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Global per capita CO_2 emissions - stable in the long run?

Abstract:
Global per capita CO_2 emissions have been relatively stable during the last decades. It has been suggested that the Intergovernmental Panel on Climate Change (IPCC) and its scenario makers have ignored this stability. This paper presents a simple analytical framework explaining generally the stability of global per capita CO_2 emissions during the last decades. The same analytical framework, supported by numerical illustrations, indicates that this stability is unlikely to persist and that current trends in regional per capita emissions are in close agreement with the IPCC scenarios.

Keywords: Global carbon emissions, SRES, IPCC, scenarios.

JEL classification: Q30, Q41.

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1 Introduction

Since 2003 there has been a debate on the findings of the Intergovernmental Panel on Climate Change (IPCC) and its Special Report on Emission Scenarios (SRES), (IPCC 2000). The origins of the debate go back to 2002 when Ian Castles and David Henderson wrote a number of critical letters to the chairman of the IPCC, Dr. R.K Pachauri. These letters were packaged together and published in *Energy & Environment* (Castles and Henderson, 2003a). A debate followed including contributions from Grübler et al. (2003), Castles and Henderson (2003b), Nakićenović et al. (2003), McKibbin et al. (2004), Ryten (2004), Castles (2004), and Henderson (2005).

An important part of Castles and Henderson's criticism was a claim that SRES exaggerated future emission projections due to a methodological mistake related to the use of exchange rates (MERs) instead of purchasing power parity (PPP) converters.

Holtsmark and Alfsen (2005) and Holtsmark and Alfsen (2004) argued that Castles and Henderson's conclusion on exaggerated emission growth was based on a logical short cut. Although we endorsed Castles and Henderson's claim that the use of exchange rates significantly inflated economic growth in the scenarios currently used for global warming forecasts, we pointed out the overestimate with respect to the emission intensity gaps between rich and poor countries. We argued that this second error effectively neutralized the effect of inflated economic growth, and consequently that the use of exchange rates has not given rise to inflated emission projections in SRES.

Our arguments appear to be accepted by Henderson. He now states that "Had we given due weight to this associated error [overstated emission intensity gaps] and its implications, we would have refrained from making, or qualified heavily, the argument that the SRES emissions projections were clearly inflated" (Henderson 2005b, cf. also Henderson 2005a).

Nevertheless, Henderson states: "It remains possible that SRES emissions projections are inflated, and an argument to this effect, for reasons quite different from the apparently ill-founded one that we suggested, has recently been made in an article by Ross McKitrick and Mark Strazicich" (Henderson 2005b). Henderson here refers to McKitrick and Strazicich (2005), which examines historical global per capita CO2-emissions and claims that these are "extremely stable" without trend, and have a constant mean of 1.14 tonnes of CO_2 per capita. McKitrick and Strazicich state:

"We examine the time-series properties of historical per capita CO_2 emissions and conclude that per capita global emissions are stationary without trend, and have a constant mean of 1.14 tonnes per person with standard deviation of 0.02. With estimates of 21th century peak population levels in the 8-10 billion range, this implies that most emission scenarios currently used for global warming forecasts are unrealistically high." (McKitrick and Strazicich 2005, p. 1).

Since the beginning of the 1970's global per capita CO_2 emissions have in fact been relatively stable around 1.1 tonnes per person (Figure 1). However, McKitrick and Strazicich do not present any theory that explains the observed stability of global per capita CO_2 emissions. Nevertheless, they have the belief that the observed stability provides a basis for strong conclusions with respect to future CO_2 emissions. This methodological approach might be questioned. Another approach is to consider historical data as a basis for assessment of economic theories. To the extent that historical data provide support of theories, the theories might be used as tools for predictions.

Likewise, this paper does not present a theory that explains the observed stability of global per capita CO_2 emissions. Instead, a simple analytical framework is used in order to show that the observed stability of global per capital emissions has been an effect of aggregation. While per capita emissions in the industrialized countries have been relatively stable, per capita emissions in the developing countries have been growing. At the same time there has been rapid population growth in the developing countries, drawing average per capita emissions downwards. This effect of demographic development is ignored by McKitrick and Strazicich. It is, however, of great importance, because population growth in the developing regions is slowing down. Taking the likely demographic development into account and the construction of a set of regional trends in per capita CO_2 emissions indicate that the stability of global per capita CO_2 emissions is unlikely to persist and that the emission scenarios presented in SRES are in reasonable agreement with historical trends in per capita emissions.

