Designing climate change mitigation plans that add up

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Supplementary Information

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Energy emissions allocation tables

Table S1 Energy conversion to sector

	Emissions (Tg of CO_{2e})				Energy conversion own emissions			Transport					Other				
	Direct emissions of CO_2 (IEA)	Complementary GHG emissions (EDGAR)	Emissions from Energy conversion	TOTAL	Electricity & heat	Energy Industry own use	Non-energy uses	Road	Aviation	Rail	Pipeline transport	Navigation	Residential	Commercial and public services	Agriculture/forestry	Fishing	Other
Fugitive emissions	NI [1]	3193 [2]		3,193	42% [3]	5% [3]	3% [3]	16% [3]	2% [3]	0% [3]	0% [3]	3% [3]	6% [3]	3% [3]	1% [3]	0% [3]	1% [3]
Transformation	NI [4]	422 [5]		422	11% [6]	4% [6]	2% [6]	19% [6]	3% [6]	0% [6]	0% [6]	3% [6]	8% [6]	3% [6]	1% [6]	0% [6]	0% [6]
Energy industry own use	1571 [7]	4 [8]	879 [10]	2,454	18% [11]		4% [11]	32% [11]	5% [11]	1% [11]	0% [11]	5% [11]	9% [11]	3% [11]	2% [11]	0% [11]	0% [11]
Electricity	11532 [7]	74 [9]	1,687 [10]	13,292		5% [13]				1% [13]	0% [13]		26% [13]	22% [13]	2% [13]	0% [13]	3% [13]
Heat	949 [7]	6 [9]	139 [10]	1,094		5% [13]							36% [14]	11% [14]	1% [14]	0% [14]	3% [14]
TOTAL					1826	879	212 [11]	1372	206	203	50	232	4349	3248	433	5	483
Emission from Non-fossil fuel sources:																	
Emissions from Lime and Dry biomass use in electricity				67	0%	5%				1%	0%		26% [13]	22% [13]	2% [13]	0% [13]	3% [13]
TOTAL incl. AFOULU and Ind. Processes					1826	883	212	1372	206	204	50	232	4367	3263	435	5	485

	Emissions (Tg of CO_{2e})				Manufacturing industries and construction												
	Direct emissions of CO_2 (IEA)	Complementary GHG emissions (EDGAR)	Emissions from Energy conversion	TOTAL	Iron and steel	Chemical and petrochemical	Non-ferrous metals	Non-metallic minerals	Transport equipment	Machinery	Mining and quarrying	Food and tobacco	Paper, pulp and printing	Wood and wood products	Construction	Textile and leather	Non-specified industry
Fugitive emissions	NI [1]	3193 [2]		3,193	5% [3]	2% [3]	0% [3]	3% [3]	0% [3]	0% [3]	0% [3]	1% [3]	1% [3]	0% [3]	0% [3]	0% [3]	3% [3]
Transformation	NI [4]	422 [5]		422	36% [6]	3% [6]	1% [6]	1% [6]	0% [6]	0% [6]	0% [6]	1% [6]	0% [6]	0% [6]	0% [6]	0% [6]	2% [6]
Energy industry own use	1571 [7]	4 [8]	879 [10]	2,454	10% [11]	2% [11]	0% [11]	2% [11]	0% [11]	0% [11]	0% [11]	1% [11]	0% [11]	0% [11]	1% [11]	0% [11]	3% [11]
Electricity	11532 [7]	74 [9]	1,687 [10]	13,292	5% [13]	6% [13]	4% [13]	3% [13]	1% [13]	4% [13]	1% [13]	2% [13]	3% [13]	0% [13]	0% [13]	1% [13]	7% [13]
Heat	949 [7]	6 [9]	139 [10]	1,094	6% [14]	16% [14]	1% [14]	1% [14]	1% [14]	2% [14]	1% [14]	4% [14]	4% [14]	2% [14]	1% [14]	2% [14]	2% [14]
TOTAL					1352	1081	597	496	177	609	230	379	406	94	101	231	1205
Emissions in Energy from Non-fossil fuel sources: [15]																	
Emissions from Lime and Dry biomass use in electricity				67	5% [13]	6% [13]	4% [13]	3% [13]	1% [13]	4% [13]	1% [13]	2% [13]	3% [13]	0% [13]	0% [13]	1% [13]	7% [13]
TOTAL incl. AFOULU and Ind. Processes					1356	1085	600	498	178	612	231	380	408	94	101	232	1210

[1] Fugitive emissions are not included in IEA CO_2 datasets.[1]

[2] From EDGAR 4.2 2012FT dataset,[2] including: "Fugitive emissions from Solid fuel", "Fugitive Emissions from Oil & Gas" and "Fossil Fuel fires". These include CO_2 emissions, as they are not included in the IEA CO_2 dataset. In the EDGAR dataset, fugitive emissions are not separated from emissions occurring with transformations. "Fugitive emissions" were separated from "Emissions from Transformation", by calculating them from IEA Energy Balances[3] and IPCC Emissions Factors.[4]

[3] Fugitive emissions are assigned by fuel use. They are first assigned to different fuels and then to the source categories that are users of these fuels. Fugitive emissions from solid fuels[2] are distributed between coal fuels (in proportion to their total energy content - we do not distinguish between some types or sources of coal resulting in more fugitive emissions than others), Fugitive emissions from Oil and Gas are similarly distributed between Oil and Gas fuels proportionally to their energy content. Emissions from Fossil fuel fires are allocated to coal fuels (in 2010 the only substantial fossil fuel fires were coal mine fires[2]) Fuel use by source category is from IEA Energy Balances.[3]

[4] Emissions from transformations are not included in IEA CO_2 dataset,[1] but can be calculated as the difference between Reference and Sectoral approach.

[5] Emissions from fuel Transformations are calculated from IPCC 2006 Emissions Factors[4] and Transformations part of the IEA 2010 Energy Balances[3] dataset, and then subtracted from Fugitive emissions in EDGAR dataset.[2] The main sources of these emissions are transformations in coke ovens, blast furnaces, gas works and in smaller part, refineries.

[6] Emissions from fuel transformation are assigned via the fuel use. Refinery emissions are distributed between all liquid fuels apart from crude oil and refinery feedstock. Coke oven and blast furnace emissions are all assigned to Iron & Steel industry.

[7] From IEA CO_2 Emissions dataset.[1] Emissions from CHP plants are allocated to heat and electricity using an exergy factor which devalues a unit of heat to 26% of a unit of elecricity.

[8] From EDGAR[2] - CH_4 and N_2O emissions from Other Energy Industries.

[9] From EDGAR[2] - CH_4 and N_2O emissions from public electricity and heat production, split between Electricity and Heat correspondingly to CO_2 emissions.

[10] These emissions are sums of emissions in the first two columns and first three rows of this table: electricity generation uses some fuels required for fuel processing and vice-versa (for example, refineries use electricity). This feedback loop is solved as a system of linear equations.

[11] Emissions from energy industry own use (refineries, coal mines, gas works etc.) are assigned by fuel use. Emissions that occur in the energy industry are first assigned to the fuels that this industry is producing and in turn the source category using the fuel. Fuel use by sectors is from IEA.[2] Refinery emissions are distributed between all liquid fuels apart from crude oil and refinery feedstock. Coke oven and blast furnace emissions are all assigned to the Iron & Steel industry.

[12] Emissions from energy transformations, that are allocated to non-energy feedstock as opposed to fuels, feature later in table S8 (Industrial Processing allocation table).

[13] Emissions from electricity are assigned according to their electricity use in IEA Energy Balances.[3]

[14] Emissions from heat are assigned according to their heat use in IEA Energy Balances.[3]

[15] For sources of these emissions see Table S9 below.

Table S2 IEA Source category to sector

`	Emissions (Tg of CO_{2e})																		
	Direct emissions of CO_2 (IEA)	Other GHG emissions (EDGAR)	Emissions from Energy conversion	TOTAL	Passenger transport	Freight	Residential	Commerce, Public	Industrial Facilities	Iron and steel	Chemical	Cement	Non-ferrous	Food Processing	Paper	Textiles	Other industry	Agriculture: vegetal	Agriculture: meat & dairy
Transport																			
Road	4972.1 [16]	81 [17]	1372 [18]	6425	61% [19]	39% [19]													
Aviation (dom. and inter.)	741 [16]	7 [17]	206 [18]	954	87% [20]	13% [20]													
Rail	100 [16]	11 [17]	203 [18]	314	29% [21]	71% [21]													
Pipeline transport	141 [16]	[17]	50 [18]	192													100%		
Navigation (dom.and inter.	776 [16]	7 [17]	232 [18]	1016		100% [22]													
Non-specified transport	18 [16]	0 [17]		19	50% [23]	50% [23]													
Other																			
Residential	1880.4 [16]	357 [17]	4349 [18]	6587			100%												
Commercial and public ser	838 [16]	30 [17]	3248 [18]	4116				100%											
Agriculture/forestry	366.95 [16]	15 [17]	433 [18]	815														50% [25]	50% [25]
Fishing	19 [16]	1 [17]	5 [18]	25															100%
Non-specified other	168 [16]	6 [17]	483 [18]	656			64% [24]	36% [24]											
Manufacturing industries																			
Iron and steel	1668 [16]	11 [17]	1352 [18]	3031					5%	95%									
Chemical and petrochemic	609 [16]	4 [17]	1081 [18]	1695					4%		96%								
Non-ferrous metals	118 [16]	1 [17]	597 [18]	715					5%				95%						
Non-metallic minerals	935 [16]	6 [17]	496 [18]	1437					10%			90%							
Transport equipment	55 [16]	0 [17]	177 [18]	232					16%								84%		
Machinery	144 [16]	1 [17]	609 [18]	754					16%								84%		
Mining and quarrying	117 [16]	1 [17]	230 [18]	348					0%								100%		
Food and tobacco	258 [16]	2 [17]	379 [18]	639					11%					89%					
Paper, pulp and printing	178 [16]	1 [17]	406 [18]	585					3%						97%				
Wood and wood products	34 [16]	0 [17]	94 [18]	128					3%								97%		
Construction	121 [16]	1 [17]	101 [18]	223					16%								84%		
Textile and leather	78 [16]	1 [17]	231 [18]	309					27%							73%			
Non-specified industry	967 [16]	7 [17]	1205 [18]	2180					12%								88%		
TOTAL	15303	553	17541	33397	4828	3899	7007	4352	1016	2892	1627	1297	680	566	568	224	3599	408	433
			[30]																
Emissions in Energy from Non-fossil fuel sources:																			
Emissions from Lime and Dry biomass use in electricity				67	0% [26]	1% [26]	26% [26]	22% [26]		5% [26]	6% [26]	2% [26]	4% [26]	2% [26]	2% [26]	1% [26]	14% [26]	1% [26]	1% [26]
Emissions from AFOLU: Biofuels				173	74% [27]	26% [27]													
Emissions from AFOLU: Dry Biomass				262			81% [28]	1% [28]		1% [28]	0% [28]	0% [28]	0% [28]	3% [28]	5% [28]		8% [28]	0% [28]	0% [28]
Emissions from F-gas use in coolers				201			37% [29]	48% [29]			5% [29]			5% [29]			5% [29]		
TOTAL incl. AFOULU and Ind. Processes				34101	4956	3945	7310	4467	1016	2899	1641	1299	683	585	582	225	3641	409	435

