus emissions) up to a threshold of approximately 25-50 GJ/capita (~3.5 t CO_2/capita), where the relationship decouples (Lamb and Rao, 2015; Steinberger and Roberts, 2010). The countries that lie on the margin between 'enough' energy consumption and 'too much' are of course interesting and a likely starting point in the search for low-carbon development trends, as they may exhibit patterns of infrastructure and service delivery that are sufficient for enabling well-being, but come at a low cost to the climate. Thus the domain known as Goldemberg's Corner (below 3.5 t CO_2/capita and above 70 years life expectancy) provides a simple framing that reduces the scope of countries, allowing us to focus in more detail on their emissions trends and intermediate well-being outcomes. Importantly, emissions accounts in this paper are defined from a consumption perspective, correcting for transfers embodied in trade that may mask actual levels of carbon a country could be deemed responsible for (Hertwich and Peters, 2009; Peters et al., 2011), but also acknowledging the closer role consumption emissions have in enabling well-being outcomes (Steinberger et al., 2012). This framing and choice of data results in a total of 20 countries, comprising approximately 12% of global population, 7% of global energy consumption and 5% of global emissions.

2.2. Indicators of human well-being

This paper takes a needs-based approach to defining well-being, most clearly articulated in Doyal & Gough's (1991) *A Theory of Human Need*. In this view, well-being is defined as the avoidance of serious harm, which requires underlying conditions of physical health and personal autonomy (i.e. the ability to participate, and choose that form of participation in society). This is an objective approach, but one that recognises there are diverse social and cultural 'satisfiers' for each dimension of human need (Max-neef, 1991). The human needs approach is related to Sen's (1990) work on capabilities, but in contrast is able to elaborate on a specific list of well-being outcomes and the necessary preconditions for meeting them (see Gough, 2014 for a review). It has substantial advantages over preference satisfaction (i.e. income), which, among other well-known critiques, assumes rationality, fails to acknowledge market externalities, and reduces all needs to substitutable preferences (Stiglitz et al., 2009).

The human needs approach emphasises the non-substitutability of needs, and thus the requirement that multiple dimensions of well-being should be simultaneously analysed – and not aggregated into single indicators such as life expectancy or income (an approach also reflected in the Sustainable Development Goals). Thus even though the countries in Goldemberg's Corner have already attained high levels of life expectancy, it is still necessary to assess their achievements in intermediate need satisfaction, as well as the crucial social and political determinants of personal autonomy, before they can be judged in terms of overall well-being.

Moving from theory to practice, important constraints are data availability, data quality and policy relevance (Reinert, 2009). In this paper, three indicators are selected to represent basic conditions for satisfying physical health outcomes: access to improved sanitation facilities (flushed latrine, sceptic tank, pit latrine, or composting toilet), access to household electricity, and adequate nourishment (a ratio of dietary energy consumption to an intake adequacy rate for the respective population). All three indicators have clear pathways to improved physical health. Sanitation enables the avoidance of bacterial and parasitic infections; household electricity access reduces indoor air pollution and resulting respiratory diseases; while adequate nourishment is a precondition for human survival, while also strengthening resistance to illnesses (Karekezi et al., 2012; Pachauri and Spreng, 2004; Wilkinson et al., 2007). By describing the proportion of a population with access to these needs, these indicators capture distributional issues, but unfortunately provide little information on the quality (e.g. intermittency) and affordability of each given service - an important limitation of this study. Respectively, they closely correspond to the United Nations Sustainable Development Goal (SDG) 2.1 (eradicate hunger and ensure access to adequate nutrition), SDG 6.2 (achieve access to adequate and equitable sanitation), and SDG 7.1 (ensure access to energy services)

Personal autonomy is a more challenging concept to operationalize. Doyal and Gough (1991) recommend indicators of knowledge acquisition and literacy, but acknowledge the sparse data available for social opportunities, economic opportunities, and the avoidance of mental distress. Again, three indicators are selected: secondary school enrolment (as a proportion of the age-relevant population), and the World Governance Indicators (WGI) for 'voice and accountability' and 'rule of law'. These latter two indicators are comprised of multiple subjective sources (e.g. interviews with households, experts and non-governmental organisations), aggregated into composite measures ranging from -2.5 (poor performance) to 2.5 (high performance). This type of data departs from the objective model of well-being, normatively prioritising Western standards of democratic governance, but are among the few indicators with sufficient global coverage that describe aspects of personal expression, association and representation (voice and accountability), as well as legal recourse and safety from violence and crime (rule of law). Of the available international education data, secondary school enrolment is one of the most comprehensive indicators (but unfortunately still lacking 6 data points in this country sample). Feasible alternatives, such as literacy rates, or primary school enrolment are less ambitious measures of educational attainment, but do have increased coverage. Again, these indicators closely correspond to SDG 4.1 (ensure free, equitable and quality primary and secondary education), SDG 16.7 (ensure responsive, inclusive, participatory and representative decision-making at all levels) and SDG 16.3 (promote the rule of law, ensure equal access to justice for all).

In analysing performance, it is useful to set thresholds, above which a country may be considered 'developed' or high performing. Inevitably, this is a normative process. For instance, the U.N. Development Reports define 'high development' in life expectancy as the international upper quartile on 10 years of data. In this paper, the thresholds are simply set at 90% for improved sanitation access, household electricity access, and adequate nourishment; and 80% for secondary school enrolment. In the first three indicators, universal (100%) access is desirable. In fact the intention of the relevant SDG goals is to achieve full access by 2030 (United Nations General Assembly, 2015). However, a lower threshold of 90% acknowledges that coverage is growing in these countries (at 10 year compounded rates averaging 2.6% for sanitation, 1.2% for electricity and 0.9% for nourishment), but that there likely remains systemic barriers to achieving full access in a sample of middle-income countries which average just 5,000$/capita (whereas those achieving universal access to sanitation, electricity and nourishment average 36,000$/capita, 21,000$/capita and 25,000$/capita, respectively). For secondary school enrolment, universal access is not necessarily desirable, as some individuals may choose to pursue vocational training upon reaching an appropriate age, thus the 80% threshold reflects a lower bound of OECD (Organisation for Economic Cooperation and Development) country ranges for this indicator (Switzerland is approximately 81%). Alternative, more basic indicators, e.g. literacy and primary enrolment, would again be aligned towards universal access. No thresholds are given for voice and accountability and rule of law, but for comparison the international median and OECD mean values for these indicators are reported in the results.

2.3. Estimating emissions trajectories

For the purpose of climate change mitigation, it is the cumulative emissions that determine likely levels of warming (Meinshausen et al., 2009). From this perspective, emissions must decline and ultimately reach net zero within an appropriate time-frame, or risk exceeding a fixed global budget for a given probability of avoiding 2^{o}C. Accordingly, this paper focuses on the cumulative emissions pathways of countries, predicting future trajectories on the basis of four factors: (1) current levels of energy consumption and carbon intensity; (2) current rates of growth in energy consumption and carbon intensity; (3) the start-date of stringent climate mitigation (and thus peaking emissions); and (4) the likely maximum sustained rate of mitigation (i.e. decline in carbon intensity).

In the first stage, current energy consumption and carbon intensities are given by the start date of the scenario (2012). Second, the rates of change in these indicators are estimated using a log-log fit on 10 years of data (2002-2011):

$$x_i = \exp(A) \cdot {t_i}^{\beta} \leftrightarrow \log(x_i) = A + \beta \cdot \log(t_i) \quad (1)$$

Where energy consumption, and carbon intensity (x), are estimated for countries *(i)* in time *(t).* The given trends in energy consumption and carbon intensity are then projected to the start date of stringent mitigation (2020), giving the cumulative 'business as usual' emissions over this period.