2 Why have global per capita emissions been stable during the last decades?

This section presents a simple framework for a qualitative analysis of global per capita CO_2-emissions. The presented theoretical framework illustrates important mechanisms that, to a large extent, explain the stability of the global per capita CO_2-emissions during the last decades. In the next section, the same theoretical framework is applied in order to give some reasons the stability is not likely to persist.

We consider the world as two regions, one rich (R) and one poor (P). Some definitions:

$E(t)$	Global emissions at time t.
$N_r(t)$	Population in region r at time t.
$N(t)$	Global population at time t, i.e. $N(t) = N_R(t) + N_P(t)$.
$e_r(t)$	Emissions per capita in region r at time t.
$e(t)$	Global emissions per capita at time t i.e. $e(t) = E(t)/N(t)$
$n_r(t)$	Population in region r as share of global population at time t, i.e.$n_r(t) = N_r(t)/N(t)$.

Total global emissions is a weighted sum of regional per capita emission

$$E = e_R N_R + e_P N_P. \tag{1}$$

Hence:

$$e = e_R n_R + e_P n_P. \tag{2}$$

We then have from (2):

$$\mathring{e} = \mathring{e}_R n_R + e_R \mathring{n}_R + \mathring{e}_P n_P + e_P \mathring{n}_P$$

where e and other variables with a dot above represent the time derivative of the variables, for example $\mathring{e}_r = \frac{de_R}{dt}$. From the definitions it follows that $n_R = 1 - n_P$, and consequently that $\mathring{n}_R = -\mathring{n}_P$. Using (3) yields:

$$\mathring{e} = \mathring{e}_R + (\mathring{e}_P - \mathring{e}_R)\, n_P + (e_P - e_R)\, \mathring{n}_P \tag{3}$$

Equation (4) constitutes a basis for an assessment of both historical and future CO_2 emissions. As an introduction, we could assume (contrafactually) that the per capita emissions are stationary in both the rich and the poor countries. In other words, if $\mathring{e}_P = \mathring{e}_R = 0$:

$$\mathring{e} = (e_P - e_R)\, \mathring{n}_P \tag{4}$$

which implies that, even if per capita emissions are stable in both regions, per capita emissions might be non–stable globally. If, for example, per capita emissions are higher in the rich countries than in the poor and the population growth is higher in the poor region, i.e., if $e_R > e_P$ and $\mathring{n}_P > 0$, stable per capita emissions in both regions would mean decreasing per capita emissions globally. The increasing population in the poor region draws the average per capita emissions downwards. This basic effect of aggregation is ignored by McKitrick and Strazicich (2005), although it constitutes an important part of the reason that global per capita emissions have been stable for some decades.

We leave the contrafactual analysis and turn to Figures 1 and 2. Figure 1 shows observed per capita CO_2 emissions from fossil fuel combustion regionally and globally during the period 1965-2004.[1] Figure 2 shows observed and predicted populations of developing countries as a share of global population for the period 1950 - 2050. We could sum up the situation of the last decades with the following characteristics:

- Relatively stable pr capita emissions in rich (industrialized) countries
- Increasing per capita emissions in poor countries
- Per capita emissions in poor countries are lower than per capita emissions in rich countries
- Poor countries' share of global population is sharply increasing

In other words:

$$\begin{aligned} \mathring{e}_R &\approx 0, \\ \mathring{e}_P &> 0 \\ e_R &> e_P \\ \mathring{n}_P &> 0 \end{aligned}$$

Hence, from (4) we have:

$$\mathring{e} \approx \mathring{e}_P n_P + (e_P - e_R)\, \mathring{n}_P \tag{5}$$

The second term on the right hand side of (6) shows that high population growth in the poor region draws global per capita emissions downwards because per capita emissions in this region are lower than per capita emissions in the rich countries (see discussions related to (5)). Hence, the second term on the right hand side of (6) is negative. The first term is positive and represents increasing per capita emissions in the poor countries and their contribution to increasing per capita emissions globally. To a large extent, these two mechanisms have neutralized each other during the last decades, an effect that is an important part of the reason global per capita emissions have been relatively stable in this period.

