Energy for Sustainable Development 26 (2015) 72–78

Contents lists available at ScienceDirect

Energy for Sustainable Development

Equity and energy in global solutions to climate change

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ARTICLE INFO

Article history:
Received 19 June 2014
Revised 13 March 2015
Accepted 13 March 2015
Available online xxxx

Keywords:
Climate change
Emission allocation
Equity
Representative concentration pathway RCP2.6

ABSTRACT

This paper explores the prospect for achieving an equitable allocation of country-specific carbon dioxide emissions from the energy sector within the framework of the Cancun climate stability target, as represented by Representative Concentration Pathway 2.6. Three allocation principles are considered, with the primary one (Egalitarian) based on equal per capita emissions for all countries by 2050. The two secondary allocation principles, termed Emission-based and GDP-based, distribute allowable emissions according to cumulative historical emissions and cumulative historical GDP respectively. Neither of these two allocation principles can deliver equal per capita emissions by 2050. Only when a global average constraint factor is introduced, designed to enable countries with less than allowed global average per capita emissions in any year to increase their emissions to this level, can emissions parity (the Egalitarian principle) be achieved by 2050. Finally, it is argued that achieving the widespread agreement needed to achieve climate stability is likely to be difficult, given both the size of reductions needed, especially by high-emission countries, and the inadequacies of the technical fixes proposed.

Introduction

Since the Conference of Parties of the United Nations Framework for Climate Change (COP UNFCCC, 2010) (the Cancun agreement), consensus toward climate change has been to stabilize atmospheric GHG concentrations to limit the average temperature rise to below 2 °C. Emission scenarios, or more recently, Representative Concentration Pathways (RCPs), have been frequently used to explore the possibility of achieving such targets (van Vuuren et al., 2011a, 2011b; Organization for Economic Cooperation and Development (OECD), 2012; Intergovernmental Panel on Climate Change (IPCC), 2013, 2014). According to the IPCC, the various RCPs 'are identified by their approximate total radiative forcing in year 2100 relative to 1750: 2.6 W/m^2 for RCP2.6, 4.5 W/m^2 for RCP4.5, 6.0 W/m^2 for RCP6.0, and 8.5 W/m^2 for RCP8.5.' The IPCC decided that these four scenarios 'would not be developed as part of the IPCC process, leaving new development to the research community' (Van Vuuren et al, 2011b). Of special interest here is RCP2.6, which aims to achieve climate stability by 2100.

Van Vuuren et al. (2011a) explored the technical feasibility of achieving the reductions in greenhouse gas (GHG) emissions needed to meet RCP2.6. They found that RCP2.6 could be met by reducing GHG emissions, such as CO_2 from global fossil fuel combustion, by using a combination of increased technical efficiency, wider use of renewable and nuclear power, the use of fossil fuel carbon capture and storage (CCS) and, to obtain negative carbon emissions, large scale use of bioenergy CCS (BECCS). In doing so, they assumed that rapid deployment of new technologies is both possible and necessary. Importantly, non-technical measures based on behavioural change (e.g., demand reduction (Moriarty and Honnery, 2010)) were not considered. Interestingly, van Vuuren et al. (2011b) assumed that for RCP2.6, the world GDP growth rate will be even faster than for the three other RCPs, despite greater emission reductions. Further, the authors concluded that reducing emissions to limit warming to less than 2 °C cannot be achieved without broadening the participation of countries in mitigation actions; the reductions needed cannot be allocated to high emitters alone.

One of the recommendations for further research was to identify national emission pathways that may be acceptable to all parties involved in climate negotiations. Van Vuuren et al. (2011a) detail a purely technical route to achieving RCP2.6, but non-technical factors will also be important (Morgan and Waskow, 2014). For example, the level of economic development of a country could severely limit its capacity to transition to a low carbon energy economy, particularly if it has access to a cheap supply of coal and limited access to renewable energy. Further, the cost of shifting from a fossil fuel based energy sector in countries with significantly lower standards of health and education could place an unacceptable burden on their capacity to lift these standards, and limited access to renewable energy resources could exacerbate this burden.

An important aspect of acceptability is the perceived fairness of any GHG allocation. The need for fairness in outcome, and the recognition of

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http://dx.doi.org/10.1016/j.esd.2015.03.001
0973-0826/

differences among countries are recognised in the UNFCCC principle of common but differentiated responsibilities (Winkler and Rajamani, 2014). It has been argued that each country having equal GHG emissions per capita provides the fairest distribution of emissions (Höhne et al, 2014; Kitzes et al, 2008; Singer, 2006). This approach, which stresses the equality of the rights of individuals, is often termed egalitarian (Cazorla and Toman, 2001). However, given the large disparity in present country level per capita emissions, achieving such a result within the constraints of RCP2.6 is likely to take time, suggesting the need for a methodology to allocate emissions until equal per capita emissions can be achieved. Also known as effort-sharing (Höhne et al, 2014), a number of approaches, based on different principles, could be used to arrive at equal future per capita emissions (e.g., Cazorla and Toman, 2001; Singer, 2006; Pierrehumbert, 2013; Zhang and Shi, 2014). For example, allocation of future GHG emissions could be based on the country's contribution to global emissions, or on a country's economic capacity to reduce GHG emissions. These are shown in Table 1 as secondary allocation principles, with equality in emissions being the primary aim. Note that the secondary allocation principles can be applied independently of the primary principle. In this paper the secondary principles are first applied in turn, then each is applied together with a constraint designed to achieve equality in emissions.