2020 is a key date in the Paris Agreement: for submitting updated "Intended Nationally Determined Contributions" (INDCs), for submitting long-term low-carbon development strategies, and for enhancing cooperation in finance and technology transfer. Thus, in the following decades (2021-2050), trends in energy consumption continue, but carbon intensities are assumed to decline at a rate of 1% per year, up to a final sustained rate of 5%; this defines the peak and decline of emissions, giving a final cumulative budget for each country.

This method presents some drawbacks. It is sensitive to the period in which growth rates are calculated. For instance, a five year period (2007-2011) would correspond with the global financial crisis and a likely low point of energy consumption and emissions, leading to very high estimated growth rates. Consequently a longer time period (10 years) is applied, while the log-log fit uses all data points to estimate trends and is thus less sensitive to extreme outliers than a simple end-point approach[1]. Linear and log-linear forms were also tested, but these resolved poorer fits and do not allow a direct comparison of growth rates (β) between countries.

A second key assumption is the projection of historical energy consumption trends across a long period of three decades. This is of course problematic, not taking into account potential technology developments, rapid social change, or an eventual stabilisation of energy consumption. However, given recent research on 'committed' infrastructures (Davis and Socolow, 2014) as well as known sources of inertia in technology development (Hanna et al., 2015), it is reasonable to expect short-term growth where this is already occurring (Raupach et al., 2014). Thus the first stage of the scenario, which projects short-term growth to an emissions peaking date after 2020, is less problematic than the second stage, which assumes continued linear growth in energy consumption to 2050, alongside a declining carbon intensity. In effect, no saturation or demand reduction of energy consumption can occur in this later stage of the scenario, denying an important potential source of mitigation, albeit one with likely rebound effects (Sorrell, 2015). In this case, it may be preferable to preferable to model energy consumption as an S-shaped transition (i.e. a logistic curve), but in fact, since just a few countries in the sample have very high rates of change in energy consumption, the long linear extrapolation has only a limited impact on the emissions pathways. The procedure is thus to proceed with a simple log-log projection, rather than a speculative logistic trend, and note cases where this heavily impacts on the results.

Finally, the assumption of a gradually peaking and then exponentially declining carbon intensity builds on work by Anderson and Bows (2011) and Raupach et al. (2014), who have argued that

[1] In three cases – Armenia, El Salvador and Uruguay – a 20 year growth rate was necessary to avoid either negative, or unrealistically rapid energy growth (e.g. > 500GJ/capita by 2050).

energy-system inertia constrains emissions trajectories to a ‘smooth’ peaking effect, rather than sudden and discontinuous change. The final sustained rate of mitigation (5% per year) is arbitrary, but a higher value may be considered “implausible” give current and foreseen technologies (Stern, 2007). Such rates of change have never been experienced outside of major economic shocks and downturns, and never on a consistent year to year basis, but they are in line with similar studies assessing transition pathways that avoid 2°C. For instance, a similar post-2020 ‘delayed mitigation’ scenario from the integrated assessment community found rates of change between 3-5%, and as high as 8% per year across 7 models (Aboumahboub et al., 2014). Indeed, far higher rates of change (e.g. >10%) would be necessary in the absence of negative emissions technologies (Anderson and Bows, 2011).

It is important to note that this predictive model of country emissions trajectories diverges from the INDC framework accepted in the Paris Agreement. Since the INDCs are individual, uncoordinated pledges, they are not able to achieve a 2°C budget stabilisation (Climate Action Tracker, 2015). Indeed, pledges based on intensity targets (e.g. China) or baseline reductions (e.g. EU, United States) cannot be easily rendered into cumulative budgets, as they require projections of GDP growth, or estimates of uncertain emissions trends between baseline and target years (Peters et al., 2015). The approach taken here is complementary to the INDCs. It is a parsimonious model based on transparent assumptions that seeks to resolve the extent to which current patterns of country emissions and growth will impact on the shared carbon space. In doing so, it acknowledges that energy-system inertia will constrain pathways to short-term emissions growth, as well as maximum sustained rates of mitigation, but it remains optimistic that action called for in the Paris Agreement can proceed after 2020.

2.4. Allocating emissions budgets

Alongside the emissions trajectory estimates, an ‘ideal’ emissions pathway is generated for each GC country using an allocation from the global carbon budget. This allows for a comparison between the country trajectories previously described - defined by current growth, as well as an upper limit on the rate of mitigation – and idealised pathways that ‘fairly’ contribute to the avoidance of 2°C climate change.

A global budget of 1000 Gt CO_2 is used (2011-2100), corresponding to an approximate 66% chance of avoiding 2°C of climate change, as summarised in the Intergovernmental Panel on Climate Change (IPCC) synthesis report (IPCC, 2014). How to fairly allocate this budget to countries is the focus of many studies; but for simplicity, and building on arguments for ‘equal access’ to the atmosphere

(Baer et al., 2000), this analysis calculates an equal per capita share of cumulative emissions budget for each country:

$$q_i = B\left(\frac{p_i}{P}\right) \quad (2)$$

Where the emissions quota *(q)* for each country *(i)* is calculated from the proportion of country population *(p)* to global population *(P)* (in 2011), multiplied by the global carbon budget *(B)*. This quota is then allocated through the 38 years of the scenario using a declining exponential function described by Raupach et al. (2014), taking into account current emissions growth and 'peaking' effects (Anderson and Bows, 2011):

$$f_{ti} = f_{0i}(1 + (r_i + m_i)\ t)\ \exp(-m_i t) \quad (3)$$

Where f is the emissions at time t, f_0 is the emissions at the start of the scenario, r is the current rate of change in emissions, and m is an applied mitigation rate to meet the specified quota (Raupach et al., 2014).

The equal per capita share will generally favour GC countries, as they tend to have lower emissions than the global average. However it does not take into account historical emissions, suggesting a role for financial transfers, technology assistance and other means to alleviate the fairness concerns of developing nations. It should be noted that high emitting nations apportioned with this regime are unlikely to meet their budgets, even with extremely aggressive rates (>10%) of emissions reductions (Anderson and Bows, 2011; Raupach et al., 2014), a finding more reflective of the extreme challenge to meet the 2^{o}C goal in contemporary mitigation scenarios (particularly without negative emissions) than the deficiencies of a particular allocation regime.

Since the INDC approach of the Paris Agreement has superseded any meaningful assessment and allocation of cumulative emissions, this per capita approach could be considered politically intractable. Nonetheless, given that the goal of this paper is to identify existing low-carbon pathways of development, rather than an ideal policy scenario, it is a straightforward method to assess how likely countries are to infringe on the shared carbon space. According to their current trends, countries will either exceed the per capita share, and thus have patterns of consumption and growth that are decidedly not low-carbon; or they will use less than their fair share and have the opportunity to avoid carbon intensive development. 'Low-carbon development' is consequently a normative definition, requiring an assumption of fairness, but it is nonetheless grounded in the science of cumulative emissions budgets.

2.5. Sources

The data sources are as follows: final energy consumption from the International Energy Agency (IEA, 2014), consumption-based carbon emissions from Peters et al. (2011), population, life expectancy, sanitation access, electricity access, secondary school enrolment, voice and accountability, and rule of law from the World Bank (2015), nourishment from the Food and Agricultural Organisation of the United Nations (FAO, 2014). In the emissions scenarios, population projections were taken from the United Nations Population Division median fertility scenario (UN, 2015). Due to sparse data, the well-being indicators are reported for the last available year: 2013 for nourishment (with some earlier data points for 3 countries, noted in the text); 2012 for sanitation, voice and accountability and rule of law; 2010 for household electricity; and the last available year for each country across 2008-2013 for secondary school enrolment.

