

**Evidence submitted to the Select Committee on Economic Affairs, House of Lords, London, for the inquiry into “Aspects of the Economics of Climate Change”,
by Professor Angus Maddison FBA, 20th February 2005**

I am not an expert on climate change. I simply provide background material useful in analysing the historical pattern and prospects for energy consumption, which may be of some use to your committee.

My submission has 4 main components:

- a) analysis of the driving forces of economic growth 1820-2001 in the two successive lead countries, the UK and USA, and those in Japan, the most successful catch-up country. It includes an estimate of the movement of their energy consumption in this period;
- b) my projections of growth of population and GDP for 2001-2030 for different parts of the world economy;
- c) analysis of the relation between the growth of world GDP and energy consumption (fossil fuels and biomass) between 1820 and 2001;
- d) an explanation of the importance of using PPP converters rather than exchange rates in comparing levels of performance between countries and in establishing measures of aggregate world output, with an illustration of the implausibility of using exchange rate converters in historical analysis or futurology (as in the IPCC, Special Report on Emissions Scenarios, Cambridge University Press, 2000)

World Development and Outlook 1820-2030: Its Implications for Energy Use

Historical Growth Accounts for Two Successive Lead Countries & the Most Successful Follower Country, 1820-2001

(1) Table 1 presents growth accounts for the UK, USA, and Japan for 1820-2001. The first two were the successive lead countries in terms of per capita income in this period, the UK to the end of the 1880s, the USA thereafter. Japan was the most successful of the follower countries, with a per capita level slightly above the average for Western Europe in 2001, and a huge deceleration in growth since 1990. There are now growth accounts of this type for about 40 countries, but none of the others go back to 1820.

Table 1 quantifies the strategic factors determining the growth experience of the three countries over the whole period of their “modern” economic growth. The first striking feature is the huge increase in the stock of physical capital, which was significant for non-residential structures, but sensational for machinery and equipment. The ratio of the latter to GDP rose 16-fold in the UK and USA between 1820 and 2001, and in Japan from 1890 to 2001. This increase was linked to the acceleration of technical progress, much of which had to be embodied in machinery. The increase in human capital, measured by years of formal educational experience of those in employment (weighted by the earnings differential associated with years of primary, secondary and tertiary) was also linked to technical progress. The increasing complexity of production processes required better educated people to make it operational, and the involvement of educated people in R&D helped institutionalise the process of innovation. Here again, there was spectacular change. The education level rose eightfold in the UK, eleven-fold in the USA and Japan. International specialization increased very significantly. The ratio of foreign trade to GDP rose from 3 to 27 percent in the UK, and from 2 to 10 per cent in the USA. Japan was an almost completely closed economy until the 1850s; between 1870 and 2001, the export ratio rose from 0.2 to 13 percent. Natural resource scarcities were not a

constraint; the land area per capita fell fourteen-fold in the USA, about four-fold in Japan and the UK. The increase in energy inputs was relatively modest in the USA (which made lavish use of its timber resources in the nineteenth century). Its per capita energy consumption rose only threefold from 1850 to 2001. The UK was able to make extensive use of coal in the nineteenth century, and its per capita energy consumption rose only six-fold from 1820 to 2001. In Japan, energy use was much more frugal in the nineteenth century, and per capita consumption rose 20-fold from 1820 to 2001. The composition of world energy consumption has changed drastically since 1820 when 94 per cent came from organic matter. In 2001, mineral fuels accounted for 89 percent per cent. The input of human energy was very significantly reduced. Hours worked per head of population dropped by 45 percent in Japan , 40 per cent in the UK and 20 percent in the USA.

Growth Projections for Leading countries, Regions and the World Economy to 2030

(2) Table 2 shows absolute levels of GDP, GDP per capita and population for different regions of the world for 1900-2001, with a quantitative assessment of the outlook to 2030. Table 3 shows the rates of growth of population and per capita GDP. The derivation of these estimates is indicated in the notes to the tables. My GDP per capita projections for 2001-2030 assume that the pace of development in the “West” will be similar to that in 1990-2001. For China, I assumed a significant slowdown in the per capita growth rate. For the rest of the world, I assumed that performance will be better than in 1990-2001. It is a fairly optimistic set of assumptions, with per capita growth about twice as fast in the rest of the world than in the West.