[1] Emissions in Figure 1 are stipulated on the basis of BP Statistics of World Energy 2005. When converting consumption data (toe) to emissions (tC) the applied conversion factors are 0.781 (oil), 0.598 (gas), and 1.105 (coal).

One numerical example: From 1970 to 2000 per capita emissions in the developing countries more than doubled (+ 102 percent, + 0.24 tC/capita) while per capita emissions in the industrialized countries increased 1.4 percent (+0.05 tC/capita). Without any demographic changes, increased per capita emissions in both regions would give increased global per capita emissions. However, global per capita emissions dropped 2,7 percent (-0.03 tC/capita) in this period. This could only be explained by the mechanism represented by the second term on the right hand side of (6). Hence, the stability of global per capita CO_2 emissions during the last decades is closely related to high population growth in the developing world.

3 Are stationary per capita emissions likely to persist?

Will the current situation, with stable global per capita emissions, be likely to persist? In order to shed some light on that question we will look at a situation in which per capita emissions in the rich countries remain stable.[2] Equation (6) then is still an adequate basis for the discussion because this equation follows from (4) if $\mathring{e}_R \approx 0$. Stable global per capita emissions then imply:

$$\mathring{e}_P n_P \approx (e_R - e_P)\, \mathring{n}_P \tag{6}$$

For some decades (7) has more or less been fulfilled. Currently, then, the left hand side of (7) is almost equal to the right hand side. Is this likely to persist?

According to Figure 1, per capita emissions in the poor region have been increasing along a relatively linear trend. Extending this trend implies that $\mathring{e}_P$ is constant. The population growth in the poor region will almost certainly be higher than in the rich region. Hence, n_P is likely to increase, and we can assume that the right hand side of equation (7), $\mathring{e}_P n_P$, is going to increase. With respect to the right hand side of (7), per capita emissions in the poor region converges (slowly) towards per

[2] It might be objected here that per capita emissions in the industrialized countries have been declining rather than remaining stable during the last decades. However, this development is strongly related to the situation in the transition countries (Figure 3). In both the USA, and Japan and in the other industrialized countries there has been an upward trend after sudden drops in per capita emissions related to the OPEC caused oil price shocks. Although there probably still is considerable potential for energy efficiency improvements in the transition countries, reduced per capita emissions in this region are unlikely to reach the rate of the years after the revolutions. Hence, it is reasonable to assume stable per capita emissions in the rich countries as far as trends are concerned.

capita emissions in the rich region, i.e. $(e_R - e_P)$ is decreasing. It follows from Figure 2 that population growth in the poor region is decreasing, which means that $\mathring{n}_P$ is declining. Hence, both factors on the right hand side of equation (7) are decreasing.

In other words, the left hand side of (7) is likely to increase in the future, while the right hand side is likely to decrease. This means that qualitatively we could conclude that if the per capita emissions in the industrialized countries are stable (or increasing), the stability of global per capita emissions is gradually to be replaced by an upward trend.

4 A numerical illustration

In this section we present a numerical example based on a time series of fossil fuels combustion from 1965 to 2004 presented in the BP Statistical Review of World Energy 2005. CO_2 emissions were stipulated from emission factors presented in footnote 1. The derived emissions series fit quite well into the series applied by McKitrick and Strazicich. Hence, different data sources cannot explain the different results. The BP data were chosen as an updated data series.[3]

With respect to demographic development, the analysis is based on the medium variant in the UN World Population Projections, the 2004 Revision.

McKitrick and Strazicich (2005) extends linearly one trend, global per capita emissions. On the contrary, the numerical examples presented here are based on linear extension of trends of per capita emissions in seven world regions, separately. With one exception, the trends are based on linear regressions with respect to the per capita emissions of the period 1965 to 2004.[4] The exception is the treatment of per capita emissions in the transition countries, which are simply assumed to be stationary at the 2004 level. The resulting trends are presented in Figure 3, which also shows the consequential trend in global per capita emissions that follows from aggregation of the regional trends taking the applied regional population projections into account.