3. Results

3.1. Human well-being performance

The countries in Goldemberg's Corner are highly diverse in terms of underlying well-being outcomes, as shown in Table 1. The colours correspond to either achieving (green), or failing to achieve (red) the threshold value for each indicator (90% for sanitation, electricity and nourishment; and 80% for secondary school enrolment). The majority of countries perform well in terms of electricity access, with only four failing to exceed the threshold, and nine achieving universal (100%) access. Sanitation coverage is systematically lower, with just eight countries above the threshold, and only Egypt and Uruguay achieving near-universal access. In the available data for nourishment and secondary school enrolment there are ten examples of high performance in the former, but only four in the latter (Armenia, Egypt, Georgia, Sri Lanka). Thresholds are not reported for voice and accountability, and rule of law, but it is clear that most countries perform poorly on these measures, with a majority below the international median (approximately 0 for voice and accountability, and -0.2 for rule of law). Two exceptions which perform relatively high are Costa Rica and Uruguay, both of which exceed a level of 1 in voice and accountability and 0.5 in Rule of Law. For comparison, OECD countries achieve on average 1.1 in the former, and 1.3 in the latter. Since our data is already several years old, it is probable that some countries close to the thresholds have already crossed them (e.g. Sri Lanka for electricity, many more in the case of nourishment).

The fact that many countries are able to meet high levels of physical needs access, despite extremely low emissions, is broadly consistent with other findings; namely that basic energy services do not entail significant greenhouse gas emissions cost (Chakravarty and Tavoni, 2013; Pachauri, 2014; Pachauri et al., 2013) and that human well-being decouples from environmental impact beyond minimum levels of consumption (Steinberger and Roberts, 2010). While good performance in a single well-being indicator could be seen as evidence of decoupling, more impressive would be performance in multiple indicators. For more than two indicators, 13 countries satisfy this criteria; for more than three indicators, six countries exceed the thresholds (Albania, Armenia, Costa Rica, Egypt, Georgia and Uruguay); while only two countries (Armenia, Georgia) satisfy at least four dimensions of human need. These synergies are expected, as some needs share similar satisfiers (such as the links between household electricity access and education and literacy), yet very good performance in one indicator alone does not guarantee success elsewhere. Indonesia, for instance, has near universal household electricity as well as 90% nourishment, but very poor levels of improved sanitation access (59%). Sri Lanka has near universal literacy, compulsory primary and secondary school attendance, and free education up to the completion of a first university degree - but alongside these achievements, significant issues in terms of food access, as well accountability and rule of law in the wake of the recent civil war. It is further notable that good levels of services promoting physical health are generally accompanied by poor standards of personal autonomy across the sample, showing that these two dimensions of human need do not necessarily co-exist (although the former may be a pre-condition for the latter).

	Physical health			Personal autonomy			
	Access to improved sanitation (%)	Access to household electricity (%)	Adequate nourish-ment (%)	Secondary school enrolment (%)	Voice and account-ability	Rule of law	No. indicators above threshold
Albania	**91**	**100**	**100**		0.0	−0.6	3
Armenia	**91**	**100**	**94**	**89**	−0.6	−0.4	4
Brazil	**81**	**100**	**94***		0.4	−0.1	2
Cambodia	**37**	**31**	**83**	**38**	−1.0	−1.0	0
Colombia	**80**	**97**	**87**	**74**	−0.1	−0.4	1
Costa Rica	**94**	**100**	**95**	**73**	1.1	0.5	3
Ecuador	**83**	**97**	**89**	**74**	−0.3	−1.2	1
Egypt	**96**	**100**		**82**	−0.8	−0.5	3
El Salvador	**71**	**94**	**87**	**62**	−0.1	−0.7	1
Georgia	**93**	**100**	**90**	**80**	0.0	0.0	4
Guatemala	**80**	**79**	**86**	**47**	−0.4	−1.1	0
Honduras	**80**	**82**	**87**		−0.5	−1.2	0
Indonesia	**59**	**96**	**90**	**76**	0.0	−0.6	2
Morocco	**75**	**100**	**95†**	**56**	−0.6	−0.2	2
Paraguay	**80**	**98**	**91**	**65**	−0.1	−0.9	2
Peru	**73**	**91**	**90**	**73**	0.1	−0.6	2
Sri Lanka	**92**	**89**	**75**	**85**	−0.6	−0.1	2
Tunisia	**90**	**100**			−0.2	−0.1	2
Uruguay	**96**	**100**	**95‡**	**72**	1.0	0.5	3

Viet Nam	75	99	87		−1.4	−0.5	1

Table 1: Human well-being performance in Goldemberg's Corner

Notes: Data points identified as green exceed the thresholds for 'high development' (90% for sanitation, electricity and nourishment; 80% for secondary school enrolment). * Data is from 2005; † Data is from 2012; ‡ Data is from 1998.

3.2. Energy consumption trends

In all countries of this sample, initial levels of final energy consumption are below 50GJ/capita in 2011. These low levels of energy consumption proceed to highly diverging outcomes by the mid-century, due to differences in current rates of growth (Figure 1; Table 2). Countries can be split into approximately 3 groups: (1) those that remain below 50 GJ/capita, due to extremely modest growth rates (Cambodia, Colombia, Guatemala, Honduras, Indonesia, Paraguay, Sri Lanka, and Tunisia); (2) those with rather higher rates of growth, exceeding 50 GJ/capita by 2050 (Albania, Armenia, Costa Rica, Ecuador, Morocco, Peru and Uruguay); and (3) countries with extremely fast growing energy consumption, ultimately projected to exceed 100 GJ/capita by 2050 (Brazil, Egypt, Georgia and Vietnam).

	Energy consumption		Carbon intensity		Cumulative emissions ($GtCO_2$)		
	β (std. error)	r2	β (std. error)	r2	Estimated trajectory (2012-2050)	Budget allocation (2012-2050)	% of alloca-tion
Albania	34 (11)	0,53*	18 (18)	0,11	0,23	0,30	77%
Armenia	62 (26)	0,25*	-31 (11)	0,48*	0,18	0,30	60%
Brazil	51 (5)	0,94***	24 (7)	0,56*	22,45	22,32	101%
Cambodia	37 (37)	0,11	190 (26)	0,78***	2,36	1,69	140%
Colombia	3 (8)	0,02	62 (11)	0,81***	3,40	4,76	71%
Costa Rica	43 (12)	0,6**	-22 (24)	0,1	0,51	0,57	89%
Ecuador	55 (6)	0,92***	-26 (10)	0,46*	1,68	1,76	95%
Egypt	76 (11)	0,85***	14 (10)	0,21	15,63	10,17	154%
El Salvador	2 (8)	0,01	53 (14)	0,63**	0,32	0,36	89%
Georgia	68 (9)	0,88***	87 (36)	0,41*	0,69	0,59	117%
Guatemala	26 (11)	0,4*	-50 (16)	0,56*	0,56	0,80	70%
Honduras	24 (9)	0,47*	-38 (13)	0,52*	0,32	0,50	64%
Indonesia	14 (3)	0,75**	78 (10)	0,89***	23,09	27,63	84%
Morocco	83 (4)	0,98***	-38 (9)	0,71**	2,93	2,96	99%
Paraguay	4 (8)	0,03	96 (15)	0,84***	0,45	0,61	74%
Peru	72 (10)	0,86***	72 (11)	0,83***	5,40	3,77	143%
Sri Lanka	18 (7)	0,48*	21 (11)	0,31	0,75	1,35	56%
Tunisia	25 (8)	0,56*	19 (11)	0,28	1,03	1,18	87%