[16] Directly from IEA CO_2 emissions.[1]

[17] From EDGAR.[2]

[18] Emissions from Energy Conversions are calculated in first table.

[19] Back-calculated from emissions associated with cars and buses vs. trucks (assuming all cars and buses are passenger transport and all trucks freight transport). That is in turn calculated based on an IEA report[5] and IEA CO_2 emissions[1]. 2- and 3 - wheeled motor vehicles are part of 'Car' category.

[20] Calculation from Eurostat.[6] Assumed a passenger equals to 110 kg of freight (to compare passenger-km and tonne-km on emission basis) (2009 data).

[21] Own calculation from IEA and International union of Railways[7] (2008 data).

[22] According to Committee on Climate Change[8] report for UK, less than 1% of emissions in shipping are due to Passenger transport. We assume that all emissions in Navigation are due to Freight shipping.

[23] For clarity, Non-specified Transport does not feature as a separate category and is instead split between Passenger and Freight equally. Non-specified Transport includes only a small proportion of transport emissions

[24] Emissions from "Non-specified other" category in IEA[1] are allocated to Residential and Commercial & Public sectors proportionally to their respective total emissions.

[25] We assume energy use on farms (tractors, pump, heating) is split between plant-based food agriculture and milk and dairy agriculture equally.

[26] Non-fossil fuel emissions associated with Electricity and Heat are calculated in Tables S8-S9 and allocated to sectors according to their electricity and heat use from IEA Energy Balances.[3]

[27] Land-use change and fertilizer emissions associated with biofuels are calculated in Tables S10-S13 and allocated to sectors according to their bio-diesel and bio-ethanol use from IEA Energy Balances.[3] Emissions from biofuel processing are not included. Biofuel use in passenger transport and freight is inferred through their use in cars, trucks and buses, which is in turn assumed to correspond to diesel (for bio-diesel) and petrol (for bio-ethanol) use.

[28] Land-use change emissions associated with dry biomass use is calculated in Tables S10-S13 and allocated to sectors according to their dry biomass and charcoal use from IEA Energy Balances.[3]

[29] F-gas emissions are calculated in Table S8. Their allocations from cooling follow energy emissions from cooling devices.

[30] For sources of these emissions, see Tables S8 and S10 below.

Table S3 Services to equipment

	Emissions (Tg of CO_{2e})																		
	Direct emissions of CO_2 (IEA)	Other GHG emissions (EDGAR)	Emissions from Energy conversion	Total	Car	Bus	Truck	Ship	Plane	Train	Tractor	Driven system	Appliances	Cooled space	Illuminated space	Hot water system	Heated space	Fired system	Steam system
Passenger transport	3698.9	59	1071	4828	70% [31]	11% [31]			17% [31]	2% [31]									
Freight	2908	49	942	3899			65% [32]	26% [32]	3% [32]	6% [32]									
Residential	1988	361	4658	7007									34% [33]	3% [33]	11% [33]	21% [33]	31% [33]		
Commerce, Public	899	32	3422	4352									33% [33]	12% [33]	15% [33]	13% [33]	27% [33]		
Industrial Facilities	422	3	591	1016									7% [35]	12% [35]	15% [35]	20% [35]	45% [35]		
Iron and steel	1592	10	1290	2892								15% [35]						80% [35]	5% [35]
Chemical	585	4	1038	1627								28% [35]						36% [35]	35% [35]
Cement	843	6	448	1297								19% [35]						80% [35]	1% [35]
Non-ferrous	112	1	568	680								9% [35]						85% [35]	6% [35]
Food Processing	229	2	336	566								26% [35]						25% [35]	49% [35]
Paper	172	1	394	568								27% [35]						6% [35]	67% [35]
Textiles	56	0	168	224								46% [35]						18% [35]	36% [35]
Other industry	1411	10	2178	3599								33% [35]						47% [35]	20% [35]
Agriculture: vegetal	183	7	217	408							49% [34]	41% [34]					10% [34]		
Agriculture: meat & dairy	203	8	222	433							49% [34]	41% [34]					10% [34]		
TOTAL	15303	553	17541	33397	3392	512	2540	1016	954	314	411	3130	3896	857	1582	2220	3909	6436	2229
			[40]																
Emissions in Energy from Non-fossil fuel sources:																			
Emissions from Lime and Dry biomass use in electricity				67						1% [36]		22% [36]	23% [36]	9% [36]	14% [36]	9% [36]	7% [36]	14% [36]	2% [36]
Emissions from AFOLU: Biofuels				173	64% [37]	10% [37]	26% [37]												
Emissions from AFOLU: Dry Biomass				262									39% [38]			14% [38]	29% [38]	9% [38]	9% [38]
Emissions from F-gas use in coolers				201								15% [39]	41% [39]	44% [39]					
TOTAL incl. AFOULU and Ind. Processes				34101	3503	529	2586	1016	954	315	411	3176	4095	951	1591	2263	3989	6469	2254

[31] Road passenger emissions are split between cars and busses according to own calculation from the combination of data from IEA,[5] where modal splits in main global regions are given for passenger transport, and IEA CO_2 emissions[1] for where road emissions for these same global regions can be obtained. Contribution of Planes and Trains to passenger transport is calculated from their respective absolute emissions, as calculated in previous allocation table. This was triangulated and double checked with results in Cullen and Allwood.[9]

[32] Contribution of each mode is calculated from their respective absolute emissions, as in previous allocation table.

[33] Equipment use in residential and commercial sector is based on three reports: IEA[10] for IEA18 countries, Energy Information Administration[11] for US and Zhou et al.[12] for China.

[34] Equipment use in agriculture and forestry is split between tractors, based on diesel fuel use in this category, driven system (pump) are assumed to be main users of electricity, and heated space, which the assumed user of other fuels, as reported by IEA.[3]

[35] Equipment use in industry is based on US DOE[13] study. For the equipment use in Non-ferrous industry (not included in the US DOE study), equipment use for aluminium productions was taken from International Aluminium Institute[14] report. Other use in Mining industry in US DOE study was classified as driven systems (it includes drilling, and material transport). Global equipment use in industry following from these two studies was crosschecked with Nakicemović[15] study and IEA[16] reports. Some discrepancies were found, summarised in the following table:

	Fired sys	Steam	Motor	Other/Facilities
US DOE [13] based	51%	18%	21%	10%
Nakicemovic et al. [15]	40%	20%	29%	11%
IEA 2006 Tech. Pers. [16]	33%	13%	26%	27%

IEA stated[16]: "No detailed statistics are available regarding how global final industrial energy use (to devices) can be allocated, (only rough estimates)". Therefore US DOE 2004 data was used, as it is the most detailed and empirically based. Facilities are divided between illumination, appliances, refrigeration, heating and hot water based on fuel use from Nakicenovic et al.[15] and a study by Ayres et al.[17]

[36] Non-fossil fuel emissions associated with Electricity and Heat are calculated in Tables S8-S9 and allocated to sectors according to their electricity and heat use from IEA.[3]

[37] Based on fuel use of Bio-diesel and Bio-ethanol in IEA Energy balances.[3] Assumptions: all biofuels are used as blends, i.e. no biofuels are used in a dedicated engines; bio-diesel and bio-ethanol are responsible for same amount of emissions/unit energy; biofuel use is distributed between cars, trucks and buses correspondingly to diesel (for bio-diesel) and petrol (for bio-ethanol). These emissions do not include biofuel processing.

[38] Based Dry biomass fuel use in Electricity generation vs. other uses (mainly use in residential sector as dry biomass stoves - here classified as biomass burners) from IEA Energy balances.[3] Includes Dry Solid Biomass and Charcoal.

[39] F-gas emissions are calculated in Table S8. Their allocations from cooling follow energy emissions from cooling devices.

[40] For sources of these emissions, see Tables S8 and S10 below.