Besides those listed above, additional factors often cited as being important to the development of equitable allocations of future GHG emissions are: a country's historical contribution to the problem, inequities in burdens from the impacts of climate change, and intergenerational equity (Giddings et. al., 2002; Sovacool, 2013; Thomas and Twyman, 2005).

Since carbon dioxide remains in the atmosphere for a long time (Archer, 2005; Hansen et al., 2008), historical emissions, expressed as past cumulative emissions, are often cited as being an important factor in assigning equitable emission allocations (COP UNFCCC, 1992; Miguez and Oliveira, 2011). To illustrate the importance of historical emissions, many OECD countries now have stagnant or even falling energy-based CO_2 emissions (and also primary energy use). In contrast, such emissions are rising strongly in many industrialising countries (BP, 2014). An important reason for this contrast is that the OECD countries have already built their energy-intensive infrastructure, whereas newly industrialising countries have not. Their infrastructure catch-up explains why China and India together produce and use most of the world's cement, and why China dominates world steel production (Moriarty and Honnery, 2014). Exner et al. (2014) have taken this argument even further, and advocated equal per capita *stocks* of geologically scarce metals such as copper.

Similarly, since most countries' pursuit of economic growth has usually led to increased emissions (Moriarty and Honnery, 2009, 2011), and because it provides an indication of capacity to respond technologically, past cumulative GDP could also be used to guide any future emission allocation. Gross GDP may provide a better indication of response capacity than does average GDP/capita for a given country, for at least two reasons. First, many low carbon technologies are likely to benefit from economies of scale (e.g., for CCS, BECSS, and nuclear power plants, unit costs reduce with plant size), and so are only available to large economies. Second, large economies such as India and China, even with low per capita incomes compared with OECD countries, have the capacity to develop a range of the innovative technologies that may be needed. Nor are gross GDP and average GDP per capita the only options. Chakravarty et al. (2009) have advocated an allocation system for CO_2 reductions ultimately based on the income of *individuals*, regardless of where they live, rather than on the income of nations. All high-emitting individuals in the world would be subject to a 'universal cap on global individual emissions'.

The time scales for past and future emissions are very different. While the benefits accruing from past emissions for mature industrial countries have occurred over a century or more (e.g., benefits from transport, energy, and buildings infrastructure), industrialising countries will now be required to reduce their emissions and transition to low carbon emitting technologies within decades.

Consideration must also be given to the unequal burdens on countries from the *impacts* of climate change (Morgan and Waskow, 2014). Numerous studies indicate that the least developed countries will suffer the most from climate change effects (Anand, 2004; IPCC, 2013; Mitchell et al., 2006; Sovacool, 2013), yet their contributions to global cumulative emissions have been minimal (BP, 2014). Intergenerational equity is also important. Failure to reduce future emissions could lead to global temperature rises as high as 4 °C by 2100 (IPCC, 2013; New et al., 2011), with the result that future generations are likely to experience severe climatic effects for actions not attributed to them. Furthermore, adaptation costs are likely to increase the longer we delay mitigatory action. But at the same time, it is also necessary to consider impacts on the present generation; mitigation requirements cannot be so stringent as to severely compromise well-being in the short-term (Giddings et al., 2002).

An important additional component to achieving equity in future allocations arises from the link between energy and emissions. As will be discussed later in this paper, provided energy use does not reduce in step with emission decreases, global emissions will become decoupled from total primary energy use. Equity in emissions is not therefore the same as equity in energy consumption; the attainment of an equitable emissions allocation must not come at the cost of reduced access to energy, particularly for those living in a state of energy poverty (Sovacool, 2012). Indeed, Bazilian et al. (2010) have argued that energy policy should drive climate change policy rather than the reverse.

In this paper we make use of the two secondary allocation principles shown in Table 1 to explore how a global emission pathway represented by RCP2.6 could be achieved with the additional constraint of arriving at equal annual per capita emissions by 2050. We first present individual mathematical representations of the two secondary allocation principles, Emission-based and GDP-based, each of which includes the role of historical responsibility. This is followed by a discussion of how these perform within the framework of the Human Development Index (HDI) by classifying all countries into one of three groups: High, Medium, and Low HDI. We then investigate the performance of a modification to these allocation principles, termed the global average constraint, which preferences emission allocations to countries with low per capita emissions. We conclude by discussing how failure to address equity in access to energy in our attempt to deliver a more stable climate could act to stall efforts to reach a global consensus on emission reductions.

Table 1
Emissions allocation principles and descriptions.
Source: Cazorla and Toman (2001).