Uruguay	38 (8)	0,54***	13 (10)	0,1	0,36	0,42	86%
Viet Nam	105 (4)	0,99***	67 (19)	0,62**	19,12	11,67	164%

Table 2: Regression and budget results

Notes: ***p<0.001, **p<0.01, *p<0.05

The trends are thus not uniform, but are largely based on strong fits, with some exceptions: Cambodia, Colombia, El Salvador and Paraguay, all of which exceed p-values of 0.05. These countries have, not coincidentally, some of the lowest growth rates in the sample and very unstable patterns of energy consumption in the past decade that are unable to provide a strong basis for projecting trends. Going forward, these weak projections are noted in the budget calculations. The trajectories of countries in the 3rd group (above 100 GJ/capita) imply final consumption levels matching those in present-day OECD countries, with perhaps some uncertainty as to the sources of this large scale growth in energy demand (although these trends are very robust in the period of the analysis, 2002-2011). Nonetheless, the majority of countries do not exceed these high levels and are instead projected to reach between 20 – 80 GJ/capita by 2050. Comparing these values to the Global Energy Assessment "GEA-Supply" scenario, a baseline scenario assuming minimal efficiency improvements, they are consistent with a range of integrated assessment projections for developing countries (32 – 71 GJ/capita) (Riahi et al., 2012).

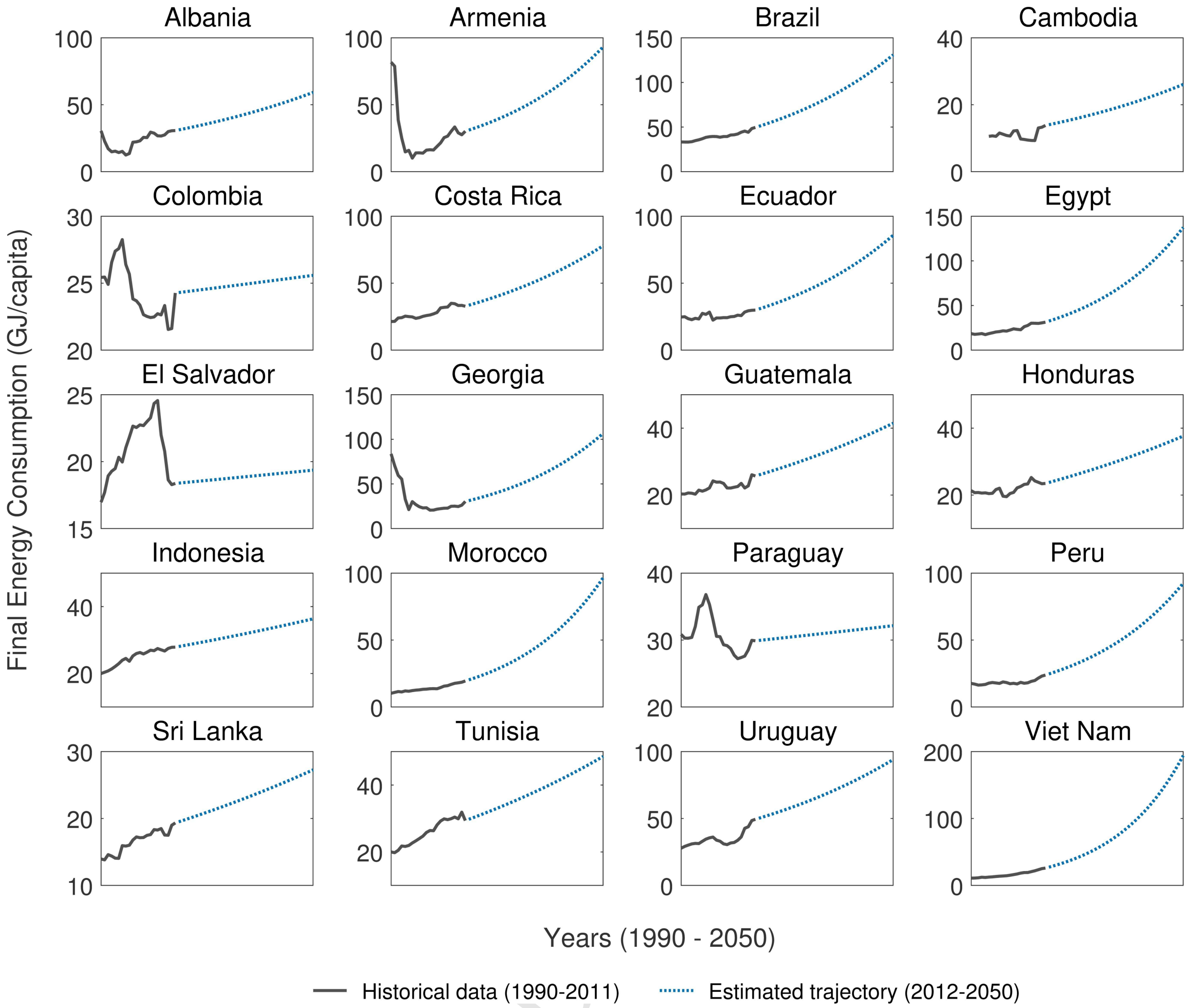

Figure 1: Trends and projections of energy consumption (1990-2050)

3.3. Carbon emissions trends

Carbon intensity trends are more challenging to estimate, with large year to year fluctuations and generally poorer goodness-of-fits than energy consumption alone (Table 2). The results show a wide range of growth rates, from extremely high and positive levels of growth (Cambodia) to countries with negative (i.e. decarbonising) trends (Armenia, Costa Rica, Ecuador, Guatemala, Honduras and Morocco). Recalling the scenario design, it should again be noted that carbon intensities are only projected to 2020, beyond which annual reductions are initiated up to a maximum rate of 5% per year, consequently, the carbon intensity projections are primarily important for determining peaking levels of emissions between 2020 and 2030. And since poor statistical fitting ($p > 0.05$) is generally associated with low beta values in the projection model (i.e. relatively stable levels of projected carbon intensity; Table 2), this source of uncertainty should not heavily impact on whether or not countries can remain within budget.

Figure 2 presents the final emissions trajectories (in blue), versus an ideal (equal per capita) allocation of the global carbon budget (in red). This allows for a simple comparison: if the blue emissions trajectory for a country tracks below the red ideal trajectory, its current trends are not likely to exceed the budget; however, if the lines intersect, or the estimated trajectory tracks above the ideal trajectory, then a country is likely to exceed its 2^{o}C allocation even with the substantial mitigation actions that are assumed (5% per year from 2020). Similarly, Table 2 details the degree to which each country remains within or exceeds its budget. Again, three broad categories of countries can be identified: (1) those with trajectories set to stay within the per capita allocation (Albania, Armenia, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Indonesia, Morocco, Paraguay, Sri Lanka, Tunisia and Uruguay); (2) those countries who marginally exceed the budget by up to 10% (Brazil); and (3) those countries who are projected to substantially exceed the budget beyond 10% (Cambodia, Egypt, Georgia, Peru, Vietnam).

How does energy consumption growth relate to final cumulative emissions? Of the countries that remain entirely within budget, the majority did not exceed 50 GJ/capita in energy consumption by the mid-century. Six countries exceeded 50 GJ/capita – Albania, Armenia, Costa Rica, Ecuador, Morocco and Uruguay – and remained within budget, but no countries exceeded 100 GJ/capita and did so. The conflict between high energy consumption growth and absolute emissions reductions are clear in specific cases – Egypt, Georgia, Peru and Vietnam – where peaking emissions between 2020-2030 are close to those of the idealised budget, but continued growth thereafter leads to 'flat tails' in the trajectories and an eventual overshoot (Figure 2). Thus in these cases, current growth rates are commensurable with short-term budget goals (the 2020-2030 peaking emissions), but are unsustainable in the long term.