Past Relation between World Economic Growth and Energy Consumption

(3) Tables 4a and 4b compare the growth of world population and GDP with energy use (in terms of both fossil fuels and biomass) from 1820 to 2001. The energy intensity of GDP rose until 1900 (to 0.42 tons of oil equivalent per \$1000) and fell in the course of the twentieth century (to 0.27 tons per \$1000 in 2001). Per capita energy use at the world level rose about eightfold from 1820 to 2001. The US Dept of Energy estimated CO₂ emissions from fossil fuels from 1820, but did not take account of those from use of biomass, consequently it exaggerates the rate of growth of total emissions since 1820, but understates their level.

The Need to Use PPP rather than Exchange Rate Converters in Assessing GDP Levels and making World Aggregates

(4) Within most countries, government statisticians provide regular estimates of growth of aggregate output and expenditure in real terms, after correction for price change over time. Virtually all economists, journalists, and politicians regard these constant price measures as key indicators of economic growth and fluctuations.

The purpose of PPP (purchasing power parity) measures is precisely analogous: to correct for inter-country price differences to permit meaningful comparisons of levels of real output and expenditure. However, many journalists, politicians and some economists don't seem to realise this, and use exchange rates instead to compare levels of real GDP. Thus Japan is frequently cited as having the world's second biggest economy, and China is sometimes considered to have a smaller economy than the UK.

Table 5 compares levels of GDP and per capita GDP for the world's 10 largest countries. It demonstrates the magnitude of the error which arises in comparisons using exchange rate conversion. The exchange rate conversions on the right hand side show much lower levels for the poorer countries (China, India, Russia and Brazil) and somewhat higher levels for the west European countries and Japan relative to the USA than the PPP converters. In the case of China the

exchange rate/PPP deviation was very large-purchasing power was more than 5 times higher than the exchange rate. In India the ratio was more than 3 times higher, in Russia twice as high and in Brazil more than 50 per cent higher. The big differential for poorer countries is a fairly systematic outcome in such comparisons. For the West European countries and Japan the differential is smaller and has varied above and below parity in the past two decades. The implausibility of exchange rate conversion is clear in historical analysis. The results for 1950 with exchange rate conversion imply a per capita GDP of \$85 in China and \$172 in India (both in 1990 prices). These levels are much too far below subsistence to be credible.

The same implausibility arises when exchange rate converters are used in long-term projections such as those of the International Panel on Climate Change (IPCC), Special Report on Emissions Scenarios, Cambridge University Press, 2000. On p. 196, their A1 scenario for per capita GDP growth, 1990-2100, for OECD and Asian countries projected a rise at an annual compound rate of 1.6 and 4.4 per cent respectively. They took the initial 1990 average per capita GDP in OECD countries to be \$19,200, and \$500 in Asia (p.195, Table 4-6), using exchange rate conversion. Applying the growth rates for their A1 scenario, they projected levels of per capita GDP (in 1990 prices) in the year 2100 of \$109,200 in OECD countries, and \$71,900 in Asia, a very substantial degree of convergence, where the income gap falls from 38:1 to 1.5:1. However, the outcome would have looked very different if they had started with PPP conversion in their benchmark year 1990. The 1990 per capita level for OECD countries would have been \$19,263, and \$2,117 for Asia (ex Japan). Applying the same growth rates for 1990-2100, we would then have a per capita level in 2100 of \$107,750 for OECD countries and \$241,421 for Asia (ex Japan). Thus the Asian countries would have achieved an average income level more than twice that in OECD countries.

Table 1 Proximate and Measurable Determinants of Growth since 1820

	UK	USA	Japan	UK	USA	Japan
	Gross Stock of Machinery & Equipment Per Capita (1990\$)			Gross Stock of Non-Residential Structures Per Capita (1990 \$)		
1820	92	87	n.a.	1,074	1,094	n.a.
1870	334	489	94 a	2,509	3,686	593a
1913	878	2,749	329	3,215	14,696	852
1950	2,122	6,110	1,381	3,412	17,211	1,929
1973	6,203	10,762	6,431	9,585	24,366	12,778
2001	16,082	30,600	32,929	22,176	36,330	57,415