Principle	Description
Primary: *Egalitarian*	People have equal rights to use atmospheric resources (i.e. equal per capita emissions).
Secondary: *Emission-based allocation*	Future emissions are allocated based on a county's net cumulative emissions as a fraction of global cumulative emissions.
GDP-based allocation	Future emissions are allocated based on a county's cumulative GDP as a fraction of global cumulative GDP.

Emission allocation methodology

As noted, the van Vuuren et al. (2011a) version of RCP2.6 provides an implementation pathway using a range of technologies to limit climate change to less than 2 °C. The allowable annual emissions under this and the other three pathways for the energy sector for the period up to 2050 are shown in Fig. 1. The business-as usual energy sector emission path, as given in the *OECD Environmental Outlook to 2050* (OECD, 2012), falls between the RCP6.0 and RCP8.5 curves in Fig. 1. The RCP2.6 limit effectively allows no more than about 800 Gt CO_2 to

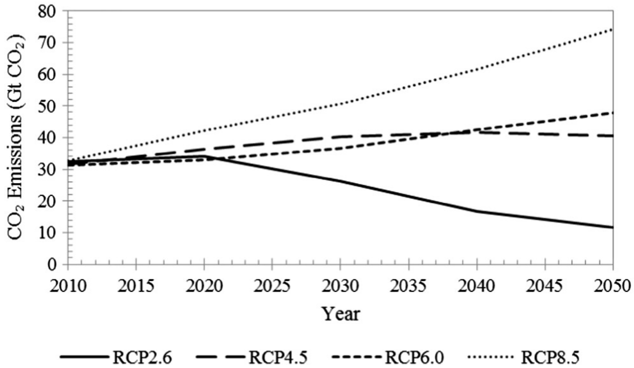

Fig. 1. Global CO_2 emissions from fossil fuel energy for all RCPs for the years 2010 to 2050. *Source*: van Vuuren et al. (2011a).

be emitted globally between 2015 and 2050. Note that the strong egalitarian aim of equal *cumulative* per capita emissions for all by 2050 is no longer a realistic option; OECD country energy-related CO_2 emissions from 1970 to 2014 totalled nearly 600 Gt. Even if OECD emissions from 2015–2050 were zero, the 800 Gt remaining global quota would not be sufficient to give all countries equal per capita cumulative emissions. Equal *annual* emissions per capita is the best that can be hoped for.

We focus here on the energy sector, and its CO_2 emissions, as it not only accounts for most emissions, but also those for which mitigation technologies are most directly applied, viz. production of electricity. Fossil fuel usage data are also fairly accurate, compared with, for example, emissions from land use changes.

Allocation of future emissions to each country is done such that the sum total of each country's emissions equals the global total allowable under RCP2.6, G_t, in any given year. This can be expressed by,

$$G_t = \sum_{i=1}^{n} E_{i,t},$$

where $E_{i,t}$ is the allowable emissions ($MtCO_2$) from country i in year t. The change in global emissions required by RCP2.6 from year to year is given by,

$$\Delta G_t = G_{t-1} - G_t = \sum_{i=1}^{n} E_{i,t-1} - \sum_{i=1}^{n} E_{i,t}.$$

From this, the allowable emissions for an individual country can be written as,

$$E_{i,t} = E_{i,t-1} - D_{i,t}\ \Delta G_t,$$

where $D_{i,t}$ is an emission distribution term equal to the fraction of the global change in emissions required by an individual country. We express this equation by writing this as,

$$E_{i,t} = [1-k]E_{i,t-1} \quad (1)$$

where $k = D_{i,t}\Delta G_t / E_{i,t-1}$. Annual global emissions are calculated by summing each country's allowable emissions in Eq. (1) over n number of countries.

Within the global constraint imposed by RCP2.6, allowable emissions will depend on the allocation principles. The allocation principles are accounted for by making the distribution term $D_{i,t}$ a function of the underlying concepts of the secondary allocation principles,

$$\text{Emissions-based:}\ D_{i,t} = \frac{\sum_{t_o}^{t-1} E_{i,t}}{\sum_i^n \left(\sum_{t_o}^{t-1} E_{i,t}\right)}$$

$$\text{GDP-based:}\ D_{i,t} = \frac{\sum_{t_o}^{t-1} GDP_{i,t}}{\sum_i^n \left(\sum_{t_o}^{t-1} GDP_{i,t}\right)}$$

For Emission-based, a country's allowable emissions depend on its cumulative CO_2 emissions relative to the world total. The higher this fraction, the greater is the change in allowable annual emissions required from year to year. As noted, this is based on the notion that those countries which have emitted the most must bear the responsibility to reduce the most. For GDP-based, a country's allowable emissions depend on its cumulative GDP relative to the world cumulative total. This approach embodies the principle that as wealth is a primary indicator of the ability to reduce emissions (e.g., by transitioning to low-carbon energy); it should be used to determine responsibility.

Both methods require a starting date at which allocation is commenced, and importantly, this date also plays a role in calculating the value of the distribution term, since historical data are used to determine the value of $D_{i,t}$. We set the starting date as $t_o = 1970$; historical emissions are taken to be from 1970 onwards. Although this year was selected primarily because of data consistency, it is worth noting that around 70% of the global emissions from the burning of fossil fuels have occurred since 1970 (Boden et al., 2010).