Table S4 Equipment to Device

	Emissions (Tg of CO_{2e})				Motion					Other (electronic and light)			Heat					
	Direct emissions of CO_2 (IEA)	Other GHG emissions (EDGAR)	Emissions from Energy conversion	Total	Petrol Engine	Diesel Engine	Aircraft engine	Other Engine (LPG, gas, coal)	Electric motor	Cooler	Electronics	Light device	Electric heater	Heat Exchanger	Oil burner	Gas burner	Coal burner	Biomass burner
Car	2598	41	752	3392	86% [41]	14% [41]												
Bus	392	6	114	512	86% [41]	14% [41]												
Truck	1895	32	614	2540	4% [41]	87% [41]		9% [41]										
Ship	758	13	245	1016		100%												
Plane	728	12	214	954			100%											
Train	236	4	74	314		38% [42]		5% [42]	57% [42]									
Tractor	189	8	215	411		100%												
Driven system	1327	14	1789	3130		7% [43]		3% [43]	79% [43]	10% [43]								
Appliances	1004	134	2759	3896		8% [44]		0% [44]	13% [44]	21% [44]	24% [44]		18% [44]	0% [44]	1% [44]	8% [44]	3% [44]	3% [45]
Cooled space	218	14	624	857						100%								
Illuminated space	418	45	1119	1582								100%						
Hot water system	614	80	1525	2220									54% [44]	8% [44]	10% [44]	19% [44]	6% [44]	2% [45]
Heated space	1095	125	2689	3909									27% [44]	12% [44]	18% [44]	30% [44]	10% [44]	3% [45]
Fired system	2999	20	3417	6436									34% [43]	4% [43]	13% [43]	13% [43]	36% [43]	
Steam system	832	6	1391	2229									9% [43]	9% [43]	8% [43]	16% [43]	58% [43]	
TOTAL	15303	553	17541	33397	3469	4838	954	346	3153	2001	948	1582	5358	1130	1989	3102	4237	290

[48]

Emissions in Energy from Non-fossil fuel sources:																	
Emissions from Lime and Dry biomass use in electricity	67					0% [46]	23% [46]	13% [46]	7% [46]	11% [46]	38% [46]	7% [46]					
Emissions from AFOLU: Biofuels	173	70% [47]	30% [47]														
Emissions from AFOLU: Dry Biomass	262																100%
Emissions from F-gas use in coolers	201							100%									
TOTAL incl. AFOULU and Ind. Processes	34101	3590	4890	954	346	3168	2211	953	1590	5384	1135	1989	3102	4237	552		

[41] The split of road transport between cars, buses and truck is based on total gasoline and diesel consumption of road source category, combined with data on the proportion of cars, buses and trucks that are diesel and petrol. Data on gasoline and diesel emissions comes from IEA.[1] The share of diesel in passenger transport energy use is assumed to be 14% (based on IEA,[10] for IEA18 countries) and 87% of trucks are diesel (also based on IEA,[10] also for IEA18 countries). Use of LPG fuel in road transport is assumed to be all by trucks.

[42] The split of trains into electric, coal (other engine) and diesel is based on respective fuel emissions as reported in IEA.[1]

[43] Allocation of different equipment to devices is based on estimates of device and fuel use in industry by Nakicemovic et al.[15]

[44] Allocation of different equipment to devices is based on estimates of shares of energy carriers for different energy services in the world as a whole in residential sector by Nakicenovic et al.[15] The estimate for coolers is derived from study by Ayres et al.[17]

[45] Only CH_4 and N_2O emissions associated with dry biomass use are inlcuded here. CO_2 emissions from biomass excluded, as they are assumed to be recycled carbon from the atmosphere, except for the case where dry biomass collection is causing land-use change related emissions, which is shown at the end of the table..

[46] Non-fossil fuel emissions associated with Electricity and Heat are calculated in Tables S8-S9 and allocated to sectors according to their electricity and heat use from IEA.[3]

[47] Based on Dry biomass fuel use in Electricity generation vs. other uses from IEA[3]. Includes Dry Solid Biomass and Charcoal.

[48] For sources of these emissions, see Tables S8 and S10 below.

Table S5 Device to Source of emissions (Final energy)

	Emissions (Tg of CO_{2e})				Allocations						
	Direct emissions of CO_2 (IEA)	Complementary GHG emissions (EDGAR)	Emissions from Energy conversion	Total	Fugitive emissions	Electricity and heat	Energy industry own use and transformations	Direct Oil use	Direct Gas use	Direct Coal use	Waste Incineration
Petrol Engine	2641	48	780	3469	9% [49]	2% [49]	12% [49]	77% [49]			
Diesel Engine	3683	66	1089	4838	9% [49]	2% [49]	12% [49]	77% [49]			
Aircraft engine	726	13	215	954	9% [49]	2% [49]	12% [49]	77% [49]			
Other Engine	283	6	56	346	9% [49]	0% [49]	7% [49]	21% [49]	58% [49]	5% [49]	
Electric motor	129	3	3021	3153	9% [49]	83% [49]	3% [49]	0% [49]	4% [49]		
Cooler	16	0	1984	2001	9% [49]	86% [49]	3% [49]	0% [49]	1% [49]		
Electronics	0	0	948	948	9% [49]	87% [49]	3% [49]				
Light device	31	1	1551	1582	9% [49]	85% [49]	4% [49]	1% [49]	1% [49]		
Electric heater	0	0	5358	5358	9% [49]	87% [49]	3% [49]				
Heat Exchanger	0	0	912	1130	9% [49]	87% [49]	3% [49]				
Oil burner	1701	31	448	1989	9% [49]	2% [49]	12% [49]	77% [49]			
Gas burner	2377	56	413	3102	9% [49]	1% [49]	3% [49]		87% [49]		
Coal burner	3716	39	766	4237	14% [49]	1% [49]	5% [49]			79% [49]	1% [49]
Biomass burner		290		290							
TOTAL	15303	553	17542	33397	3092	12304	2146	9003	2790	3733	37

Emissions from Non-energy uses of fossil fuels	784 [50]	7	212 [51]	1003	96 [51]		116 [51]	455 [50]	212 [50]	124 [50]	
TOTAL Emissions from fossil fuels				34400	3189	12304	2261	9457	3002	3857	37

[49] The allocation is based on the source of emissions: whether the emissions derive from direct fossil fuel combustion (which correspond to CQ emissions in IEA[1] dataset), are associated with the fuel use (fugitive emissions and emissions from energy industry own use), or are due to electricity use. Because some electricity is used in fuel conversions, even devices using only direct fuel contribute to electricity use.

[50] Emissions from non-energy uses of fossil fuels (bitumen, anodes, and solvents). Both EDGAR[2] and IEA[1] provide this information, with some methodological differences. The total is taken from EDGAR and the split by fuels from IEA.

[51] See Table S1.

Table S6 Final energy to Fuel

	Emissions (Tg of CO_{2e})				Allocations				
	Direct emissions of CO_2 (IEA)	Complementary GHG emissions (EDGAR)	Emissions from Energy conversion	Total	Oil	Natural Gas	Coal	Waste	Biomass
Electricity and heat			12304	12304	7% [52]	21% [52]	72% [52]	1% [52]	
Fugitive emissions			3189	3189	36% [53]	18% [54]	46% [55]		
Energy industry own use and transformations			2261	2261	39% [56]	36% [56]	25% [56]		
Direct Oil use	9293	164		9457	100%				
Direct Gas use	2938	64		3002		100%			
Direct Coal use	3819	41		3859			100%		
Waste Incineration	37	0		37				100%	
Biomass burner		290		290					100%
TOTAL	16087	560	17754	34400	12350	6942	14676	141	290

[52] Emissions of electricity and heat production are split between fossil fuels according to IEA CO_2 Emissions.[1]

[53] From Table S1.

[54] The share of fugitive emissions from Gas production out of all fugitive emissions is calculated based on "Fugitive emissions from oil and gas "category EDGAR[2], split between Oil and Gas according to their shares in direct emissions.

[55] The share of fugitive emissions from Gas production out of all fugitive emissions is calculated based on "Fugitive emissions from solid fuels" in EDGAR[2].

[56] Based on different fuel use in "Energy Industry Own use" and "Transformation" in IEA Energy Balances[3] and IPCC 2006 Emission factors.[4]

Table S7 Fuel to Emissions

	Emissions (Tg of CO_{2e})				Allocations			
	Direct emissions of CO_2 (IEA)	Complementary GHG emissions (EDGAR)		Total	CO2	CH4	N2O	F-gas
Oil	10353	1997		12350	89% [57]	10% [58]	1% [58]	
Natural Gas	5936	1006		6942	90% [57]	10% [58]	1% [58]	
Coal	12924	1752		14677	90% [57]	10% [59]	1% [59]	
Waste	141	0		141	100%			
Biomass		290		290		83%	17%	
SUBTOTAL	29354	5045		34400	30569	3551	279	0
Emissions from other sources [60]								
Calcination		1695		1695	1696			
Chemical use		1073		1073			133	940
Land-use Change		6108		6108	5331	401	377	
Methanogenesis		5340		5340		5340		
Nitrification		1965		1965			1965	
TOTAL				**50580**	37597	9293	2754	940

[57] Includes CO_2 emissions from direct combustion (excluding non-energy uses) from IEA[1] and CO_2 fugitive emissions from solid fuels from EDGAR[2].

[58] CH_4 and N_2O emissions from "Fugitive emissions from oil and gas "category EDGAR[2], split between Oil and Gas according to their shares in direct emissions and also other CH_4 and N_2O emissions in energy sector in EDGAR[2], split between coal, oil and gas according to their contributions to source categories.

[59] CH_4 and N_2O emissions from "Fugitive emissions from solid fuels" in EDGAR[2]; Other CH_4 and N_2O emissions in energy sector in EDGAR associated with coal production.

[60] For sources of these emissions, see tables below.

Industrial Processes allocation tables

Table S8 EDGAR sources categories to Sector/Final Energy

	Emissions (Tg of CO_{2e})					Allocation to sectors						to device	
	CO_2	CH_4	N_2O	F-gas	TOTAL	Iron and steel	Chemical	Cement	Non-ferrous	Other industry	Waste	Electricity gen.	Cooler
Cement production	1352	0	0	0	1352			100%					
Lime production	242	0	0	0	242	33% [61]	15% [61]	12% [61]	8% [61]		11% [61]	22% [61]	
Prod.of other minerals	102				102			100%					
Prod. of chem.	602 [63]	5	133		740		100%						
Prod. of metals	331 [63]	2		0	333				100% [62]				
Prod. of haloc. and SF6				219	219		100%						
Refrig. and Air Con				201	201								100%
Foam Blowing				13	13		100%						
Fire Extinguishers				0	0		100%						
Aerosols				23	23		100%						
F-gas as Solvent				3	3		100%						
Semiconductor/Electronics				17	17					100%			
Electrical Equipment				103	103					100%			
Other F-gas use				361	361		100%						
Non-en. use of lubric.	32 [63]				32		100%						
Paint use	21 [63]				21		100%						
Degrease use	4 [63]				4		100%						
Chemicals use	5 [63]				5		100%						
Other solvents use	0 [63]				0		100%						
TOTAL					3772	80	1456	1483	352.1	120.3	26	53	201.2

[61] Based on product split from USGS Lime statistics 2008[18], Table 3: construction 12%, chemicals 15%, steel 33%, aluminium 8%, wastewater 11%, electricity 22%.