	UK	USA	Japan	UK	USA	Japan
	Primary Energy Consumption Per Capita (tons of oil equiv.)			Average Years of Education* Per Person Employed		
1820	.61	2.45b	0.20	2.00	1.75	1.50
1870	2.21	2.45	0.20	4.44	3.92	1.50
1913	3.24	4.47	0.42	8.82	7.86	5.36
1950	3.14	5.68	0.54	10.60	11.2	9.11
1973	3.93	8.19	2.98	11.66	14.58	12.09
2001	3.94	8.00	4.10	15.45	20.21	16.61

	UK	USA	Japan	UK	USA	Japan
	Land Area Per Capita (hectares)			Exports Per Capita (1990 \$)		
1820	1.48	48.1	1.23	53	25	n.a.
1870	1.00	23.4	1.11	390	62	1.5
1913	0.69	9.6	0.74	862	197	33
1950	0.48	6.2	0.44	781	283	42
1973	0.43	4.4	0.35	1,684	824	875
2001	0.41	3.3	0.30	5,447	2,843	2,696

	UK	USA	Japan	UK	USA	Japan
	Hours Worked Per Head of Population			GDP Per Man hour (1990 \$)		
1820	1,153	968	1,598	1.49	1.30	0.42
1870	1,251	1,084	1,598	2.55	2.25	0.46
1913	1,181	1,036	1,290	4.31	5.12	1.08
1950	904	756	925	7.93	12.65	2.08
1973	750	704	988	15.97	23.72	11.57
2001	704	770	883	28.59	36.29	23.42

	UK	USA	Japan	UK	USA	Japan
	Capital-Output Ratio Machinery & Equipment/GDP			Capital-Output Ratio Non-Residential Structures/GDP		
1820	.05	.07	n.a.	.63	.87	n.a.
1870	.11	.20	.10a	.79	1.51	.59a
1913	.18	.52	.24	.65	2.77	.61
1950	.31	.64	.72	.49	1.80	1.00
1973	.52	.64	.93	.80	1.46	1.12
2001	.80	1.09	1.59	1.10	1.30	2.77

	UK	USA	Japan	UK	USA	Japan
	Labour Productivity			Total Factor Productivity		
	(annual average compound growth rates)					
1820-70	1.10	1.10	0.18	0.15	-0.15	n.a.
1870-1913	1.22	1.93	2.00	0.31	0.36	-0.05c
1913-50	1.66	2.47	1.79	0.81	1.62	0.20
1950-73	3.09	2.77	7.75	1.48	1.75	5.12
1973-2001	2.10	1.53	2.55	0.69	0.54	0.49

a) 1890; b) 1850; c) 1890-1913; *) in equivalent years of primary education. Source: Appendix K of MADDISON, MONITORING THE WORLD ECONOMY (1995, pp. 252-55), amended and updated.

Table 2 Population, GDP and GDP per capita,1900-2030					
GDP per capita (1990 int \$)					
	1900	1950	1990	2001	2030
W Europe	2,893	4,579	15,966	19,256	30,503
USA	4,091	9,561	23,201	27,948	44,286
*Other W. O.	3,435	7,424	17,902	21,718	42,694
Japan	1,180	1,921	18,789	20,683	32,774
"West"	2,952	5,649	18,781	22,509	35,932
E Europe	1,438	2,111	5,450	6,027	12,334
f USSR	1,237	2,841	6,878	4,626	9,508
L America	1,109	2,506	5,053	5,811	8,949
China	545	439	1,858	3,583	11,174
India	599	619	1,309	1,957	6,103
Other Asia	802	918	3,084	3,997	12,465
Africa	601	894	1,444	1,489	1,987
"Rest"	749	1,091	2,713	3,377	8,304
World	1,262	2,111	5,157	6,049	11,689
Population (million)					
	1900	1950	1990	2001	2030
W Europe	234	305	377	392	392
USA	76	152	250	285	358
*Other W. O.	10	24	48	55	67
Japan	44	84	124	127	121
"West"	364	565	800	859	938
E Europe	71	87	122	121	120
f USSR	125	180	289	290	295
L America	65	166	443	531	666
China	400	547	1,135	1,275	1,477
**India	285	359	839	1,024	1,414
Other Asia	145	393	1,005	1,228	1,426
Africa	110	227	627	821	1,319
"Rest"	1,200	1,959	4,460	5,290	6,717
World	1,564	2,524	5,260	6,149	7,655
GDP (billion 1990 int. \$)					
	1900	1950	1990	2001	2030
W Europe	676	1,396	6,033	7,550	11,964
USA	313	1,456	5,803	7,965	15,851
*Other W.O	34	180	862	1,190	1,914
Japan	52	161	2,321	2,625	3,975
"West"	1,075	3,192	15,020	19,331	33,704
E Europe	102	185	663	729	1,480
f USSR	154	510	1,988	1,343	2,805
L America	72	416	2,239	3,087	5,960
China	218	240	2,109	4,570	16,504
India	171	222	1,098	2,003	8,630
Other Asia	116	361	3,099	4,908	17,775
Africa	66	203	905	1,223	2,622
"Rest"	899	2,137	12,101	17,863	55,776
World	1974	5,330	27,122	37,194	89,480