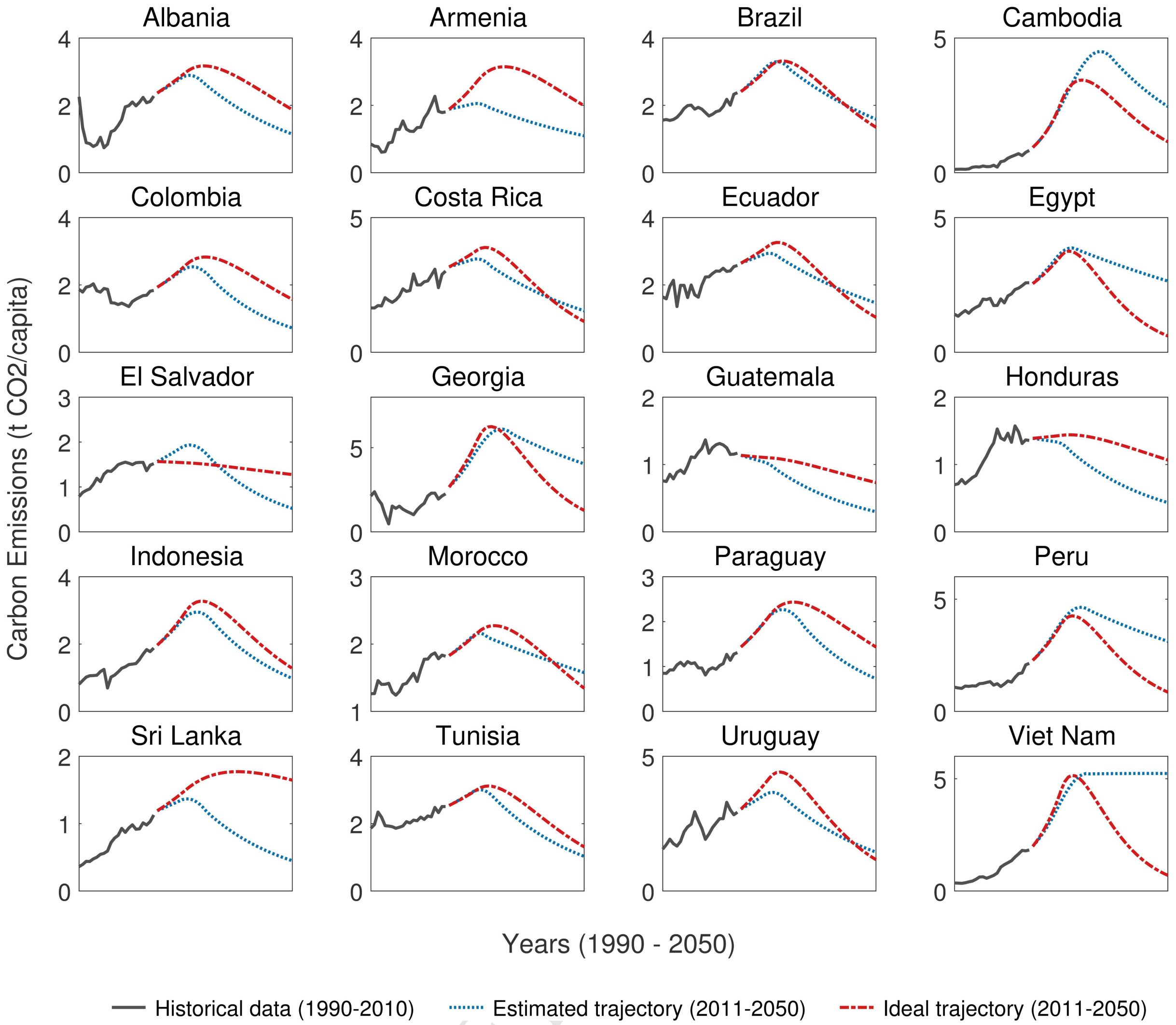

Figure 2: Trends and projections of carbon emissions (1990-2050)

Since the emissions in this analysis are accounted from a consumption perspective, CO_2 can arise from both domestic and global activities. Whereas the former is captured by final energy consumption, and would arise primarily from heating demand, transportation, and domestic-oriented manufacturing; the latter is determined by the average carbon intensity of global production and the extent to which these countries participate in trade. Thus a strong link between energy consumption and carbon emissions is expected, but may be nuanced by the particular economic structure of a country, with a potentially greater impact on those with high levels of trade and low carbon intensities in relation to the global average (an interesting, but relatively unexplored topic). Nonetheless, among the countries that exceed the per capita allocation, there are examples of both open, highly trading economies (Cambodia, Vietnam), relatively more closed ones (Brazil, Egypt, Peru), as well as a transitioning former-Soviet state (Georgia) (Lamb et al., 2014).

With the exception of Brazil, where countries exceeding the per capita allocation, they tend to do so to a large extent: Cambodia (140%), Egypt (154%), Peru (143%) and Vietnam (164%). Apart from Cambodia, all of these energy consumption trajectories are based on very strong ($p < 0.001$) fits, reflecting consistent and steady trends of growth in the past decade. And of these, Peru and Vietnam have also shown consistent ($p < 0.01$) and strong rates of carbon intensity growth in the same period, leading to high peaking levels of emissions in the scenario. However, in some other countries the underlying energy and emissions trends have been exceptionally unstable. In particular, it is debatable whether Colombia, El Salvador and Paraguay are in fact moving towards low-carbon development, or will continue to fluctuate in their end-use energy patterns. Similarly, Cambodia and Georgia are projected to have a massive, but statistically weak increase in pre-2020 carbon intensity, which causes these countries to overshoot a peaking level of emissions that would correspond with the per capita allocation. These problems in estimating growth rates are expected insofar as the relatively small countries in this sample can be disproportionately affected by sector-specific trends, such as the short-term growth or decline of steel production. Additionally, consumption-based emissions are more closely driven by socio-economic factors (such as income and trade) than production-based accounts (Lamb et al., 2014; Teixidó-Figueras et al., 2016), meaning that economic instability could have a relatively larger impact on carbon intensity change in this analysis.

Group	No. well-being indicators above threshold	Peak Emissions (t CO2/capita)	Emissions budget performance
High performers			
Albania	3	2.9	77%
Armenia	4	1.9	60%
Costa Rica	3	3.4	89%
Uruguay	3	3.6	86%
Moderate performers			
Sri Lanka	2	1.3	56%
Tunisia	2	3.0	87%
Indonesia	2	3.0	84%
Morocco	2	2.2	99%
Low performers (emissions)			
Brazil	2	3.4	101%
Egypt	3	4.0	154%
Peru	2	4.7	143%
Vietnam	1	5.2	164%
Low performers (well-being)			
Ecuador	1	2.9	95%

Guatemala	0	1.2	70%
Honduras	0	1.3	64%
Uncertain trends (energy)			
Colombia	1	2.5	71%
El Salvador	1	1.9	89%
Paraguay	2	2.2	74%
Uncertain trends (emissions)			
Cambodia	0	4.5	140%
Georgia	4	5.9	117%

Table 3: Country groups according to well-being achievement and current emissions trajectories

Nonetheless, the resulting levels of per capita carbon emissions, between approximately 2-4 t CO_2 at peak emissions (Table 3), fall well within the realm of international experience. In fact only two countries, Georgia and Vietnam, peak at emissions above 5 t CO_2/capita – the approximate world average in 2011, and far below the range of contemporary consumption-based emissions estimates for OECD nations, which typically exceed 10 t CO_2/capita. Perhaps more surprising is the predominance of extremely low emissions trajectories. Ten countries are not projected to exceed even 3t CO_2/capita, while many of these – particularly Albania, Armenia and Sri Lanka – have a substantial portion of emissions budget to spare.