Consequently, the global per capita emissions are steadily increasing (Figure 3). In 2050 the estimated emissions are 1.39 tC/capita, which is 22 percent higher than the stationary per capita emissions of 1.14 tC/capita estimated by McKitrick and Strazicich.

The resulting total global emissions are provided by Figure 4. The stipulated trend scenario, based on aggregation of the regional trends, is found below the two highest SRES scenarios A1 and A2, but significantly

[3] The data series in McKitrick and Strazicich (2005) end at 2000.

[4] Least square regression is applied to the model $e_r = a_r + b_r t + u_r(t)$.

above the two lowest SRES scenarios B1 and B2, at least in 2050.

5 Conclusion

Global per capita CO_2 emissions have been relatively stable since the beginning of the 1970's. It is important to acknowledge that this stability is an aggregation effect. High population growth in regions with low per capita emissions has been a key factor behind the stability. In the same regions the population growth is declining. Hence, some well-known characteristics of the global demographic development indicates strongly that stationary trends with respect to per capita emissions are unlikely to persist.

A simple numerical analysis is presented. The trends, with respect to per capita CO_2-emissions in seven world regions, are extended into the future. The result is increasing global per capita emissions and notably higher emissions than in the scenario presented by McKitrick and Strazicich. The constructed trend scenario presented here provides estimated emissions in the middle of main SRES scenarios. Hence, McKitrick and Strazicich's claim that per capita emissions are likely to remain stable and that the SRES emissions scenarios are biased upwards, appears to be weakly founded.

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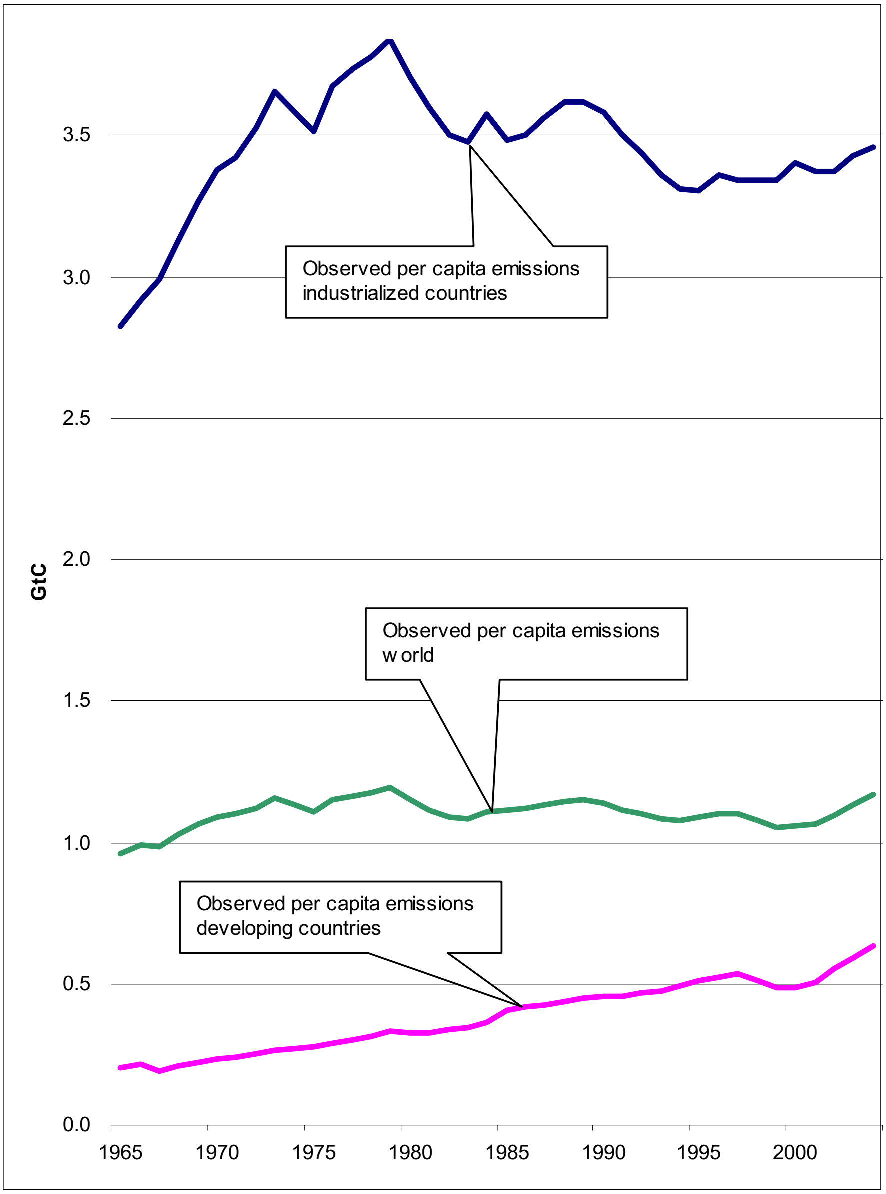