[62] This includes emissions in metal production, for example anode oxidation in aluminium production, PFC emissions from Aluminium and F-gas emissions from Magnesium production (all from EDGAR[2]).

[63] In addition to the direct emissions from corresponding categories in EDGAR[2] , this also includes the proportional contribution of corresponding fugitive and fossil fire emissions, associated with non-energy use of fossil fuels, as calculated in Table S1.

Land use allocation tables

Table S9 EDGAR sources categories to Land management

	Emissions (Tg of CO_{2e})				Allocation to sector									
	CO_2	CH_4	N_2O	F-gas	Logging	Clearing for settlements	Clearing for agriculture	Clearing for biomass energy use	Tilling and erosion	Fertiliser use	Rice Paddies	Manure	Enteric fermentation	Waste
Enteric fermentation	0	2533.1	0	2533									100%	
Manure management	0	292	102	394								100%		
Rice cultivation	0	939	0	939							100%			
Direct soil emissions	0	0	915	915						100%				
Manure in pasture	0	0	567	567								100%		
Indirect N2O from agric.	0	0	256	256						100%				
Other direct soil emis.	120	0	0	120					100%					
Savanna burning	0	232	230	462	16% [64]	11% [64]	66% [64]	7% [64]						
Agricultural waste burning	0	40	12	52			100%							
Forest fires	1482.2	162.94	57	1703	16% [64]	11% [64]	66% [64]	7% [64]						
Grassland fires	0	6.9954	7	14	16% [64]	11% [64]	66% [64]	7% [64]						
Peat fires and decay	1263.4	0	0	1263	16% [64]	11% [64]	66% [64]	7% [64]						
Forest Fires-Post decay	2465.3	0	82	2548	16% [64]	11% [64]	66% [64]	7% [64]						
Solid waste disposal	0	735.12	0	735										100%
Wastewater handling	0	793.75	104	898										100%
Other waste handling	0	9.3091	8	18										100%
Total - CO2	5331.3			5331	812	584	3453	363	120	0	0	0	0	0
Total - CH4		5743.7		5744	63	45	306	28	0	0	939	292	2533	1538
Total - N2O			2341.7	2342	59	42	262	26	0	1171	0	669	0	112
TOTAL				13417	933	670.8	4021	417	120.4	1171	939.2	961.1	2533	1650

[64] Splitting land-use change emissions according to the cause (driver) of land-use change: Three sources[19-21] were indentified that can be used for assigning and quantifying drivers for global land-use change, presented separately in Table S13. Some authors stressed that Land-use Change is caused by many drivers in combination; therefore allocating land-use change emissions to an economic sector is difficult. Other studies from the literature focus instead on socio-economic factors, such as poverty and population growth as opposed to sectors. Only three studies (two expert assessments and one meta-analysis) from this substantial literature review attempted to estimate drivers for land-use change emissions on a global scale. Emissions from land-use change of forests, grasslands, peat lands and post-burn decay are all allocated the same driver and split to sectors. Since many of the identification studies were performed before the big expansion of biofuel production since 2006, we used a proxy to allocate actual emissions from biofuel combustion to land-use change as its source, as suggested by Haberl et al.[22]

Table S10 Land management to Land-Use

	Emissions (Tg of CO_{2e})				Allocation								to energy	
	CO_2	CH_4	N_2O	F-gas	Forestry	Settlements	Food-crops cropland	Feedlots	Pasture	Livestock	Fibre crops	Landfills	Waste-water	Biofuels	Biomass
Logging	812	63	59	933	####										
Clearing for settlements	584	45	42	671		100%									
Clearing for agriculture	3453	306	262	4021			62% [65]	16% [65]	22% [65]						
Clearing for biomass	363	28	26	417										34% [65]	66% [65]
Tilling and erosion	120	0	0	120			79% [66]	21% [66]							
Fertiliser use	0	0	1171	1171			72% [67]	21% [67]			4% [67]			3% [67]	
Rice Paddies	0	939	0	939			100%								
Manure	0	292	669	961					59% [68]	41% [69]					
Enteric fermentation	0	2533	0	2533						100%					
Waste	0	1538	112	1650								46% [70]	54% [71]		
Total - CO2	5331			5331	812	584	2235	594	744	0	0	0	0	122	241
Total - CH4		5744		5744	63	45	1129	50	238	2653	0	702	837	9	19
Total - N2O			2342	2342	59	42	1008	290	451	274	46	51	61	42	17
TOTAL				13417	933	671	4372	934	1433	2927	46	753	898	173	277

[65] See Table S9.

[66] The allocation of emissions from agricultural practices is based on total global split of agricultural produce between food and animal feed calculated from FAO Food Balances.[23]

[67] Based on global shares of Nitrogen fertilizer use based on IFA 2008[24] statistics by main crop groups: Wheat 17%, Rice 16%, Maize 17%, Other CG 5%, Soybean 1%, Oil Palm 1%, Other Oilseeds 4%, Cotton 4%, Sugar Crops 3%, Fruit and Vegetables 16%, Other Crops 16%. The share of use for food, animal feed, and fibre and bio-fuel feedstock was calculated within each crop group based on FAO Food Balances[23] and The Biofuels Platform 2008 statistics.[25]

[68] CH_4 and N_2O emissions from the category: "Manure in pasture/range/paddock" in EDGAR.[2] This can be considered useful manure, as nutrients are recycled back to the pasture land.

[69] CH_4 and N_2O emissions from the category: "Manure management" in EDGAR.[2]

[70] Corresponds to emissions in "Solid waste disposal on land "and "Other waste handling" from EDGAR.[2]

[71] Corresponds to emissions in "Wastewater handling "in EDGAR.[2]

Table S11 Land-Use to Sector

	Emissions (Tg of CO_{2e})										
	CO_2	CH_4	N_2O	F-gas	Paper	Other industry	Settlements	Textiles	Agriculture: vegetal	Agriculture: meat & dairy	Waste
Forestry	812	63	59	933	34% [72]	66% [72]					
Settlements	584	45	42	671			100%				
Food-crops cropland	2235	1129	1008	4372					100%		
Feedlots	594	50	290	934						100%	
Pasture	744	238	451	1433						100%	
Livestock	0	2653	274	2927						100%	
Fibre Crops	0	0	46	46				100%			
Landfills	0	702	51	753							100%
Waste-water	0	837	61	898							100%
Total - CO2	4968			4968	274	537	584	0	2235	1338	0
Total - CH4		5716		5716	21	41	45	0	1129	2941	1538
Total - N2O			2282	2282	19.8	38.8	42.2	46.1	1008	1016	112
TOTAL				12967	315	618	671	46	4372	5295	1650

[72] Allocated based on the production volumes for paper and timber (as opposed to how the two industries fair in terms of sustainable forestry). Based on production quantities (in m^3) of roundwood from FAOSTAT[26]: Pulpwood 34%, Sawlogs 57%, Other industrial roundwood 9%. Pulpwood was allocated to "Paper", Sawlogs and Other Industrial roundwood to "Timber" and later "Construction".

Table S12 Land-Use to Final Energy / Devices

	Emissions (Tg of CO_{2e})											
	CO_2	CH_4	N_2O	F-gas	Electricity generation	Biomass burner - Industry (Fired Systems)	Biomass burner - Industry (Steam Systems)	burner - Residential - Cooking (appliances)	Biomass burner - Residential - Heated Space	Biomass burner - Residential - Hot water	Petrol Engine	Diesel Engine
Dry Biomass	241	19	17	277	5% [73]	8% [73]	9% [73]	37% [73]	27% [73]	14% [73]		
Biofuels	122	9	42	173							0.7 [73]	0.3 [73]
Total - CO2	363			363	12	20	21	88	66	33	85	37
Total - CH4		28		28	1	2	2	7	5	3	7	3
Total - N2O			59.234	59	0.88	1.46	1.53	6.39	4.76	2.36	29.2	12.6
TOTAL				450	14	23	24	102	76	38	121	52

[73] Based on fuel use of Bio-diesel and Bio-ethanol in IEA Energy balances.[3] We assume: all biofuels are used as blends, i.e. no biofuels are used in a dedicated engines; bio-diesel and bio-ethanol are responsible for same amount of emissions/unit energy; their use is distributed between cars, trucks and buses correspondingly to diesel (for bio-diesel) and petrol (for bio-ethanol) use. These emissions do not include biofuel processing.

[73] Based Dry biomass fuel use in Electricity generation vs. other uses (mainly use in residential sector as dry biomass stoves - here classified as biomass burners) from IEA Energy balances.[3] Includes Dry Solid Biomass and Charcoal.

Table S13 Land-Use Change Drivers analysis

	Cropland and shifting cultivation	Pasture	Logging for timber and paper	Woody biomass	Biofuels	Settlements and infrastructure
UNFCCC (2007)	62%	12%	14%	11%	-	-
Geist and Lambin (2002)	21%	19%	23%	6%	-	31%
Houghton (2012)	76%	12%	10%	2%	-	-
Used in this study	52%	14%	16%	5%	2%	11%

See notes under Table S9.