The primary database used for the emission distribution model is the IEA CO_2 emissions from fuel combustion (IEA, 2012). Baseline GDP and population data are taken from the International Futures forecasting system (University of Denver, 2013), while the anticipated changes in GDP per unit change in CO_2 emissions were taken from the *OECD Environmental Outlook to 2050* (OECD, 2012). For example, this approach is used to approximate losses in GDP resulting from moving from fossil fuels to low-carbon energy. (These assumed losses contrast with the *gains* in GDP growth assumed by van Vuuren et al (2011b) in moving to a low carbon economy, discussed earlier.) The model can then map the evolution of GDP relative to CO_2 emission reductions. The evolution of GDP in turn influences the value for the GDP-based distribution term, $D_{i,t}$.

Calculated data is presented for three discrete groups of countries based on different levels of the HDI. The HDI levels were adopted directly from the UN Human Development indicator data (UN, 2012; UNDP, 2013). The HDI measures three normalised indices, based on life expectancy at birth, number of years of formal schooling, and Gross National Income per capita. The HDI is the geometric mean of these three normalised indices (UNDP, 2015). In accordance with this data, HDI values ≥ 0.8 represent countries classified as highly developed (High); HDI values ≤ 0.53 represent countries classified as least developed (Low); and HDI values within the range $0.8 > x > 0.53$ represent countries classified as developing (Medium). The characteristics of each of the representative groups for 2010 based on averages across the total populations in each HDI group, along with the global averages where relevant, are shown in Table 2. What is immediately evident from this

Table 2
Characteristic population weighted data of the three representative HDI groups for the year 2010.
Sources: IEA, 2012; UN, 2012; UNDP, 2013.

	Global average	High	Medium	Low
HDI	0.67	0.87	0.69	0.43
Population share (%)		17.0	67.7	15.3
Primary energy share (%)		43.2	52.4	4.3
CO_2 emissions share (%)		42.2	56.3	1.5
CO_2 (tonne/capita)	4.58	11.5	3.72	0.40
GDP (PPP 2005) (%)		53.5	42.3	4.2
GDP ($1000 PPP (2005)/capita)	10.2	32.55	6.31	2.46
Primary energy (GJ/capita)	75.4	192	58.3	21.2
Electricity generation (MWh/capita)	3.19	9.56	2.25	0.27
GDP/Electricity generated ($ PPP 2005)/kWh)	3.19	3.34	2.80	9.11
GDP/CO_2 ($1000 PPP 2005/tonne CO_2)	2.22	2.83	1.70	6.15

data is the considerable disparity between the three groups in the important areas of emissions and GDP. Also, the Medium HDI group, which includes both China and India, contains over two-thirds of the global population.

Allocations by emission principle

Fig. 2 shows allowable emissions per capita for the three HDI groups up to 2050 as well as the global average, based on achieving RCP2.6 annual global emission limits through use of the secondary allocation principles only. The year 2050 is chosen for examination because response within the time leading up to 2050 is crucial if we are to meet the low emission target represented by RCP2.6, and also because it allows sufficient time to examine the effect of implementing the allocation principle. Globally, emissions per capita under RCP2.6 drop from 4.58 tCO_2 in 2010 to 1.37 tCO_2 by 2050.

What is evident from the data in Fig. 2 is that, while emissions have decreased for all three HDI groups for both secondary allocation principles, significant disparity remains in per capita emissions by 2050 between the three groups; that is, neither of these two emission allocation principles alone is able to arrive at equal emissions per capita by 2050. For the High HDI group, high historical responsibility greatly reduces emission allocations for both cases. The high historical GDP for this group of countries reduces per capita allocation almost to zero for the GDP-based allocation principle. The emission reductions needed are for both cases even greater than if annual rather than cumulative emissions were used as the basis for allocation (Ekanayake, 2014).

For the Medium HDI countries under the Emission-based allocation principle, allowable emissions remain at or near the global average, while for the GDP-based allocation principle allowable emissions diverge from the global average after 2030. This divergence is caused by a reduction in the distribution term, since their historical GDP is considerably lower than for High HDI countries.