Figure 1: Observed regional and global per capita CO2-emissions from fossil fuel combustion.

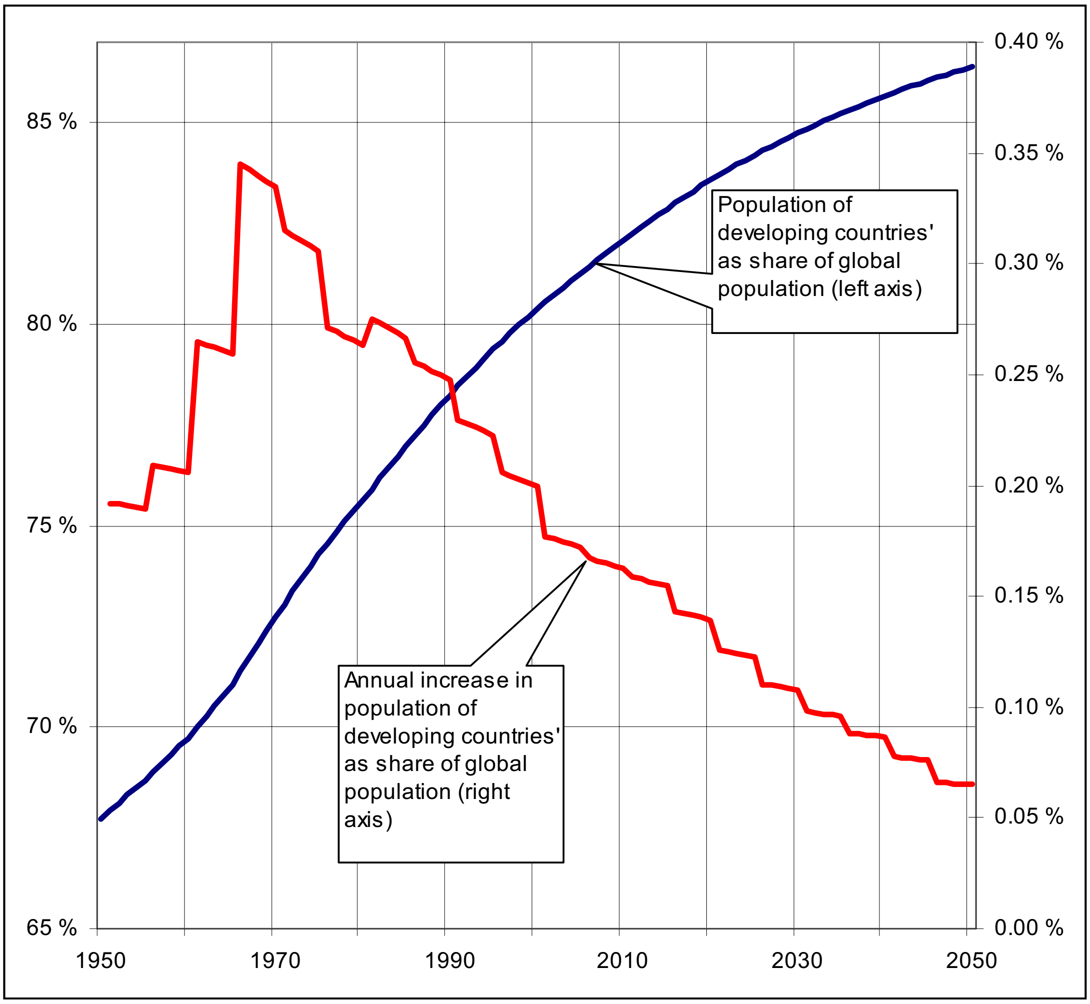

Figure 2: Population of developing countries as share of global population. Source: UN World Population Projections. 2004 Update.