Sector to Service Allocation table (Energy, Land-use and other)

Table S14 Sector to Service (Energy, AFOLU and other)

	Emissions (Tg of CO_{2e})																			
	Direct emissions of CO_2 (IEA)	Other GHG emissions (EDGAR)	Emissions from Energy conversion	Land-use emissions	Industrial Processes	Processing and ALFOLU emissions in Energy processes	TOTAL	Travel	Commuting	Freight	Washing	Thermal comfort	Light	Communication	Textiles	Industrial Equipment	Buildings and infrastructure in construction	Food	Waste
Passenger transport	3699	59	1071			128	4956	72% [74]	28% [74]										
Freight	2908	49	942			46	3945			100%									
Residential	1988	361	4658			303	7310				28%	36%	11%	7%				18%	
Commerce, Public	899	32	3422			115	4467				20%	40%	15%	7%				18%	
Industrial facilities	422	3	591			0	1016				20%	57%	15%	7%					
Iron and steel	1592	10	1290		80	6	2979	7% [75]	3% [75]	5% [75]	2% [75]	1% [75]	0% [75]	3% [75]		21% [75]	54% [75]	5% [75]	
Chemical	585	4	1038		1456	14	3097	4% [76]	2% [76]	2% [76]	17% [76]	0% [76]	0% [76]	8% [76]	11% [76]		20% [76]	36% [76]	
Cement	843	6	448		1483	2	2782	0%	0%	0%	0%	0%	0%	0%	0%		100%	0%	
Non-ferrous	112	1	568		352	3	1035	15% [77]	6% [77]	7% [77]	1% [77]	0% [77]	0% [77]	2% [77]	0% [77]	23% [77]	30% [77]	15% [77]	
Food Processing	229	2	336			19	585	0%	0%	0%	0%	0%	0%	0%			0%	100%	
Paper	172	1	394	315		14	897	0%	0%	0%	12% [78]	0%	0%	51% [78]			12% [78]	25% [78]	
Textiles	56	0	168	46		1	271								100%				
Other industry	1411	10	2178	618	120	41	4380	6% [78]	2% [78]	3% [78]	11% [78]	0% [78]	0% [78]	15% [78]	3% [78]	14% [78]	35% [78]	11% [78]	
Agriculture: vegetal	183	7	217	4372		2	4781											100%	
Agriculture: animal	203	8	222	5295		2	5729											100%	
Settlements				671			671										100%		
Waste				1650	26		1676												100%
TOTAL	15303	553	17541	12967	3518	696	**50580**	4337	1684	4333	4352	5028	1604	2361	727	1466	7647	15293	1676

[74] "Passenger transport" is split between "Commuting" and "Personal travel" based on data for UK (Department for Transport Statistics[27], 2008 data) and US (Department for Transport statistics: National Household Travel Survey[28], 2001 data) for road travel and based on UK[29] (2007 data) for air travel. Commuting includes: travel to work, for work and business, school and education. "Personal Travel" includes: travel for personal business, family, shopping, visiting friends, sport and entertainment and holiday categories. Calculated splits for road transport were Commuting, work, education and business travel 30%, Family & shopping 46%, Tourism, sport, leisure 25%. There were no significant differences between US and UK. Developing countries are not represented. Air travel splits are: Commuting, work, education and business travel 20%, Family & shopping 16%, Tourism, sport, leisure 65%.

[75] Based on product breakdown of global steel industry in World Steel Association Sustainability report of the world steel industry[30] and, p.7: Construction 50%, Mechanical Engineering 14%, Automotive 12%, Domestic appliances 3%, Shipyards 3%, Metal goods 15%,Electronic equipment 3%. Domestic appliances are split equally between washing and cooking. Metal goods are split between Thermal comfort, Construction, Industrial Equipment, Washing, Food and Communication. Electric equipment is allocated to Industrial equipment. Automotive is split as in Cullen et al.[31]

[76] Based on breakdown in a IEA report[32], p.62 and 260: Plastics 46%, Fibres 8% (allocated to "Textiles"), Synthetic rubbers 2% (allocated to "Transport"), Solvents 4% (allocated to "Construction"), Surfactants 3% (allocated to "Washing"), Fertilisers 22% (allocated to "Food"), Cl2 and NaOH 7% (allocated to Washing), Carbon black 1% (allocated to Transport). Plastics are further broken down my mass into Packaging 38%, Building and construction 20%, Household (sport, leisure) 9%, Electrical and electronic 7%, Automotive 7%, Furniture 3%, Agricultural 2%, Medical 2%, Other 12%. Based on this breakdown, plastics are allocated 30% to Construction (including furniture), 16% to "Washing", 38% to "Food", 13% to "Communication", 7% to "Passenger transport" and 1% to "Freight".

[77] Based on Global end-use markets for finished aluminium products from 2004 by Global Aluminium Recycling Committee[33], fig.9, p.15: Engineering and cables 18% (allocated to "Construction"), Packaging 13% (allocated to "Food"), Building 25% (allocated to "Construction"), Transport 28%, Other 16% (allocated to "Construction"). As with allocating steel and plastics to transport, if not otherwise specified, material use is split 17% to 83% for "Freight" vs. "Passenger transport", based on Cullen at al.[31]

[78] Based on product split by mass from FAOSTAT[26] for 2009: Printing + Writing Paper 29%, Newsprint 9% (both allocated to "Communication"), Other Paper (Packaging) +Paperboard 61% (Split between "Food" - 21%, "Washing" 10%, "Communication" 10% and "Construction" 10%). We have not made any adjustment for higher emission intensity by higher quality paper.

Inventories' category descriptions

Table S15 Detailed categories descriptions: Sector Inventory

Category Name	Emissions associated with:
Passenger transport	Transport by cars, 2- and 3- wheeled motorised vehicles and buses. 87% of aviation transport and 29% of train travel.
Freight	Transport by trucks, vans, and ships. Remainder of transport by planes and trains.
Residential	As defined by IEA[34]: emissions from fuels, electricity and heat consumed by households, excluding transport and including households with employed persons.
Commerce, Public	As defined by IEA[34]: emissions from fuels, electricity and heat consumed by the following sectors: Wholesale and retail trade; Warehousing and support activities for transportation; Postal and courier activities; Accommodation and food service activities; Information and communication; Financial and insurance activities; Real estate activities; Professional, scientific and technical activities; Administrative and support service activities; Public administration (excluding military); Education; Human health and social work activities; Arts, entertainment and recreation; Repair and installation of machinery, equipment and transport vehicles; Water supply; sewerage, waste management and remediation activities. After UN ISIC Rev.4[35]
Industrial facilities	Includes emissions from energy use in Facilities from all industries defined below.
Iron and steel	Emissions from Manufacture of basic iron and steel and Casting of iron and steel (as defined in UN ISIC Rev.4 [35]), excluding facilities.
Chemical	Emissions from Manufacture of chemicals and chemical products (incl. fertilizer) and Manufacture of basic pharmaceutical products and pharmaceutical preparations (as defined in UN ISIC Rev.4[35]), excluding facilities.
Cement	Emissions from Manufacture of other non-metallic mineral products (cement, lime, glass) (as defined in UN ISIC Rev.4 [35]), excluding facilities.
Non-ferrous	Emissions from Manufacture of basic precious and other non-ferrous metals and Casting of non-ferrous metals (as defined in UN ISIC Rev.4 [35]), excluding facilities.
Food Processing	Emissions from Manufacture of food products, beverages, and tobacco products (as defined in UN ISIC Rev.4 [35]), excluding facilities.
Paper	Emissions from Manufacture of paper and paper products and Printing and reproduction of recorded media (as defined in UN ISIC Rev.4 [35]), excluding facilities.
Textiles	Emissions from Manufacture of textiles, wearing apparel and leather and related products (as defined in UN ISIC Rev.4 [35]), excluding facilities.
Other industry	Manufacturing industry not included above, in the order of significance: Machinery, Mining and quarrying, Transport equipment, Construction and Wood industry.
Agriculture: vegetal	Emissions from land-use change, fertilizer use and on-farm energy use (including tractors) associated with production of vegetal agricultural products. Does not include food processing, transport, cooking or emissions from fertilizer production.
Agriculture: animal	Emissions from land-use change, fertilizer use and on-farm energy use (including tractors) associated with production of vegetal agricultural products intended for human consumption directly. Does not include food processing, transport, cooking or emissions from fertilizer production.
Settlements	Emissions from land-use change, soil disturbance, fertilizer use and on-farm energy use (including tractors) associated with production of livestock feeds and livestock rearing itself. Does not include food processing, transport, cooking or emissions from fertilizer production.
Waste	Emissions form land-fills and (not treated or inappropriately treated) waste water.

Table S16 Detailed categories descriptions: Equipment/Land-use Inventory

Category Name	Emissions associated with:
Car	Cars and 2- and 3- wheeled motorised vehicle use.
Bus	Bus and Minibus use.
Truck	Truck and Van use.
Ship	Ship use (domestic and international navigation)
Plane	Aviation (domestic and international aviation)
Train	Rail.
Tractor	Diesel use in agriculture sector, assumed to be mostly associated with Tractor use on farm.
Driven system	Conveyor belts, Pumps, Refrigerator (industrial use), air compressor and other motorised systems used in Industry.
Appliances	Refrigerator (used in households and commercial), cooker, washer, dryer, dishwasher, electronic devices
Cooled space	Cooling (air conditioning) of residential, commercial, public and industrial buildings.
Illuminated space	Illumination of residential, commercial, public and industrial buildings. Excludes illumination by transport devices.
Hot water system	Water heating for washing.
Heated space	Heating of residential, commercial, public and industrial buildings.
Fired system	High, medium and low temperature application: blast furnace, arc furnace, smelter, oven (after (*20*)).
Steam system	Medium and low temperature application involving steam: petrochemical cracker, reaction vessel, cleaning facility (after [9]).
Forestry	Land-use change emissions associated with timber and pulp production.
Settlements	Land-use change emissions associated with creating space for settlements and infrastructure.
Food crops	Non-energy emissions from land-use change, soil disturbance and fertilizer use associated with production of vegetal agricultural products for human consumption. Includes methane emissions from Rice paddies.
Feedlots	Non-energy emissions from land-use change, soil disturbance and fertilizer use associated with production of grains and other feedlots fed to livestock.
Pasture	Non-energy emissions from land-use change, soil disturbance and manure use associated with pasture land-use.
Livestock	Emissions resulting from enteric fermentation in livestock digestive systems and manure not applied to any land.