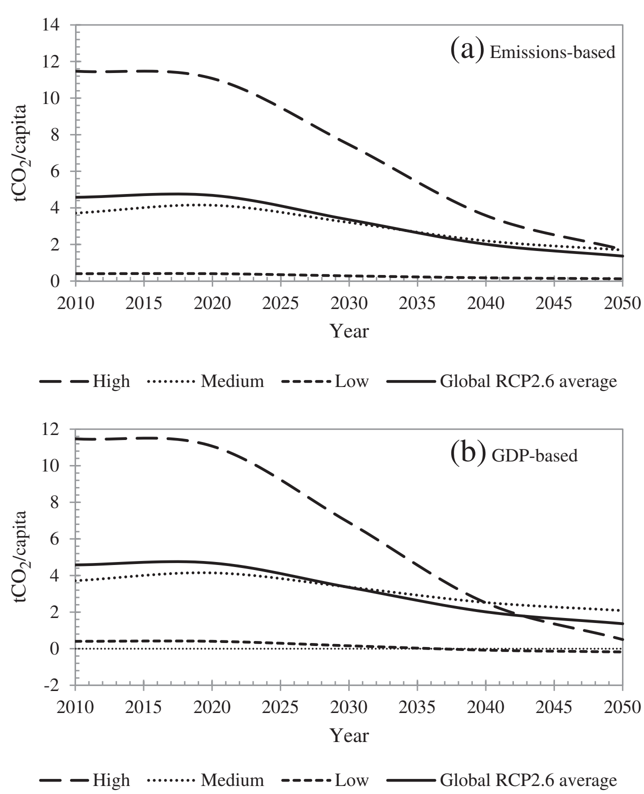

Fig. 2. (a) Allowable emissions for the three HDI groups for the Emission-based allocation principle, Eq. (2). (b) Allowable emissions for the three HDI groups for the GDP-based allocation principle Eq. (2).

For the Low HDI countries, using the Emission-based allocation principle requires these countries to decrease their already-low emissions from 0.40 tCO_2/capita in 2010 to 0.13 tCO_2/capita by 2050. For GDP-based allocation, the Low HDI countries are required to decrease emissions still further and even go negative by 2035. Their emission reduction efforts would have to be greater than for the other two HDI groups. Negative emissions in Low HDI countries would require that traditional use of bioenergy for cooking and heating competes with bioenergy used for electricity production in BECCS systems.

In addition to these observations, the effect of total population size differences between the three groups is evidenced by the relative changes between the three groups. Small emission increases in the highly populated Medium HDI group are at the expense of significant reductions in per capita emissions from the less-populated High HDI group. The Low HDI group is the least affected.

The effect of these two allocation methodologies on individual countries is shown in Fig. 3. The figure presents the change in emissions from 2010 to 2050 with countries grouped in the three HDI categories; emissions are shown as per capita emissions relative to the global average. Increased equity in per capita emissions among countries would be indicated by a shift toward a uniform value of 1.0 by 2050. This shift is not exhibited in Fig. 3; significant disparity remains globally among countries and also among countries within each HDI group. The improved equity for the Medium and High HDI group of countries found for the Emission-based allocation principle (Fig. 2a) is shown in Fig. 3 to occur though a balance of gains and losses among individual countries, rather than being the result of a uniform reduction. To better examine this, the root mean square of the population weighted relative per capita emissions can be used as a measure of the disparity among individuals globally and in each HDI country group, Table 3; the higher this value, the greater the disparity. From this measure, rather than reducing disparity, global emissions disparity increases over the period 2010–2050 for the two allocation principles. Among the HDI country groups, disparity among the Medium HDI countries is seen to increase considerably. Thus, while reductions in emissions occur sufficient to match the constraints of RCP2.6, the disparity between nations in per capita CO_2 emissions increases.

Under the two secondary allocation principles illustrated in Fig. 2, per capita emissions for the Low HDI countries still remain well below the global average by 2050—in fact, close to zero for many countries, Fig. 3. To remedy this difference, we modify the distribution to enable individual countries with below average per capita energy emissions to increase their emissions up to a specific allocation. We term this the *global average constraint*. Eq. (1) then becomes,

$$E_{i,t} = [1-k_e]E_{i,t-1}. \quad (3)$$

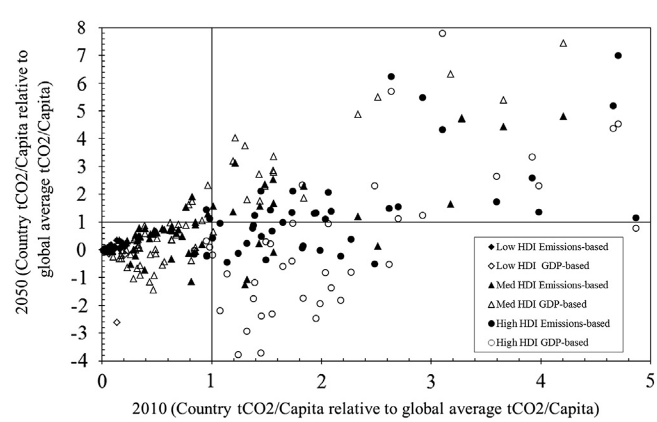

Fig. 3. 2010 Country per capita tCO_2 emissions relative to the global average against 2050 relative missions for Emission- and GDP- based allocation principles for the three HDI country groups.

Table 3
Root mean square of population weighted country tCO_2/capita relative to global average tCO_2/capita for 2010 and 2050 for the two secondary allocation principles, and repeated for 2050 with the global mean average constraint.