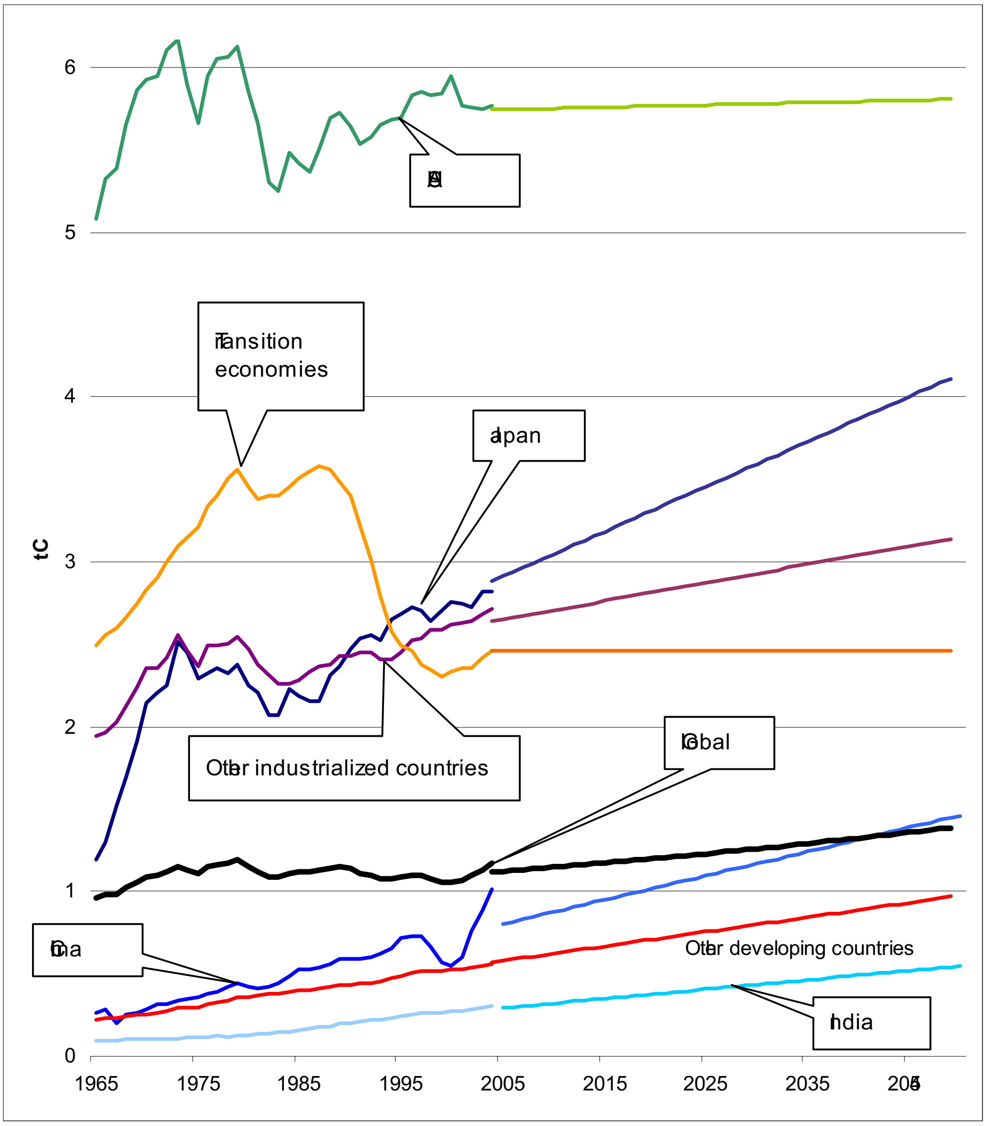

Figure 3: Observed regional and global per capita CO_2 emissions with trends