Table 3a GDP per Capita (annual average compound growth rate)					
	1900-50	1950-90	1990-2001	2001-2030	
W Europe	0.92	3.17	1.72	1.6	
USA	1.71	2.24	1.71	1.6	
*Other W. O	1.55	2.22	1.77	1.6	
Japan	0.98	5.87	0.88	1.6	
"West"	1.31	3.05	1.66	1.63	
E Europe	0.77	2.40	0.92	2.5	
f USSR	1.67	2.24	-2.90	2.5	
L America	1.64	1.77	1.28	1.5	
China	-0.43	3.67	6.15	4.0	
India	0.07	1.89	3.72	4.0	
Other Asia	0.27	3.08	4.26	4.0	
Africa	0.8	1.21	0.28	1.0	
"Rest"	0.76	2.30	2.01	3.15	
World	1.03	2.26	1.46	2.30	
Table 3b Population (annual average compound rate)					
	1900-50	1950-90	1990-2001	2001-2030	
W Europe	0.53	0.54	0.34	0.00	
USA	1.40	1.25	1.20	0.79	
Other W.O*	1.77	1.75	1.25	0.68	
Japan	1.29	0.97	0.24	-0.16	
"West"	0.88	0.87	0.65	0.30	
E Europe	0.42	0.82	-0.05	-0.03	
f USSR	0.74	1.20	0.04	0.06	
L America	1.90	2.28	1.66	0.78	
China	0.63	1.84	1.06	0.51	
India	0.46	2.14	1.83	0.52	
Other Asia	2.01	2.38	1.56	0.52	
Africa	1.46	2.57	2.48	1.65	
"Rest"	0.65	2.08	1.56	0.83	
World	0.96	1.85	1.43	0.76	
*Other W.O	refers to Australia, Canada & N. Zealand				
**1950 population including Bangladesh and Pakistan	would have been 444 million, & growth rate 0.89				
Source: 1900-2001 from Maddison (2003), The World Economy: Historical Statistics , OECD, Paris. Population projections 2001-2030 derived from the median variant of UN Population Division, World Population Prospects, 2000 Revision , New York, 2001 and their World Population in 2300 , 9 December, 2003. The projections of rates of change in per capita GDP are not the result of an econometric exercise, but are based on an analysis of changes in the momentum of growth in different parts of the world economy and the likelihood of their continuation or change, see Maddison (2002) "The West and the Rest in the International Economic Order" in Development is Back , OECD, Paris; this paper is also available on my website www.eco.rug.nl/~Maddison/					

Table 4a World Energy Consumption, Carbon Emissions, Population and GDP, 1820-2001					
	CO2	Primary	Energy		alleged
	emissions	million tons of oil equivalent			metric tons
	million	modern	biomass	total	of CO2
	metric	sources			emissions
	tons				per capita
1820	12	12.9	208.2	221.1	0.012
1870	147	134.5	254.0	388.5	0.116
1900	534	502.4	322.8	825.2	0.341
1913	943	735.2	358.2	1,093.4	0.526
1950	1,630	1,624.7	504.9	2,129.6	0.646
1973	4,633	5,368.8	673.8	6,042.6	1.184
1998	6,649	8,427.7	1,062.4	9,490.1	1.124
2000	6,611				
2001		9,071.5	1,093.5	10,165.0	