	Low HDI	Medium HDI	High HDI	Global
2010	0.99	0.28	2.58	1.02
2050 Emissions	0.99	1.45	1.61	1.21
2050 GDP	0.89	2.20	2.28	1.90
With global average constraint				
2050 Emissions	0.61	0.51	1.01	0.63
2050 GDP	0.37	0.42	0.25	0.37

The new variable k_e is defined such that it may either reduce CO_2 emissions (i.e. similar to the previous models), or increase them, depending on the key constraint: annual per capita CO_2 emissions. If per capita emissions of a given country are greater than or equal to global RCP2.6 average per capita emissions in year t_{i-1}, $k_e = k$, otherwise k_e takes the form:

$$k_e = -\left(D^e_{i,t} C_t / E_{i,t-1}\right).$$

C_t is the total quantity of CO_2 needed to ensure no country's per capita emissions fall below a minimum per capita value. For this case, $D^e_{i,t}$ is used to distribute C_t evenly across the countries with below average per capita emissions, consequently allowing per capita emissions to converge on the global RCP2.6 average. $D^e_{i,t}$ takes the form:

$$D^e_{i,t} = \frac{P_{i,t}}{\sum_i^{n_e} P_{i,t}},$$

where $D^e_{i,t}$ is equal to the population of country i at year t, relative to the total population of all countries n_e that qualify for the increase in emissions. For all three HDI groups to reach the same global per capita emissions by 2050, the minimum per capita value used is varied depending on the allocation principle, but typically ranges between 0.5 and 2.0 tCO_2/capita over the period 2020 to 2050.

In calculating the GDP-based principle for this case, the model assumes that unit GDP increases are proportional to the 2010 world averaged ratio of GDP to CO_2 emissions from fossil fuel use. We assume that increasing allowable emissions either increases fossil fuel use proportional to the aforementioned ratio (hence increasing GDP through better energy access) or increases GDP due to a form of carbon trading, as discussed in the next section.

From Fig. 4, it can be seen that introduction of the global average constraint has achieved the target of having equal average per capita emissions by 2050, but with significant penalty to the High HDI countries. In order to enable the Low HDI countries to increase their emissions from non-CCS fossil fuels, the High HDI countries must severely limit use of the same energy source after 2030, particularly for the GDP-based, which shows emissions from High HDI countries needing to go negative (e.g., dominant use of BECCS) to accommodate emissions from the Low HDI countries reaching equity with the global average. For the Emission-based distribution, the High HDI countries must continue to limit use of non-CCS fossil fuels to well below those of the other two groups after 2035, although there is a capacity for a modest per capita increase in emissions as the other two groups converge on the global average. Looking once again at the results for individual countries, Fig. 5, the impact of the global average constraint is directly apparent; there is a significant shift toward a relative emission value of 1.0 by 2050. From Table 3, globally, the disparity in emissions among individual nations has decreased significantly, particularly for the GDP-based allocation. For the HDI country groups, disparity has fallen for the Low and High HDI groups, but increased for the Medium group for both allocation principles. Thus, use of the average global constraint has reduced the emission disparity among individual countries at a global level, but at the cost of increased emission disparity for the Medium HDI countries. Further, while global emissions disparity is lowest for the GDP-based allocation, the reductions required by the High HDI countries in the decade before 2050 are much greater than required for the Emission-based allocation. The severity of the reductions required by the High HDI countries for the GDP-based allocation principle could be interpreted as having the potential to compromise the well-being of that group in that decade (Giddings et al., 2002).

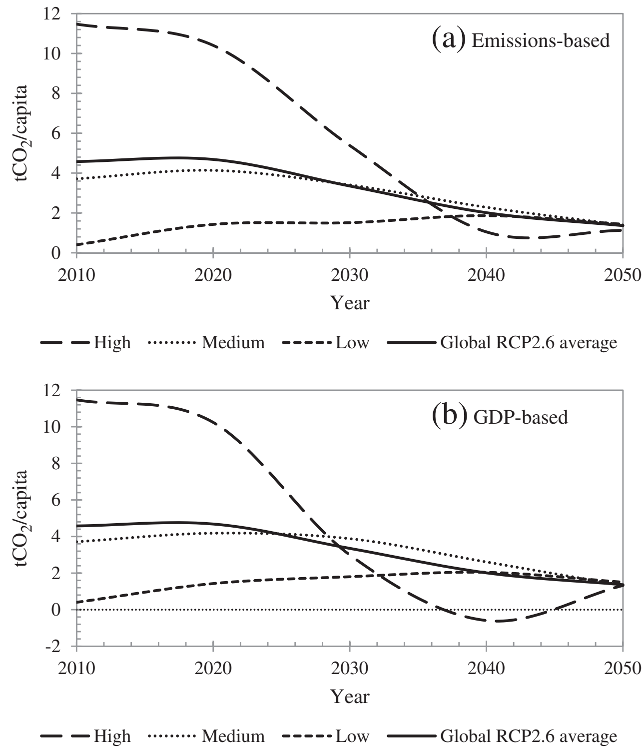

Fig. 4. (a) Allowable emissions for the three HDI groups for the global average constraint adjusted Emission-based distribution, Eq. (3). (b) Allowable emissions for the three HDI groups for the global average constraint adjusted GDP-based distribution, Eq. (3).