Comparing these results to achievement in well-being, the clear highest performers are Albania, Armenia, Costa Rica, and Uruguay. These countries have low-carbon trajectories which will have a minimal impact on the shared carbon space, combined with high rates of needs access across three infrastructural indicators. In addition, Costa Rica and Uruguay have the highest levels of voice and accountability and rule of law relative to this sample. Other moderate performers are Sri Lanka, Tunisia, Indonesia and Morocco, all of which are estimated to remain within budget, while delivering sufficient needs access in at least two indicators. The remaining countries either exceed their allocated budgets, fail to achieve good outcomes in more than one dimension of human need, or have energy and emissions trends too unstable to estimate near-term emissions impact. In summary, a relatively limited number of countries exhibit broad success in development and emissions terms, with many more deficient in one or more dimensions of human need, while none are fully satisfying their social needs – defined here as perceived access to democratic institutions and the avoidance of crime.

4. Discussion

The countries in this analysis were selected for their low emissions and high life expectancies, definitions that alone are no guarantee of sustainability. A deeper exploration of their emissions trajectories reveals striking results: rates of energy and carbon intensity growth are extremely varied, such that many countries in Goldemberg's Corner have an opportunity to entirely avoid carbon-intensive development. The reality of a climate-constrained world means that these countries will still have to initiate mitigation soon after 2020; but the cumulative emissions framework is able to assess which patterns of growth can still be reconciled with budget limits, and thus which countries can be said to have low-emissions pathways.

From a development perspective, it is similarly impressive that these low levels of emissions and growth have been accompanied by a high degree of access to household energy services and adequate food supply. However, there is still much room for improvement: in sanitation coverage, education outcomes and opportunities for democratic and legal recourse. In this sense, life expectancy appears to be a poor proxy for underlying human needs, masking some serious deficiencies, such as the extremely low levels of access to sanitation in Cambodia (37%), or secondary education enrolment in Guatemala (47%). The disaggregation of multiple indicators and goals of development is consequently an important step towards understanding real outcomes in such countries – a vindication of the broad SDG approach, but also a challenge to researchers and policy makers working with fragmented and often absent data.

In terms of energy consumption, emissions and human well-being, Goldemberg's Corner lies between the industrialised nations of the OECD, and the low-development countries of the global South. Is this domain of well-being and emissions impact simply a 'stage of development', a transition area en route to high consumption and well-being? This is a highly relevant question when it comes to understanding future trends in emissions and well-being progress. Researchers have offered competing theories. There are those that argue development is a process of convergence, a systematic progression of poor countries towards industrialisation, high consuming lifestyles and an increasing dependence on energy consumption – ultimately levelling their emissions impacts with those of the wealthy world (Jakob et al., 2012; Pretty, 2013). Others argue that development is a process of divergence, where an international division of labour separates extraction, production and consumption activities, leading to a static hierarchy of end-use energy levels, large flows of carbon embodied in trade, and persistent unequal emissions impacts across the world (Arrighi et al., 2003; Hornborg, 2009). Whereas the former view identifies Goldemberg's Corner as a transition area, through which countries pass to converge in socio-economic development with the rich world, the latter claims that this is a level of the development hierarchy, where socio-economic conditions stagnate and consumption-based emissions impacts are unlikely to catch up with those of the global North.

On the side of convergence, it is notable that several large peripheral countries – Brazil, Egypt, and Vietnam – have been shown to be undergoing a period of rapid expansion in final energy consumption. This is occurring alongside an acceleration of carbon intensities in some cases (e.g. Colombia, Indonesia, Paraguay, Peru, Vietnam), which is consistent with findings that a global 'renaissance' of fossil fuel consumption is occurring, particularly in fast growing developing countries (Steckel et al., 2015). Similarly, high levels of infrastructure access across many countries in Goldemberg's Corner, along with consistent (linear) rates of improvement in these indicators demonstrated elsewhere (Lamb and Rao, 2015), tend to suggest that development outcomes, at least in terms of physical health, are 'catching-up' with the universal access levels of the industrialised world.

On the other hand, there are evident discontinuities in supposed patterns of convergence. Many countries in Goldemberg's Corner are in an effective steady state of energy consumption, with growth that will still not exceed 50GJ/capita by 2050. Of these, a number of countries have experienced substantial shocks and declines in energy supply over the past decades (particularly Colombia, El Salvador, Paraguay and Georgia), while trends in carbon intensity have also declined for some (Costa Rica, Ecuador, Guatemala, Honduras and Morocco). In the literature emphasising divergence, particularly world-systems theory, considerable weight is given to class relations, and asymmetries of trade, finance and military power as key barriers to socio-economic development (Roberts and Parks, 2009). It is therefore notable that the majority of countries in Goldemberg's Corner remain challenged in their social and political well-being, and indeed that some of the slowest rates of energy consumption growth, and poorest development outcomes, can be found in Guatemala, Honduras, and El Salvador – all of which have historically succumbed to foreign military intervention or sponsored suppressions of civil liberties (Chomsky, 1985). That Costa Rica is an exception in this regard, with both high physical and social need satisfaction, speaks to the importance of a strong social democratic state in withstanding international market forces and pursuing human development progress on the periphery (Sandbrook et al., 2007).

The evidence of this study leans towards divergence. Rather than following a modernizing pathway of economic growth, structural change and democratisation, the countries in Goldemberg's Corner have diverse patterns of growth and stabilisation, as well as persistent social and political challenges, bringing into question their eventual convergence with consumption patterns of the industrial

North. This is not to say that high energy consumption (and thus high income) equates with high well-being; evidently these countries are on a threshold of decoupling between the two, certainly in the ‘bare necessities’ that constitute the physical need indicators. The question is whether high standards of social well-being (i.e. democratisation) are universally attainable given the current structure of the world economy, which in recent decades has shown tendencies of widespread social and political dislocation in the periphery (Arrighi et al., 2003) – thus highlighting the enormous challenge of enabling human well-being within the systematic inequalities of capitalism, as well as the physical constraints of a 2^{o}C carbon budget.

This work has several limitations. In the first instance, it has explored high level trends only, rather than the underlying determinants of energy-system change in Goldemberg’s Corner. Yet given the general lack of studies on country development pathways (particularly from a climate and development perspective), this is a useful first step and has identified specific states that are be worthy of further attention. For example, those countries that have experienced rapid energy consumption and carbon intensity growth over the past decade (Egypt, Peru, Vietnam) will be highly relevant to the widely discussed issue of ‘technological lock-in’ (Unruh and Carrillo-Hermosilla, 2006) and the role of investment cycles and durable assets in determining future emissions growth (Davis and Socolow, 2014). Equally, in cases where well-being is proceeding with little cumulative emissions cost (e.g. Armenia, Costa Rica, Uruguay, Sri Lanka, Tunisia), questions are raised as to the social and political determinants of low-carbon development, with relevance for on-going claims of a ‘climate-development conflict’. A further limitation of this study is the absence of non-CO_2 greenhouse gas emissions in country trajectories, which are known to be systematically higher in developing countries (Smith et al., 2013). This is a constraint of the cumulative emissions approach, in which short-lived greenhouse gasses cannot be easily incorporated in long-term warming estimates. Indeed there may be important trade-offs between low-emissions pathways and other types of environmental load (e.g. ecosystem degradation) whose mitigation will be critical to the long-term sustainability of human well-being.