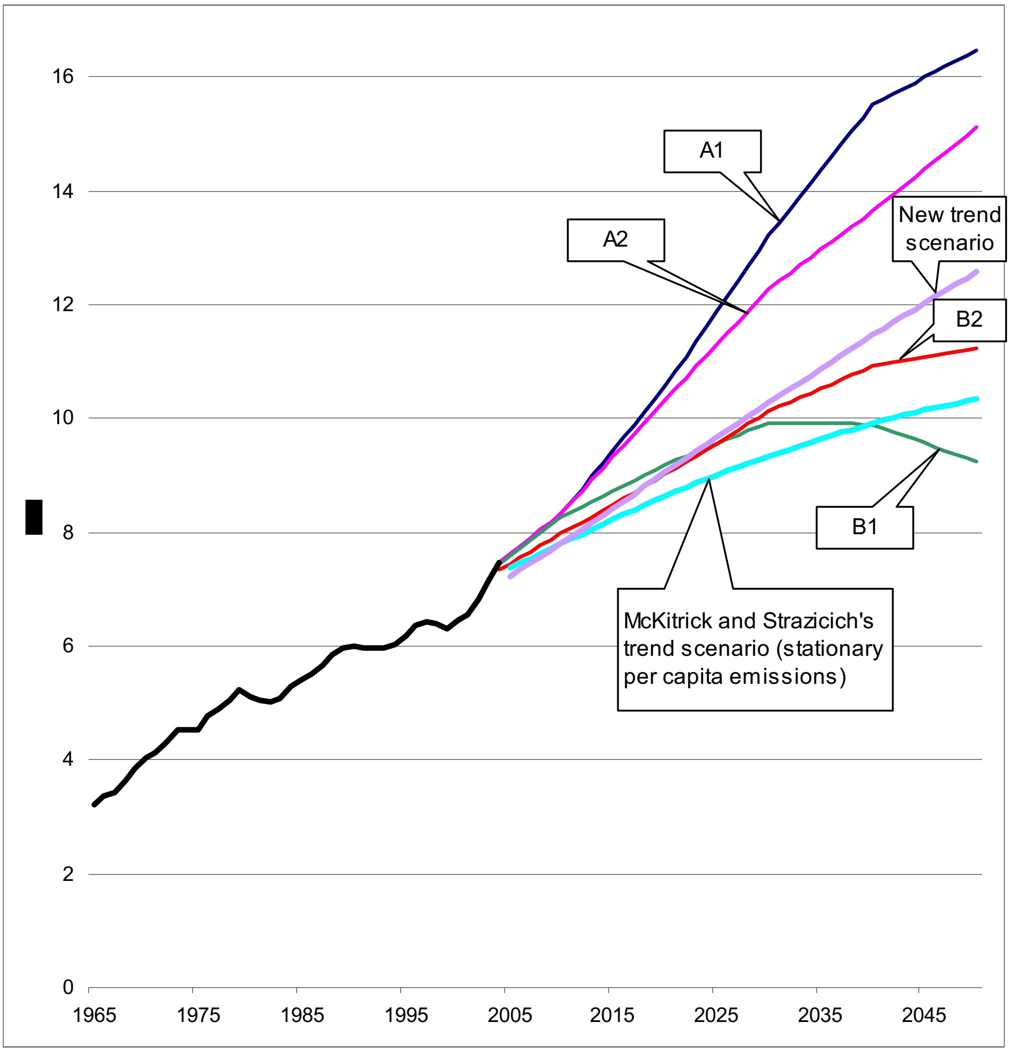

Figure 4: Global CO_2 emissions. Historical and scenarios.

Table 1: Observed and estimated CO2-emission. MtC.