Table S17 Detailed categories descriptions: Device/Land-management Inventory. Devices defined as in Cullen and Alwood [9]

Category Name	**Emissions associated with:**
Petrol Engine	Spark ignition Otto engine: car, bus, truck, generator, garden machinery (incl. two-stroke)
Diesel Engine	Compression ignition diesel engine in trucks, cars, buses, ships, trains, generators
Aircraft engine	Turbofan and turbo propeller engines.
Other Engine	Steam (coal/biomass) or natural gas powered engine.
Electric motor	Aviation (domestic and international aviation)
Cooler	AC/DC induction motor (excl. Refrigeration)
Electronics	Computers, televisions, portable devices
Light device	Light devices excluding light devices in vehicles.
Electric heater	Electric resistance heater, electric arc furnace.
Heat Exchanger	Direct heat application, heat from CHP, district heat, heat pumps.
Oil burner	Oil combustion device: boiler, petrochemical cracker, chemical reactor
Gas burner	Gas combustion device: open fire, stove, boiler, chemical reactor
Coal burner	Coal combustion device: open-fire, stove, boiler, blast furnace, chemical reactor
Biomass burner	Wood/biomass combustion device: open fire, stove, boiler.
Clearing for agri.	Land-use change associated with making space for annual and permanent crops (incl. shifting agriculture, but deducing re-growth effects from it; excluding crops used for biofuels)
Fertilizer use	N2O emissions from fertilizer use from soil and indirect (leached nitrogen)
Rice paddies	Methane emissions from anaerobic conditions characteristic for paddy rice agriculture.
Manure	Emissions from manure (applied or not-applied).
Enteric fermentation	Non-energy emissions enteric fermentation of ruminants (cattle, sheep, goats).

Table S18 Detailed categories descriptions: Final energy

Category Name	**Emissions associated with:**
Direct Oil use	Direct oil use - correspond to direct emissions in other GHG data-sets.
Refineries, extraction.	Energy use and transformation losses in non-electricity energy industries: refineries, mines, oil and gas platforms, coke ovens, blast furnaces gas works, liquefactions plants, BKB plants.
Fugitive emissions	Fugitive natural gas from oil extraction (flared or vented), oil and gas transportation and coal mines. Includes fossil fuels fires.
Electricity and heat	Electricity and heat production, including auto producers and including own use of electricity.
Direct Gas use	Direct natural gas use - correspond to direct emissions in other GHG data-sets.
Direct Oil use	Direct coal and peat use - correspond to direct emissions in other GHG data-sets.
Biofuels	Land-use change associated with making space for crops grown for production into liquid fuels (includes bioethanol and biodiesel). Includes emissions from fertilizer application.
Dry biomass	Land-use change emissions associated with de-forestation and forest degradation from dry biomass collection.

Per capita services calculations

Table S19 Assumptions and calculations of per person emissions for final services

POPULATION		GLOBAL	USA	CHINA	NORTH AMERICA
Population (2010)		6,895,889,018 [1]	310,383,948 [1]	1,341,335,152 [1]	344,528,824 [1]
Population (2006)		6,583,958,568 [1]	299,564,470 [1]	1,314,581,402 [1]	332,320,168 [1]
TRAVEL	**UNITS**	**GLOBAL**	**USA**	**CHINA**	
CO2 emissions	GtCO2	7.5 [2]	2.4 [3]	0.6 [3]	
Passenger	p-km	2.2E+13 [4]			
Car	*p-km*	*1.7E+16* [4]			
Air	*p-km*	*5.5E+15* [4]			
Cars/Light Trucks	$MtCO_{2eq}$		1,199 [5,6]	75 [5,6]	
Air	$MtCO_{2eq}$		282 [5,6]	88 [5,6]	
Buses /minibuses	$MtCO_{2eq}$		17 [5,6]	109 [5,6]	
2/3 wheeler	$MtCO_{2eq}$		6 [5,6]	83 [5,6]	
Rail	$MtCO_{2eq}$		2 [5,6]	23 [5,6]	
Weighted total	$MtCO_{2eq}$	4,800 [7]	1,506	377	
			31%	8%	
GHG emissions	$GtCO_{2eq}$	5.3 [8]	1.67	0.42	
	tCO2/person/year	**0.77**	**4.86**	**0.31**	
Freight	t-km	4.7E+13 [4]			
Truck	*t-km*	*1.4E+16* [4]			
Train	*t-km*	*2.1E+16* [4]			
Ship	*t-km*	*1.2E+16* [4]			
Rail	$MtCO_{2eq}$		36 [6,9]	40 [6,9]	
Road	$MtCO_{2eq}$		495 [6,9]	120 [6,9]	
Weight total	$MtCO_{2eq}$	2,700 [10]	531	160	
			20%	6%	
GHG emissions	$GtCO_{2eq}$	4.1 [8]	0.8	0.2	
	tCO2/person/year	**0.59**	**2.59**	**0.18**	
WASHING					
	m3K	*1.5E+12* [4]			
	Nm	*2.8E+18* [4]			
Final Energy	EJ	33 [4]	2.7 [11]	5.3 [12]	
			8%	16%	
GHG emissions	$GtCO_{2eq}$	3.1 [8]	0.3	0.5	
	tCO2/person/year	**0.45**	**0.82**	**0.37**	
THERMAL COMFORT					
	m3K	*3.0E+16* [4]			
Final Energy	EJ	59 [4]	6.0 [11]	5.8 [12]	
			10%	10%	
GHG emissions	$GtCO_{2eq}$	5.01 [8]	0.5	0.5	
	tCO2/person/year	**0.73**	**1.63**	**0.37**	
ILLUMINATION					
	lm.s	*4.80E+20* [4]			
	lm.s/person	7.6E+10 [13]	3.6E+11 [14]	3.6E+10 [14]	
efficacy	lm/W	48 [15]	50 [15]	58 [15]	
electricity	J/person	1.6E+09	7.3E+09	6.2E+08	
	EJ	11	2.5E+00	8.3E-01	
			23%	8%	
GHG emissions	$GtCO_{2eq}$	1.6 [8]	0.37	0.12	
	tCO2/person/year	**0.23**	**1.19**	**0.09**	
COMMUNICATION					
Digital	*byte*	*2.80E+20* [4,16]			
Computer ownership	per person	0.15 [17]	0.806 [17]	0.056 [17]	
Computers		1.1E+09	2.8E+08	7.5E+07	
	byte	1.8E+21 [18]	4.8E+20	1.3E+20	
GHG emissions	$GtCO_{2eq}$	0.9 [8]	0.24	0.06	
	tCO2/person/year	**0.13**	**0.76**	**0.05**	
INDUSTRY					
Structure (total)	$m^3\ MPa^{2/3}$	*1.2E+10* [4]			
	$GtCO_{2eq}$	16.0	1.9	5.4	
direct emissions	%		12% [19]	34% [19]	
Steel	$m^3\ MPa^{2/3}$	*7.7E+08* [4]			
Apparent steel consumption	*kg/person*	206 [20]	267.3 [20]	427.4 [20]	
Apparent steel consumption	*Mt*	1,422	83.0	573.3	
Steel production	*Mt*	1,417 [20]	80.5 [20]	626.7 [20]	
Trade (net exports)	*Mt*		-2.5	53.4	
GHG emissions (prod.)	MtCO2eq	2,979 [8]	115 [8]	1,938 [8]	
Emissions intensity	tCO2/t steel	2.10	1	3	
GHG emissions (cons.)	MtCO2eq	2,979 [8]	120 [20]	1,773 [20]	
Steel total	GtCO2eq	3.0 [8]	0.1	1.8	
Steel	**tCO2/person/year**	**0.43**	**0.39**	**1.32**	
Chemicals	$m^3\ MPa^{2/3}$	6.4E+07 [4]			
	GtCO2eq	3 [8]	1	2 [21]	
Chemicals	**tCO2/person/year**	**0.45**	**3.47**	**1.14**	
Cement/concrete	$m^3\ MPa^{2/3}$	*1.1E+10* [4]			
Cement consumption	Mt	3,310 [22]	67 [22]	1,880 [22]	
GHG emissions	MtCO2eq	2,782 [8]	14803% [8]	139925% [8]	
Emissions intensity	tCO2/t cement	0.8	2.2	0.7	
	GtCO2eq	2.8 [8]	0.1	1.4	
Cement	**tCO2/person/year**	**0.40**	**0.48**	**1.04**	