5. Conclusions

This article assesses emissions trajectories and development outcomes in a group of 20 low to middle-income countries (Goldemberg’s Corner). It has elaborated on a definition of low-carbon development, based on a cumulative emissions framework and a human needs perspective on well-being. Given assumptions of stringent post-2020 climate policy and a maximum sustained mitigation rate of 5% per year, it finds that at least 11 countries in Goldemberg’s Corner (Albania, Armenia, Costa Rica, Ecuador, Guatemala, Honduras, Indonesia, Morocco, Sri Lanka, Tunisia, and Uruguay) have consistent trajectories that will not exceed an equal per capita allocation of the global carbon budget (or: 'low-carbon' trajectories that will not infringe more than proportionally on the shared carbon space). The remaining countries exceed this normative boundary by various degrees, or have trends that are too unstable to reliably estimate current growth. In Cambodia, Brazil, Egypt, Georgia, Peru, and Vietnam, recent trends in energy consumption and carbon intensity growth will need to be curtailed in order to avoid high-carbon development pathways, as remaining below 100GJ/capita has been shown to be pre-requisite to meeting a fair emissions budget allocation.

Considering underlying well-being outcomes, this study confirms previous work demonstrating the decoupling of human well-being from environmental impact, finding that as of 2011 high levels of human need satisfaction are present in countries with low levels of energy consumption (<50 GJ/capita) and emissions (<3.5 t CO_2/capita). That several of these high performing countries (Albania, Armenia, Costa Rica, Uruguay, Sri Lanka, and Tunisia) also have growth rates that are commensurate with a cumulative emissions definition of low-carbon development is even more impressive. These results are in stark contrast to the carbon intensive pathways followed by most nations in the global North, as well as recently emerging countries such as China, most of which would be unable to meet their emissions budgets under the same allocation scheme (Raupach et al., 2014). Nonetheless, Goldemberg's Corner is a domain of poor social need satisfaction, with unresolved issues of crime, representation and democratic accountability. And given their diversity of energy consumption and carbon intensity trends, from growth to steady-state or decline, it is questionable whether these countries are converging in emissions with the wealthy and industrialised world. If pathways of development are not converging, then Goldenberg's Corner may represent a position in the international development hierarchy, where countries are able to satisfy a basic floor of health, energy and household services, but are otherwise trapped in stagnating socio-economic conditions.

This study raises many potential areas of research. The scope of countries could be extended further, to identify good well-being and emissions performance at different levels of development. This may be complimentary to both the Sustainable Development Goals and the INDCs of the Paris Agreement – political goals that are clearly interlinked, but have yet to be investigated in a systematic way for trade-offs and synergies. To build on the examples of low-carbon development identified in this analysis, a next step is to identify their underlying systems of need provision, i.e. their social welfare regimes, physical infrastructures, and consumption of goods and services. This is a challenge for the research community, which currently lacks theoretical work linking human well-being, physical resources and energy consumption. Nonetheless, the outcomes demonstrated here – that household services and physical health can be delivered at extremely low cost to the climate –

underline the powerful role a well-being frame may have in climate policy; from demonstrating the existence of low-carbon development pathways, to highlighting the excessive levels of energy consumption in wealthy countries, far beyond what is necessary for satisfying human needs.

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References

Aboumahboub, T., Luderer, G., Calvin, K., Demaere, G., 2014. What does the 2oC target imply for a global climate agreement in 2020? The LIMITS study on Durban Platform scenarios. Clim. Chang. Econ.

Anderson, K., Bows, A., 2011. Beyond “dangerous” climate change: emission scenarios for a new world. Philos. Trans. A. Math. Phys. Eng. Sci. 369, 20–44. doi:10.1098/rsta.2010.0290

Arrighi, G., Silver, B.J., Brewer, B.D., 2003. Industrial convergence, globalization, and the persistence of the North-South divide. Stud. Comp. Int. Dev. 38, 3–31. doi:10.1007/BF02686319

Baer, P., Harte, J., Haya, B., Herzog, A. V., Holdren, J., Hultman, N.E., Kammen, D.M., Norgaard, R.B., Raymond, L., 2000. CLIMATE CHANGE: Equity and Greenhouse Gas Responsibility. Science (80-.). 289, 2287–2287. doi:10.1126/science.289.5488.2287

Chakravarty, S., Tavoni, M., 2013. Energy poverty alleviation and climate change mitigation: Is there a trade off? Energy Econ. 40, S67–S73. doi:10.1016/j.eneco.2013.09.022

Chomsky, N., 1985. Turning the Tide: US Intervention in Central America and the Struggle for Peace. South End Press, Boston.

Climate Action Tracker, 2015. Assessment of mitigation contributions to the Paris Agreement [WWW Document]. URL http://climateactiontracker.org/indcs.html (accessed 2.8.16).

Costa, L., Rybski, D., Kropp, J.P., 2011. A human development framework for CO2 reductions. PLoS One 6, e29262. doi:10.1371/journal.pone.0029262

Davis, S.J., Socolow, R.H., 2014. Commitment accounting of CO2 emissions. Environ. Res. Lett. 9, 084018. doi:10.1088/1748-9326/9/8/084018

Dietz, T., Rosa, E.A., York, R., 2009. Environmentally Efficient Well-Being : Rethinking Sustainability as the Relationship between Human Well-being and Environmental Impacts. Hum. Ecol. Rev. 16, 114–123.

Doyal, L., Gough, I., 1991. A Theory of Human Need. Macmillan, London.

FAO, 2014. Food and Agriculture Organisation of the United Nations: FAOSTAT Database [WWW Document]. URL http://faostat.fao.org/ (accessed 5.29.14).

Gough, I., 2015. Climate Change and Sustainable Welfare : An Argument for the Centrality of Human Needs. Cambridge J. Econ. 1–24. doi:10.1093/cje/bev039

Gough, I., 2014. Lists and thresholds: comparing the Doyal-Gough theory of human need with Nussbaum’s capabilities approach, in: Comim, F., Nussbaum, M.C. (Eds.), Capabilities, Gender, Equality. Cambridge University Press, Cambridge, UK, pp. 357–381.

Hanna, R., Gross, R., Speirs, J., Heptonstall, P., Gambhir, A., 2015. Innovation timelines from invention to maturity: A rapid review of the evidence on the time taken for new technologies to reach widespread commercialisation.

Hertwich, E.G., Peters, G.P., 2009. Carbon footprint of nations: a global, trade-linked analysis. Environ. Sci. Technol. 43, 6414–20.

Hornborg, a., 2009. Zero-Sum World: Challenges in Conceptualizing Environmental Load Displacement and Ecologically Unequal Exchange in the World-System. Int. J. Comp. Sociol. 50, 237–262. doi:10.1177/0020715209105141

IEA, 2014. World Energy Balances, 2013th ed. International Energy Agency, Paris.

IPCC, 2014. Climate Change 2014: Synthesis Report., in: Core Writing Team, Pachauri, R.K., Meyer, L.A. (Eds.), Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

Jakob, M., Haller, M., Marschinski, R., 2012. Will history repeat itself? Economic convergence and convergence in energy use patterns. Energy Econ. 34, 95–104. doi:10.1016/j.eneco.2011.07.008

Jorgenson, A.K., 2014. Economic development and the carbon intensity of human well-being. Nat. Clim. Chang. 4, 186–189. doi:10.1038/NCLIMATE2110

Karekezi, S., McDade, S., Boardman, B., Kimani, J., 2012. Energy, Poverty, and Development, in: Global Energy Assessment - Toward a Sustainable Future. Cambridge University Press, Cambridge, UK, pp. 151–190.