Discussion

In addition to recognising the need for some groups to do more than others in achieving an equitable solution to climate change is the need to recognise that equity in emissions does not necessarily give equity

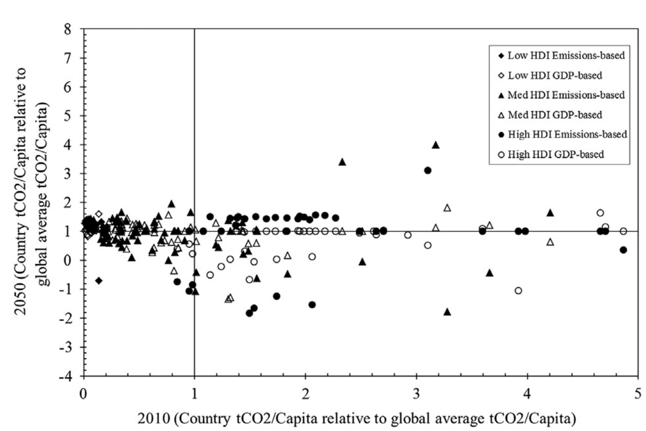

Fig. 5. 2010 Country per capita tCO_2 emissions relative to the global average against 2050 relative missions for Emission- and GDP-based allocation principles the three HDI country groups adjusted by the global average constraint.

in access to energy. Just as failure to reduce disparity in individual CO_2 emissions could limit willingness to be involved in any global emission reduction agreement, so too could failure to address equity in access to energy.

One consequence of reducing GHG emissions while increasing total energy supply is that the link between GHG emissions and energy access becomes weaker; CO_2 emission intensity will decline as shown in Fig. 6. This occurs because future GHG emissions, rather than being a measure of almost all energy consumption (fossil fuels currently provide more than 80% of primary energy), will provide a measure of energy consumption from non-CCS fossil fuels only. Such fuels are projected to supply 35% of energy in 2050, falling to about 13% by 2100 in the van Vuuren et al. (2011a) analysis. Should per capita emissions equalise at the required global average by 2050, use of fossil fuels without CCS would be equivalent to only about 30 GJ/capita for all three HDI groups (assuming equal access to the year 2050 fossil fuel mix). This value is less than 40% of the expected average of ~80 GJ/capita primary energy supplied by 2050; present global average primary energy supply is about 75 GJ/capita. In High HDI countries it averages around 192 GJ/capita, and for Low HDI, 21 GJ/capita (Table 2). Without policy mechanisms to redress the imbalance in access to energy that currently exists between the High and Low HDI countries, many Low HDI countries may question the value of participating in any global emissions agreement.

An additional consideration comes from the possible inclusion of emission pricing mechanisms to drive GHG reductions to RCP2.6 levels; prices as high as 160 USD/tonne CO_2 by 2050 have been argued as being necessary (van Vuuren et al., 2011a). If per capita energy sector emissions of Low HDI countries were to reach the RCP2.6 global average by 2050, their total CO_2 emissions would have to increase on average more than seven-fold from their present value of 0.4 Gt. This represents such a large emission growth rate that low HDI countries may well have unused quota. One possibility would be for them to sell their unused emission quotas in any year to other countries, assuming that carbon markets are in place in these countries. Selling this unused quota may well provide more economic benefits than using their full quota. Given the differences in per capita GDP shown in Table 2, without this mechanism or some other form of alleviation, many Low HDI countries would likely have little reason to join global programs to reduce emissions.

Reaching a global emission agreement will also need consideration of the difficulty in achieving a target as ambitious as RCP2.6. As noted, the van Vuuren et al. (2011a) model achieves the RCP2.6 reductions in GHG emissions using a combination of fossil fuel with CCS and BECCS, wider use of renewable and nuclear power, and decreased energy (and carbon) intensity. Given the substantial shift toward low-carbon energy required, the importance of fossil fuel with CCS in achieving emission reductions consistent with the RCP2.6 scenario becomes obvious, especially for High and Medium HDI countries. In their model, by 2050 just over 30% of global primary energy is assumed to be supplied by either fossil fuels with CCS, or BECCS. Large scale implementation of fossil fuel with CCS would accelerate reserve depletion, because of its lower efficiency. There is also the prospect of greater uptake of lower quality fossil fuels, with their higher extraction and processing costs (Boßmann et al., 2012; IPCC, 2014; Moriarty and Honnery, 2011).

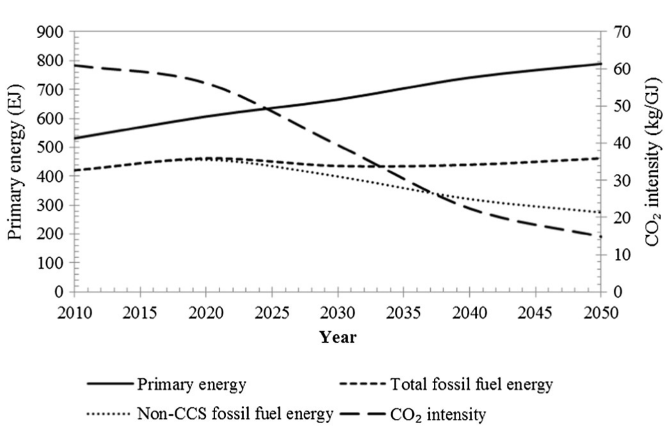

Fig. 6. Assumed total primary energy consumption (RCP2.6) and CO_2 emission intensity up to 2050. Also shown are the contributions from non-CCS fossil fuel and total fossil fuel energy. *Source*: van Vuuren et al. (2011a).