INDUSTRY CONTINUED	UNITS	GLOBAL	USA	CHINA
Non-ferrous	$m^3MPa^{2/3}$	7.5E+07 [4]		
Al consumption	Mt	41 [23]	12.0 [23]	7.0 [23]
Al consumption (adj.)	Mt	38	7.6 [23]	6.5 [23]
Al production	Mt	38 [23]	2.6 [23]	12.6 [23]
(AL production)	Mt	41	4.7	16.1
Trade (net exports)	Mt		-5.0	6.1
GHG emissions (prod.)	MtCO2eq	1,035 [8]	174.4 [8]	565.6 [8]
Emissions intensity	tCO2/t aluminium	27	68.4	44.9
GHG emissions (cons.)	MtCO2eq	1,035 [8]	311 [23]	314 [23]
6%	GtCO2eq	1.0 [8]	0.3	0.3
Non-ferrous	**tCO2/person/year**	**0.15**	**1.00**	**0.23**
Food processing				
GHG emissions	MtCO2eq	585.0 [8]	161.6 [8]	256.8 [8]
	GtCO2eq	0.6	0.2	0.3
Food processing	**tCO2/person/year**	**0.08**	**0.52**	**0.19**
Paper				
Paper consumption	kg/person	55.0 [25]	304.0 [25]	46.0 [25]
Paper consumption	Mt	362	91	60
GHG emissions	MtCO2eq	897 [8]	143 [8]	142 [8]
	GtCO2eq	0.9	0.1	0.1
Paper	**tCO2/person/year**	**0.13**	**0.46**	**0.11**
Textiles	*Mt*	*70.5* [26]		
Textiles consumption	kg/person	10 [27]	36.0 [27]	8.5 [27]
Textiles consumption	Mt	72	11.2	11.4
Manmade fibres production	Mt	42 [26]	2.3 [26]	26.3 [26]
Cotton production	Mt	22 [26]	2.7 [26]	6.9 [26]
Other production	Mt	7	0.8	2.2
Textiles production	Mt	72 [26]	5.8	35.4
Trade (net exports)	Mt		-5.3	24.0
GHG emissions (prod.)	MtCO2eq	271 [8]	34 [8]	242 [8]
Emissions intensity	tCO2/t fibre	4	6	7
GHG emissions (cons.)	MtCO2eq	271 [8]	54.1 [27]	77.9 [27]
	GtCO2eq	0.3	0.03	0.24
Textiles	**tCO2/person/year**	**0.04**	**0.11**	**0.18**
Other industry			4%	46%
GHG emissions	MtCO2eq	4380 [8]	338 [8]	990 [8]
	GtCO2eq	4.4	0.3	1.0
Other industry	**tCO2/person/year**	**0.64**	**0.74**	**0.74**
SETTLEMENTS				
	% of global		5% [28]	50% [28]
GHG emissions	MtCO2eq	670.8	3569%	33735%
	GtCO2eq	0.7	0.0	0.3
Other industry	**tCO2/person/year**	**0.10**	**0.11**	**0.37**
FOOD				
Total food	kcal	7.1E+15 [8]		
GHG emissions		12.1		
	tCO_2/person/year	**2.22**	**4.85**	**2.10**
Vegetal food	***J (food)***			
Food consumption	kcal/person/day	2,330 [29]	2,675 [29]	2,342 [29]
Food production	kcal/person/day		3,265 [29]	2,260
Trade (net exports)			590	-82
Emission efficiency	kg CO2/1000 kcal	1.4	2.7 [30]	1.5 [30]
GHG emissions	GtCO2eq	8.2 [8]	0.83	1.72
Vegetal food	**tCO2/person/year**	**1.18**	**2.66**	**1.28**
Animal food				
Food consumption	kcal/person/day	501 [29]	1,013 [29]	694 [29]
Food production	kcal/person/day		1,049 [29]	658 [29]
Trade (net exports)			36	-36
Emission efficiency	kg CO2/1000 kcal	5.9	5.9 [30]	3.1 [30]
GHG emissions	GtCO2eq	7.1 [8]	0.68	1.09
Animal food	**tCO2/person/year**	**1.03**	**2.19**	**0.82**
WASTE				
	GtCO2eq	1.68 [8]	0.03	0.19
	tCO_2/person/year	**0.24** [31]	**0.11** [31]	**0.14** [31]

[1] Population data for 2006 and 2010[36]

[2] Well-to-wheel transport CO_2eq emissions, for 2007 (IEA[37], p.606, fig 16.6)

[3] Well-to-wheel transport CO_2eq emissions by region, for 2007 (IEA[37], p.270, fig 7.12)

[4] Physical energy service estimates from Cullen and Allwood[9]; final energy values from Cullen and Allwood[38]

[5] Passenger data by region for 2005 in passenger-kilometres (IEA[5], p.210, fig 5.6).Values are calculated by taking vehicle stock data,

[6] Emissions intensity values for each type of passenger vehicle and freight vehicle, for OECD versus non-OECD, for 2007 (IEA[37], p.261, fig 7.5). Emissions intensities are multiplied with passenger/tonne kilometres for each vehicle type, to give absolute CO2eq emissions.

[7] Total passenger CO2eq emissions, wheel to wheel for 2007 is 4.8GtCO2eq (IEA[37], p.267, fig 7.9).

[8] GHG emissions from the Sankey diagram analysis in this paper, and for the USA and China

[9] Freight data by region for 2007 in tonne-kilometres (IEA[37], p.260, fig 7.4).

[10] Total freight CO2eq emissions, wheel to wheel for 2007 is 2.7 GtCO2eq (IEA[37], p.268, fig 7.10).

[11] Final energy data for USA[11] (p.140-142)

[12] Final energy data for China[12]

[13] "For 2005 it is estimated that the global consumption of artificial light was 134.7 petalumen-hours (Plmh), of which 99.0% (133.3 Plmh) was for electric grid connected lighting, 0.9% (1.3 Plmh) for vehicle lighting and 0.1% (0.086 Plmh) for off-grid fuel-based lighting. Overall this amounts to an average annual consumption of 21 megalumen-hours (Mlmh) of artificial light per person" (IEA [39] p173).

[14] Estimated light consumption per person in 2005 for North America (101Mlmh) and China (10Mlmh) (IEA[39] p.173, fig 4.1)

[15] Average lighting-system efficacy (=efficiency) in 2005 for North America (50lm/W) and China (58lm/W) (IEA 2006, p.44, fig OR.4), with the global average in 2005 equal to 48 lm/W (IEA[39], p.44).

[16] The digital universe in 2007: 2.25 x 1021 bits (=281 exabytes=281 billion gigabytes)[40] (p2); 280 x10[18] Cullen and Allwood[9].

[17] Computer ownership per person in 2006[41] is used as a proxy for determining the bytes in USA and China.

[18] The amount of information created and replicated in 2011 is estimated to surpass 1.8 zettabytes (1.8 trillion gigabytes) [40].

[19] Breakdown of direct emissions: North America 13%, China 34%. North America is adjusted using the ratio of population, to get a % for USA. The Other Industry category is adjusted so that the same breakdown is found for all industry GHG emissions.

[20] Production of Crude Steel (World Steel Association [30], Table 1) and Apparent Steel Use per Capita (finished steel products) (World Steel Association [30], Table 40). Consumption of 'finished steel' does not consider steel embedded in final products (cars, ships, machines, white goods, etc), called indirect trade in steel. We correct for international trade by using country-based emissions intensities for indigenousness production consumed within the country and an average global emissions intensity for imported products.

[21] The GHG emissions for Chemicals are allocated to USA and China based on reported energy use (incl. feedstocks and electricity) in 2006 (IEA[42], p.114, tab 4.2)

[22] Cement production data for 2010[43]. Cement production and consumption are closely matched for countries given the low value per mass of cement products making local production more cost-effective.

[23] Production data for aluminium by region, for 2007 (IEA 2009 [42], p.161, tab 6.1). Consumption data for aluminium by region, for 2006 (IEA 2009 [42], p.171, tab 6.3) is adjusted to match 2007 production data (prorata for US and China based on drop in global production from 41Mt in 2006 to 38Mt in 2007), while N.Amerian consumption data is corrected to US based using a per capita basis. COnsumption does include trade of final products. Aluminium is used as a proxy for all non-ferrous metal production. We correct for international trade by using country-based emissions intensities for indigenousness production consumed within the country and an average global emissions intensity for imported products.

[24] Primary energy data for food processing, by region, for 2009 (IEA 2009)

[25] Per capita consumption of paper and paperboard, by region, for 2006 (IEA 2009 [42], p.146, tab 5.4). Production of paper and paperboard, for 2006 (IEA 2009 [42], p.147, tab 5.6).

[26] World supply of fibre (including manmade and cotton/wool/silk) for 2009 (Oerlikon 2010, p.5)

[27] Per capita textile fibre available for consumption (cotton, wool, flax, cellulosic, synthetics) for 2008, which accounts for mill consumption plus the trade balance of fibre/textiles[45] (p.7). We correct for international trade by using country-based emissions intensities for indigenousness production consumed within the country and an average global emissions intensity for imported products.

[28] The GHG emissions from land use change for settlements are calculated for USA and China based on the production of cement.

[29] Food production and consumption data, by region, for 2009 from FAOSTAT Food Balances.[23.] We correct for international trade by using country-based emissions intensities for indigenousness production consumed within the country and an average global emissions intensity for imported products.

[30] Emissions intensity of food production, by region, calculated by taking regional emissions from this paper (based on IEA Energy Balances[3], IEA CO_2 dataset[1], EDGAR[2]) divided by food production in China and USA[23]

[31] Landfill, wastewater and other waste handling emissions for US and China, EDGAR[2]

Table S20 Allocation of per person emissions, for the world, USA and China, to final services

	World	USA	China	World	Travel	Commuting	Freight	Washing	Thermal comfort	Illumination	Communication	Textiles	Industrial Equipment	Construction	Food	Waste	
	tCO2/person/year			GtCO2													
Services in physical units (annual flow)					1.6E+13 passenger-km	6.3E+12 passenger-km	4.7E+13 tonne-km	1.5E+12 m3K 2.8E+18 Nm (work)	3.0E+16 m3K	4.8E+20 lm.s	2.8E+20 bytes	7.1E+01 tonnes (fibre)	1.9E+08 tonnes (steel/aluminum)	1.2E+10 m3MPa2/3	6.9E+15 kcal (food)	8.4E+08 tonnes	
Passenger	0.72	3.40	0.29	5.0	72%	28%											
Freight transport	0.57	2.50	0.17	3.9			100%										
Washing	0.45	0.82	0.37	3.1				100%									
Thermal comfort	0.73	1.63	0.37	5.0					100%								
Illumination	0.23	1.58	0.09	1.6						100%							
Communication	0.13	1.01	0.05	0.9							100%						
Steel	0.43	0.39	1.32	3.0	7.2%	2.8%	5.0%	2.3%	0.8%		3.0%		20.8%	53.8%	4.5%		
Chemicals	0.45	3.47	1.14	3.1	4.4%	1.7%	1.8%	17.4%			7.9%	10.5%		20.2%	36.1%		
Cement	0.40	0.48	1.04	2.8										100.0%			
Non-ferrous	0.15	1.00	0.23	1.0	15.1%	5.9%	7.0%	0.9%			2.3%	0.0%	23.3%	30.3%	14.8%		
Food processing	0.08	0.52	0.19	0.6											100.0%		
Paper	0.13	0.46	0.11	0.9				12.3%			50.9%			12.3%	24.5%		
Textiles	0.04	0.11	0.18	0.3								100.0%					
Other industry	0.64	0.74	0.74	4.4	6%	2%	3%	11%			12%	3%	17%	36%	11%		
Settlements	0.10	0.11	0.37	0.7										100.0%			
Food	2.22	4.85	2.10	12.6											100%		
Waste	0.24	0.54	0.22	1.7												100%	
TOTAL	7.71	23.61	8.99	50.5													**Total**
World			tCO2/per	7.7	0.63	0.25	0.63	0.63	0.73	0.23	0.32	0.11	0.23	1.11	2.61	0.24	**7.7**
USA			tCO2/per	23.6	2.82	1.10	2.67	1.59	1.64	1.58	1.64	0.50	0.44	2.12	6.98	0.54	**23.6**
China			tCO2/per	9.0	0.43	0.17	0.30	0.70	0.38	0.09	0.32	0.32	0.45	2.71	2.90	0.22	**9.0**