	China	India	Other developing countries	USA	Japan	Other industr. countries	Transition countries*	World
1965	192	49	244	1 016	118	603	992	3 214
1970	241	57	325	1 244	224	761	1 174	4 028
1975	336	72	428	1 247	255	793	1 385	4 516
1980	423	88	588	1 352	263	856	1 537	5 108
1985	560	121	727	1 318	264	806	1 609	5 406
1990	684	171	902	1 443	305	881	1 613	5 999
1995	878	227	1 120	1 534	337	912	1 189	6 196
2000	696	284	1 326	1 691	350	995	1 109	6 451
2004	1 320	337	1 529	1 704	361	1 051	1 160	7 462
2005	1 057	323	1 579	1 713	369	1 027	1 158	7 226
2010	1 187	381	1 849	1 796	388	1 067	1 149	7 816
2015	1 323	441	2 144	1 876	404	1 104	1 139	8 431
2020	1 457	504	2 459	1 951	417	1 139	1 127	9 055
2025	1 580	568	2 792	2 021	428	1 173	1 111	9 673
2030	1 692	631	3 139	2 086	437	1 204	1 091	10 281
2035	1 794	694	3 499	2 145	445	1 232	1 070	10 879
2040	1 887	756	3 868	2 199	452	1 257	1 049	11 466
2045	1 969	817	4 240	2 248	457	1 279	1 026	12 036
2050	2 037	876	4 610	2 294	462	1 298	1 002	12 578

* Azerbaijan, Kazakhstan, Turkmenistan, Uzbekistan, Belarus, Bulgaria, Czech Republic, Germany, Hungary, Lithuania, Poland, Romania, Russian Federation, Slovakia, Ukraine, Other Europe & Eurasia.
Source of observed data: BP Statistical Review of World Energy. When converting consumption data (toe) to emissions (tC) the applied conversion factors have been 0.781 (oil), 0.598 (gas), and 1.105 (coal). Future emissions represent a trend scenario discussed in the text.

Table 2: Observed and predicted population. 1000.

	China	India	Other developing countries	USA	Japan	Other industr. countries	Transition countries*	World
1965	729 191	495 157	1 106 619	199 796	98 881	310 643	397 687	3 337 974
1970	830 675	554 911	1 257 754	210 111	104 331	323 786	415 020	3 696 588
1975	927 808	620 701	1 427 234	220 165	111 524	335 745	430 563	4 073 740
1980	998 877	688 856	1 616 381	230 917	116 807	345 634	444 823	4 442 295
1985	1 070 175	766 053	1 831 874	243 056	120 837	353 426	458 526	4 843 947
1990	1 155 305	849 415	2 059 629	255 539	123 537	362 237	473 857	5 279 519
1995	1 219 331	935 572	2 294 081	269 603	125 472	371 361	476 933	5 692 353
2000	1273 979	1 021 084	2 525 840	284 154	127 034	379 106	474 375	6 085 572
2004	1 307 471	1 086 914	2 713 446	295 401	127 875	386 855	470 953	6 388 914
2005	1 315 844	1 103 371	2 760 347	298 213	128 085	388 792	470 098	6 464 750
2010	1 354 533	1 183 293	3 002 296	312 253	128 457	395 748	466 343	6 842 923
2015	1 392 980	1 260 366	3 248 805	325 723	127 993	401 137	462 427	7 219 431
2020	1 423 939	1 332 032	3 493 591	338 427	126 713	405 709	457 478	7 577 889
2025	1 441 426	1 395 496	3 733 007	350 103	124 819	409 492	450 896	7 905 239
2030	1 446 453	1 449 078	3 964 781	360 894	122 566	412 324	443 008	8 199 104
2035	1 442 974	1 494 269	4 186 643	370 709	120 140	414 032	434 498	8 463 265
2040	1 433 431	1 534 402	4 396 004	379 544	117 621	414 633	425 684	8 701 319
2045	1 416 926	1 567 734	4 589 496	387 531	114 983	414 256	416 491	8 907 417
2050	1 392 307	1 592 704	4 763 952	394 976	112 198	413 129	406 637	9 075 903

Belarus, Bulgaria, Czech Republic, Germany, Hungary, Latvia, Lithuania, Poland, Romania, Russian Federation, Slovakia, Ukraine, Bosnia and Herzegovina, Croatia, Cyprus, Estonia, Slovenia, The former Yugoslav Republic of Macedonia, Armenia, Azerbaijan, Kazakhstan, Uzbekistan, Georgia, Kyrgyzstan, Tajikistan, Turkmenistan.
Source: UN World Population Projections. Revision 2004.

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