Failure of CCS to provide significant emission reductions will place considerable pressure on remaining low-carbon technologies, particularly renewable and nuclear energy resources, to make up the difference. But these may also provide less carbon-free energy than desired. Renewable energy faces many environmental problems, particularly as annual output increases (Moriarty and Honnery, 2012). Nor can it be assumed that energy returns will increase with improving technology, as greater uptake of renewable energy will require accessing sites with progressively lower quality resources or higher environmental impact, particularly for wind (Honnery and Moriarty, 2009).

Van Vuuren et al. (2011a) project nuclear energy output to approximately double by 2050 and increase around 6-fold by 2100 with high growth rates forecast for many Medium HDI countries. Yet nuclear's share of world electricity output has been declining for two decades (BP, 2014). Schneider and Froggatt (2012) have stressed that the aging reactor fleet means that much new construction will be needed merely to replace retiring reactors, without expanding capacity. Further, Dittmar (2013) has argued that future uranium supplies cannot support for long even a modest rise in nuclear output.

There have been energy efficiency gains in recent decades, but they have not stemmed the steady rise in global energy use or energy CO_2 emissions (BP, 2014). Overall, then, the prospect for technical fixes to effect deep reductions in CO_2 emissions seems poor. This is important, since if CO_2 reductions were readily made and were relatively inexpensive, the challenges facing the achievement of RCP2.6 would largely disappear. Instead, such technical solutions will need to be supplemented by energy and CO_2 reductions driven by lifestyle changes, particularly in the High HDI countries. Should such changes prove necessary, they will compound the difficulties in achieving the RCP2.6 target that present inequality in energy access and use brings.

An important remaining question is whether some countries can legitimately claim exemption from emission equality. Many countries can offer plausible reasons for exemption. They can argue that they have cold climates, with high demands for heating energy, or alternatively, they have hot climates, and so need more energy for air-conditioning. Or, their culture demands high energy use, and so on.

A more compelling reason has to do with *net* national emissions, taking into account imports and exports. Davis and Caldeira (2010) have looked at global CO_2 emissions from a 'consumption-based accounting' viewpoint. They reported that 'In some wealthy countries, including Switzerland, Sweden, Austria, the United Kingdom, and France, >30% of consumption-based emissions were imported, with net imports to many Europeans of >4 tons CO_2 per person in 2004.' (Note that 4 tonne/capita is almost three times higher than the RCP2.6 allowable global average in 2050.) These imports of CO_2 were mainly balanced by corresponding exports from Asian countries, particularly energy (and CO_2-) intensive manufactures from China. No similar data is available for other years, so the present analysis could not be done with net national emissions. Clearly though, equity in *net* emissions by 2050 would be a fairer allocation solution.

Conclusions

Limiting the global average temperature increase to less than 2 °C will require large reductions in GHG emissions, as shown by future emission scenarios such as RCP2.6. As well as having the resources and technology needed to achieve this target, countries must agree to participate in achieving the target. Greatest participation is likely to occur when the method of allocating future GHG emissions is perceived as equitable. For the purpose of this investigation, we define equity as reducing the presently large disparity in per capita emissions so that equal per capita emissions can be achieved by 2050, bounded by the need for global emissions to follow RCP2.6. We have shown that an emission allocation can be achieved which significantly reduces the global disparity in per capita CO_2 emissions while limiting global emissions to those of RCP2.6. Importantly, however, allocation methodologies based solely on historical CO_2 emissions or economic performance are unable to reduce disparity among individual countries; indeed, globally and particularly for countries with Medium HDI, disparity is greatly increased.

Reducing disparity in per capita emissions requires the recognition that countries with above average emissions must do more to reduce their emissions than would be indicated by history alone, so that those with below average can increase theirs. Providing an additional mechanism (termed the global average constraint) to enable emissions from low emitting countries to be increased at the cost of high emitting countries brings with it an increase in the emissions disparity for countries with Medium HDI, but far less so than occurs without this mechanism. A further consequence of this approach is that High HDI countries must reduce their emissions by a greater amount in the decades before 2050 for an emission allocation based on historical economic performance than for one based on historical CO_2 emissions. Use of emission trading could potentially help the economic development of Low HDI countries, as an alternative to full uptake of their emission quota.

Finally, the difficulties in attaining the RCP2.6 reductions are discussed. The favoured approach is to de-couple emission levels from energy supply, through heavy use of CCS/BECCS, non-carbon fuels and energy efficiency. However, these approaches have their own problems; they are unlikely to be cheap, implemented rapidly, or in some cases, even technically feasible. Achieving the emission reductions necessary for climate stability will likely require major lifestyle changes, particularly in High HDI countries.

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