Table 4b Energy Use per \$1000 of GDP (tons of oil equivalent, GDP in 1990 Geary-Khamis dollars)						
	1820	1913	1973	1998		
USA	1.95	0.84	0.49	0.30		
UK	0.36	0.66	0.29	0.21		
Japan		0.30	0.26	0.19		
China			0.57	0.27		
India			0.39	0.28		
Other Asia			0.22	0.17		
former USSR			0.57	0.79		
Africa			0.39	0.44		
Latin America			0.20	0.20		
World	0.32	0.40	0.38	0.28		

Sources for Tables 4a and 4b: Modern sources are coal, oil, natural gas, water and atomic power; biomass is derived from wood, peat, dung, straw and other crop residues. Conversion coefficients, one metric ton of wood = .323 of oil; one metric ton of coal = .6458 tons of oil. 1973 and 2001 modern sources and biomass from International Energy Agency, *Energy Balances of OECD Countries 2000-2001*, Paris, 2003; and *Energy Balances of Non-OECD Countries 2000-2001*, Paris, 2003. Modern sources 1870-1950 derived from W.S.Woytinsky and E.S. Woytinsky (1953), *World Population and Production*, Twentieth Century Fund, New York, 1953, p. 930, 1820 from B. R. Mitchell, *European Historical Statistics, 1750-1970*, Macmillan, London (1975). Biomass 1820-50 assumed to be .20 tons per head of population, see V. Smil, *Energy in World History*, Boulder-Oxford (1994), pp.185-7 for rough estimates of biomass back to 1700. My estimate of biomass 1820-1950 is somewhat lower than Smil suggests. In 1973 world per capita supply of biomass was 0.17 and in 1998 0.18 of a ton. World population, GDP and per capita GDP from Maddison, *World Economy: Historical Statistics*, OECD, Paris 2003 (see also www.eco.rug.nl/~Maddison/). CO2 emissions from US Dept of Energy, Oak Ridge (cdiac.esd.ornl.gov/trends/emis/); their figures exclude emissions from use of biomass. For further detail on the figures for individual countries, see Maddison, "Growth Accounts, Technological Change, and the Role of Energy in Western Growth", *Economia e Energia*, Istituto Datini, Prato, 2002 (see also Maddison website).

Table 5a World's 10 Largest Countries: Comparative Ranking of GDP Levels, 1950,1990 & 2001, at constant 1990 prices, using 1990 Geary-Khamis PPP converters and 1990 Exchange Rates

GDP	1950	1990	2001	1950	1990	2001
	\$billion, with 1990 PPP conversion			\$billion, with 1990 exchange rate conversion		
USA	1,456	5,803	7,966	1,456	5,803	7,966
China	240	2,109	4,570	47	409	886
Japan	161	2,321	2,625	206	2,970	3,358
India	222	1,098	2,003	62	306	558
Germany	265	1,264	1,537	337	1,606	1,951
France	221	1,027	1,258	261	1,216	1,491
UK	348	945	1,202	363	985	1,253
Italy	165	926	1,101	191	1,069	1,272
Brazil	89	7447	990	58	479	638
Russia	315	1,151	791	154	565	388
GDP per head	\$ with 1990 PPP conversion			\$ with 1990 exchange rate conversion		
USA	9,561	23,201	27,948	9,561	23,201	27,948
China	439	1,858	3,583	85	360	695
Japan	1,921	18,789	20,683	2,458	24,042	26,466
India	619	1,309	1,957	172	365	545
Germany	3,881	15,929	18,677	4,928	20,227	23,717
France	5,271	18,093	21,092	6,244	21,432	24,985
UK	6,939	16,430	20,127	7,266	17,131	20,985
Italy	3,502	16,313	19,040	4,046	18,846	21,996
Brazil	1,672	4,923	5,570	1,077	3,165	3,588
Russia	3,086	7,773	5,435	1,515	3,817	2,669

Table 5b 1990 Exchange Rates, Geary-Khamis PPPs & ER/PPP Ratios

	units of national currency per US \$		
	Exch Rate	PPP	ER/PPP
USA	1.0000	1.0000	1.0000
China	4.7832	0.9273	5.1580
Japan	144.7900	185.2700	0.7815
India	17.5040	4.8769	3.5892
Germany	1.6160	2.0520	0.7875
France	5.4450	6.4500	0.8442
UK	0.5630	0.5870	0.9591
Italy	1,181.1000	1,384.1100	0.8656
Brazil	68.3000	44.0000	1.5523
Russia	1.0590	0.5200	2.0365