Lamb, W.F., Rao, N.D., 2015. Human development in a climate-constrained world: What the past says about the future. Glob. Environ. Chang. 33, 14–22. doi:10.1016/j.gloenvcha.2015.03.010

Lamb, W.F., Steinberger, J.K., Bows-Larkin, A., Peters, G.P., Roberts, J.T., Wood, F.R., 2014. Transitions in pathways of human development and carbon emissions. Environ. Res. Lett. 9, 1–9. doi:10.1088/1748-9326/9/1/014011

Max-neef, M., 1991. Human-Scale Development: Conception, Application and Further Reflection. Apex Press, London.

Mazur, A., Rosa, E.A., 1974. Energy and Life-Style. Science (80-.). 186, 607–610.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C.B., Frieler, K., Knutti, R., Frame, D.J., Allen, M.R., 2009. Greenhouse-gas emission targets for limiting global warming to 2 degrees C. Nature 458, 1158–62. doi:10.1038/nature08017

O'Neill, D.W., 2015. The proximity of nations to a socially sustainable steady-state economy. J. Clean. Prod. doi:10.1016/j.jclepro.2015.07.116

Pachauri, S., 2014. Household electricity access a trivial contributor to CO2 emissions growth in India. Nat. Clim. Chang. 2–5. doi:10.1038/nclimate2414

Pachauri, S., Spreng, D., 2004. Energy in and Use Relation Access Energy to Poverty. Econ. Polit. Wkly. 39, 271–278.

Pachauri, S., van Ruijven, B.J., Nagai, Y., Riahi, K., van Vuuren, D.P., Brew-Hammond, A., Nakicenovic, N., 2013. Pathways to achieve universal household access to modern energy by 2030. Environ. Res. Lett. 8, 024015. doi:10.1088/1748-9326/8/2/024015

Peters, G.P., Andrew, R.M., Solomon, S., Friedlingstein, P., 2015. Measuring a fair and ambitious climate agreement using cumulative emissions. Environ. Res. Lett. 10, 105004. doi:10.1088/1748-9326/10/10/105004

Peters, G.P., Minx, J.C., Weber, C.L., Edenhofer, O., 2011. Growth in emission transfers via international trade from 1990 to 2008. Proc. Natl. Acad. Sci. U. S. A. 108, 8903–8. doi:10.1073/pnas.1006388108

Pretty, J., 2013. The Consumption of a Finite Planet : Well-Being , Convergence , Divergence and the Nascent Green Economy. Environ. Resour. Econ. 55, 475–499. doi:10.1007/s10640-013-9680-9

Rao, N.D., Baer, P., 2012. "Decent Living" Emissions: A Conceptual Framework. Sustainability 4, 656–681. doi:10.3390/su4040656

Rao, N.D., Riahi, K., Grubler, A., 2014. Climate impacts of poverty eradication. Nat. Clim. Chang. 4, 749–751. doi:10.1038/nclimate2340

Raupach, M.R., Davis, S.J., Peters, G.P., Andrew, R.M., Canadell, J.G., Ciais, P., Friedlingstein, P., Jotzo, F., van Vuuren, D.P., Le Quéré, C., 2014. Sharing a quota on cumulative carbon emissions. Nat. Clim. Chang. 873–879. doi:10.1038/nclimate2384

Reinert, K.A., 2009. No Small Hope: The Basic Goods Imperative. Rev. Soc. Econ. 69, 55–76. doi:10.1080/00346760802714875

Riahi, K., Dentener, F., Gielen, D., Grubler, A., Jewell, J., Klimont, Z., Krey, V., Mccollum, D., Pachauri, S., Rao, S., van Ruijven, B.J., van Vuuren, D.P., Wilson, C., 2012. Energy Pathways for Sustainable Development, in: Global Energy Assessment - Toward a Sustainable Future. Cambridge University Press, Cambridge, UK, pp. 1203–1306.

Roberts, J.T., Parks, B.C., 2009. Ecologically Unequal Exchange, Ecological Debt, and Climate Justice: The History and Implications of Three Related Ideas for a New Social Movement. Int. J. Comp. Sociol. 50, 385–409. doi:10.1177/0020715209105147

Sandbrook, R., Edelman, M., Heller, P., Teichman, J., 2007. Social Democracy in the Global Periphery: Origins, Challenges, Prospects. Cambridge University Press, Cambridge, UK.

Sen, A., 1990. Development as Capability Expansion, in: Griffin, K., Knight, J. (Eds.), Human Development and the International Development Strategy for the 1990s. Macmillan, London, pp. 41–58.

Smith, K.R., Desai, M. a, Rogers, J. V, Houghton, R.A., 2013. Joint CO2 and CH4 accountability for global warming. Proc. Natl. Acad. Sci. U. S. A. 110, E2865–74. doi:10.1073/pnas.1308004110

Sorrell, S., 2015. Reducing energy demand: A review of issues, challenges and approaches. Renew. Sustain. Energy Rev. 47, 74–82. doi:10.1016/j.rser.2015.03.002

Steckel, J.C., Edenhofer, O., Jakob, M., 2015. Drivers for the renaissance of coal. Proc. Natl. Acad. Sci. E3775–E3781. doi:10.1073/pnas.1422722112

Steinberger, J.K., Roberts, J.T., 2010. From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005. Ecol. Econ. 70, 425–433. doi:10.1016/j.ecolecon.2010.09.014

Steinberger, J.K., Timmons Roberts, J., Peters, G.P., Baiocchi, G., 2012. Pathways of human development and carbon emissions embodied in trade. Nat. Clim. Chang. 2, 81–85. doi:10.1038/NCLIMATE1371

Stern, N., 2007. The Economics of Climate Change: The Stern Review. Cambridge University Press, Cambridge.

Stiglitz, J.E., Sen, A., Fitoussi, J.-P., 2009. Report by the Commission on the Measurement of Economic Performance and Social Progress. Commission on the Measurement of Economic Performance and Social Progress, Paris. doi:10.2139/ssrn.1714428

Teixidó-Figueras, J., Steinberger, J.K., Krausmann, F., Haberl, H., Wiedmann, T., Peters, G.P., Duro, J.A., Kastner, T., 2016. International inequality of environmental pressures: Decomposition and comparative analysis. Ecol. Indic. 62, 163–173. doi:10.1016/j.ecolind.2015.11.041

UN, 2015. World Population Prospects: The 2015 Revision. United Nations Department of Economic and Social Affairs Population Division.

UNFCCC, 2015. Adoption of the Paris Agreement. Geneva (Switzerland).

United Nations General Assembly, 2015. Transforming our world: the 2030 Agenda for Sustainable Development. New York, USA.

Unruh, G.C., Carrillo-Hermosilla, J., 2006. Globalizing carbon lock-in. Energy Policy 34, 1185–1197. doi:10.1016/j.enpol.2004.10.013

Wilkinson, P., Smith, K.R., Joffe, M., Haines, A., 2007. A global perspective on energy: health effects and injustices. Lancet 370, 965–978. doi:10.1016/S0140-6736(07)61252-5

World Bank, 2015. World Bank Development Indicators [WWW Document]. URL http://data.worldbank.org/ (accessed 5.2.15).

- 20 middle income countries are assessed on development performance and emissions
- 8 are found to have low-carbon trajectories but high human need satisfaction
- Climate-development policy can learn from efficient historical pathways
- Climate policy following 2020 is required to avoid locking-in high carbon pathways