Estimates of services in physical units have been taken from Cullen and Allwood [9], except for: animal and vegetal food, FAO [23]; steel and aluminium (post-fabrication) in mechanical and electrical industrial equipment, Cullen et al. [31]; the fibre in textiles, Oerlikon [44]; landfilled waste, Matthews and Themelis. [46]

Table S21 Calculations for Commuting mitigation options

		Emission reductions from mitigation options applied separatelly (Tg of CO_{2e})						Emission reductions from mitigation options applied togehter, in order from left to right (Tg of CO_{2e})					
Represented tecnologies (chains)	Assumed emission factor (gCO_{2e} / pkm)	Demand reduction: 20% car sharing	20% modal swich to train	Vehicle light-weighting	Technology switch: all to diesel	Car engine improvements	False total mitigation potential (without interactions)	Demand reduction: car sharing	20% modal swich to train	Vehicle light-weighting	Technology switch: all to diesel	Car engine improvements	True total mitigation potential (including interactions)
Petrol car	186	224	224	224	1122	224		224	179	144	574	0	
Diesel car	160	43	43	43	-965	43		43	34	27	-494	121	
Petrol bus	48	0	7	39	169	0		0	0	0	169	0	
Diesel bus	40	0	0	6	-141	0		0	0	0	-106	0	
Diesel train	46	0	-33	2	0	0		0	-27	0	0	0	
Electric train	41	0	-29	6	0	0		0	-24	0	0	0	
Embodied emissions		52	0	65	0	0		52	0	54	0	0	
Total		319	211	385	185	267	**1368**	319	163	225	143	121	**971**
% reduction of direct car emissions only		20%	20%	20%	12%	20%	**92%**	20%	12%	13%	6%	9%	**60%**
% reduction on total commuting (incl. ind.)		17%	11%	20%	10%	14%	**72%**	17%	9%	12%	8%	6%	**51%**

References in Supplementary Information

1. *CO_2 Emissions from Fuel Combustion (Edition: 2012*), International Energy Agency, ESDS International, University of Manchester, 2012; DOI: http://dx.doi.org/10.5257/iea/co2/2012, 2012

2. *Emission Database for Global Atmospheric Research (EDGAR), release version 4.2.,* European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL), 2012; http://edgar.jrc.ec.europa.eu

3. *World Energy Balances (Edition: 2012),* International Energy Agency, ESDS International, University of Manchester, 2012; DOI: http://dx.doi.org/10.5257/iea/web/2012, 2012

4. Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K. Eds; *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2*. The Intergovernmental Panel on Climate Change, IGES, Japan, 2006.

5. *Transport, energy and CO2;* International Energy Agency, OECD Paris, 2009.

6. *Eurostat*, Air transport statistics website. http://epp.eurostat.ec.europa.eu/portal/page/portal/transport/data/main_tables

7. *Railway handbook 2012: Energy consumption and CO2 emissions*, International Energy Agency, International union of Railways, 2012

8. *Review of UK shipping emissions*; Committee on Climate Change, London, UK, 2011.

9. Cullen, J. M.; Allwood, J. M. The efficient use of energy: Tracing the global flow of energy from fuel to service. *Energy Policy* **2010**, 38, 75–81.

10. *Worldwide Trends in Energy Use and Efficiency*, International Energy Agency, Paris, 2008.

11. *Annual Energy Outlook* 2012; U.S. Energy Information Administration, 2012.

12. Zhou, N.; Mcneil, M. A.; Fridley, D.; Lin, J.; Price, L.; De, S.; Sathaye, J.; Levine, M. *Energy Use in China : Sectoral Trends and Future Outlook*; 2007.

13. *Energy Use, Loss and Opportunities Analysis: US Manufacturing & Mining*, US Department of Energy, 2004.

14. *Life cycle assessment of aluminium: inventory data for the primary aluminium industry*, International Aluminium Institute, 2007.

15. Nakicenovic, N.; Gilli, P. V.; Kurz, R. Regional and global exergy and energy efficiencies. *Energy* **1996**, *21*, 223–237.

16. *Energy Technology Perspectives*, International Energy Agency, Paris, 2006

17. Ayres, R. U.; Ayres, L. W.; Pokrovsky, V. On the efficiency of US electricity usage since 1900. *Energy* **2005**, *30*, 1092–1145USGS, "2008 Minerals Yearbook- Lime" (2010).

18. 2008 Minerals Yearbook- Lime; United States Geological Society, 2010

19. Geist, H. J.; Lambin, E. F. Proximate Causes and Underlying Driving Forces of Tropical Deforestation. *BioScience* **2002**, *52*, 143–150.

20. *Investement and financial flows to address climate change*; United Nations Framework Convention on Climate Change, 2007.

21. Houghton, R. A. Carbon emissions and the drivers of deforestation and forest degradation in the tropics. *Current Opinion in Environmental Sustainability* **2012**.

22. Haberl, H.; Sprinz, D.; Bonazountas, M.; Cocco, P.; Desaubies, Y.; Henze, M.; Hertel, O.; Johnson, R. K.; Kastrup, U.; Laconte, P.; Lange, E.; Novak, P.; Paavola, J.; Reenberg, A.; van den Hove, S.; Vermeire, T.; Wadhams, P.; Searchinger, T. Correcting a fundamental error in greenhouse gas accounting related to bioenergy. *Energy Policy* **2012**, *45*, 18–23.

23. FAO Statistical Databases: Food balances 2009. (http://faostat.fao.org/site/377/default.aspx#ancor, 2012).

24. Heffer P., Assessment *of Fertilizer Use by Crop at the Global Level*, International Fertilizer Industry Association, Paris, 2009.

25. Production of biofuels in the world in 2008, The Biofuels Platform, www.biofuels-platform.ch/en/infos/production.php

26. FAO Statistical Databases: Forestry 2008 http://faostat.fao.org/site/377/default.aspx#ancor

27. *National Travel Survey 2008*, Department for Transport Statistics, http://www.dft.gov.uk/statistics/series/national-travel-survey

28. *Highlights of the 2001 National Household Travel Survey*, U.S. Department of Transportation, Bureau of Transport statistics, 2003; http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/highlights_of_the_2001_national_household_travel_survey/pdf/entire.pdf

29. *CAA Passenger Survey Report 2007 / 2008.* United Kingdom Civil Aviation Authority; http://www.caa.co.uk/docs/81/2007CAAPaxSurveyReport.pdf

30. *2008 Sustainability Report of the world steel industry*, World Steel Association; http://www.worldsteel.org/publications/bookshop?bookID=f13f3d5c-7c1e-4e4f-ae81-4fcb738c439a

31. Cullen, J.M.; Allwood, J.M.; Bambach M. Mapping the global flow of steel: from steelmaking to end-use products, *Environmental Science and Technology*, **2012,** *46*(24), 13048–13055.

32. *Tracking Industrial Energy Efficiency and CO2 Emissions,* International Energy Agency, OECD, Paris, 2007.

33. *Global Aluminium Recycling: A Cornerstone of Sustainable Development,* The Global Aluminium Recycling Committee, 2006. http://www.world-aluminium.org/cache/fl0000181.pdf

34. *Energy balances of Non-OECD Countries. Documentation for beyond 2020 files.* International Energy Agency, OECD, Paris, 2012. pp. 1–89.

35. United Nations Statistics Division, Detailed structure and explanatory notes on ISIC Rev.4; http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=27

36. United Nations, Population website, http://esa.un.org/unpd/wpp/Sorting-Tables/tab-sorting_population.htm

37. *Energy Technology Perspectives*, International Energy Agency, OECD, Paris, 2010.

38. Cullen, J. M.; Allwood, J. M. Theoretical efficiency limits for energy conversion devices. *Energy* **2010**, 35, 2059–2069.

39. *Light's labour's lost: policies for energy-efficient lighting,* International Energy Agency, Paris, 2006.

40. Gantz J.; Reinsel D. Extracting Value from Chaos. http://uk.emc.com/collateral/analyst-reports/idc-extracting-value-from-chaos-ar.pdf, 2011

41. Econostats website http://www.econstats.com/wdi/wdiv_597.htm

42. *Energy Technology Transitions for Industry: strategies for the next industrial revolution*, International Energy Agency, Paris, 2009

43. *Cement: mineral commodity study,* United States Geological Survey; http://minerals.usgs.gov/minerals/

44. *The fibre year 2009/10: A world survey on textile and nonwovens industry,* Oerlikon. http://www.oerlikontextile.com/Portaldata/1/Resources/saurer_textile_solutions/media_center/fiber_year_2009_10/The_Fibre_Year_2010_en_0607.pdf

45. *A summary of the world apparel fibre consumption survey 2005-2008,* FAO http://www.fao.org/fileadmin/templates/est/comm_markets_monitoring/Cotton/Documents/World_Apparel_Fiber_Consumption_Survey_2011_-_Summary_English.pdf

46. Matthews, E.; Themelis, N. J. Potential for Reducing Global Methane Emissions From Landfills, 2000-2030. In *Eleventh International Waste Management and Landfill Symposium*; 2007; pp. 1–5.