Physical Constraints on Global Social-Ecological Energy System

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This file contains four tables.

Table S1 details world power plant losses, total production and final consumptions and efficiency (i.e.: ratio between total final consumption and total production) from year 1990 to year 2015. Data are expressed in units of [TW], except from efficiency, expressed as percentage.

Table S2 contains the data for performance analysis at Country level for selected Countries (DATA source: IEA). The first column refers to Total Primary Power Supply (derived from Total Primary Energy Supply). The second column refers to efficient power, calculated as the product of efficiency (at Country level: TPES/final consumption) and final power consumption. Data are expressed in units of terawatts, referring to years 2000, 2005, 2010 and 2015. Countries in red identify the nations, whose performance is below the optimum level defined by maximum empower principle. In parallel, Countries in red identify the nations, whose performance is above the optimum level defined by maximum empower principle.

Table S3 contains data of total World power production (in [TW]), world GDP (in billion USD) and energy efficiency (as power intensity, according to International Energy Agency definition). Data refer to the years' period 1990-2011.

Table S4 contains data of world Total Primary Energy Production, sectorial energy consumption (for: (i) industry, agriculture and fisheries; (ii) services, excluding residential sector; (iii) residential sector) and power plant losses. Values, expressed in terawatts, refer to years 1973-2015 (DATA source: IEA).

Table S1. World power plant losses, total production and final consumptions. Data are expressed in units of [W]. Efficiency, being the ratio between total final consumption and total production, is expressed as percentage.

Year	Power plant losses [TW]	Total production [TW]	Total final consumtpion [TW]	Efficiency
1990	2.11	11.68	8.31	71.2%
1991	2.18	11.70	8.39	71.7%
1992	2.22	11.64	8.37	71.9%
1993	2.23	11.81	8.42	71.3%
1994	2.28	11.98	8.46	70.6%
1995	2.36	12.28	8.67	70.6%
1996	2.49	12.57	8.82	70.1%
1997	2.52	12.74	8.93	70.0%
1998	2.57	12.89	8.94	69.4%
1999	2.59	12.91	9.11	70.6%
2000	2.68	13.29	9.33	70.2%
2001	2.76	13.51	9.38	69.4%
2002	2.80	13.60	9.53	70.0%
2003	2.92	14.16	9.82	69.3%
2004	3.05	14.85	10.26	69.1%
2005	3.16	15.31	10.52	68.7%
2006	3.25	15.76	10.79	68.5%
2007	3.34	16.02	11.10	69.3%
2008	3.34	16.34	11.20	68.5%
2009	3.30	16.20	11.07	68.4%
2010	3.49	16.97	11.64	68.6%
2011	3.57	17.39	11.83	68.0%

2012	3.61	17.62	11.95	67.8%
2013	3.65	17.87	12.17	68.1%
2014	3.69	18.17	12.31	67.8%
2015	3.67	18.28	12.44	68.0%

Table S2. Performance analysis at Country level for selected Countries (DATA source: IEA). The first column refers to Total Primary Power Supply (derived from Total Primary Energy Supply). The second column refers to efficient power, calculated as the product of efficiency (at Country level: TPES/final consumption) and final power consumption. Data are expressed in units of terawatts, referring to years 2000, 2005, 2010 and 2015. Data are ranked in growing order of W_{in}. Countries in red identify the nations, whose performance is below the optimum level defined by maximum empower principle. In parallel, Countries in red identify the nations, whose performance is above the optimum level defined by maximum empower principle.

	2000			2005			2010			2015	
Country	P [TW]	Win [TW]	Country	P [TW]	Win [TW]	Country	P [TW]	Win [TW]	Country	P [TW]	Win [TW]
Iceland	0.00	0.00	Iceland	0.00	0.00	Luxembourg	0.00	0.01	Luxembourg	0.00	0.00
Luxembourg	0.00	0.00	Luxembourg	0.00	0.01	Latvia	0.00	0.01	Latvia	0.00	0.01
Latvia	0.00	0.01	Latvia	0.00	0.01	Iceland	0.00	0.01	Estonia	0.00	0.01
Estonia	0.00	0.01	Estonia	0.00	0.01	Estonia	0.00	0.01	Iceland	0.00	0.01
Slovenia	0.00	0.01	Slovenia	0.00	0.01	Slovenia	0.00	0.01	Slovenia	0.00	0.01
Morocco	0.01	0.01	Ireland	0.01	0.02	Ireland	0.01	0.02	Ireland	0.01	0.02
Ireland	0.01	0.02	Morocco	0.01	0.02	Morocco	0.01	0.02	Denmark	0.01	0.02
New Zealand	0.01	0.02	New Zealand	0.01	0.02	Slovak Republic	0.01	0.02	Slovak Republic	0.01	0.02
Slovak Republic	0.01	0.02	Israel	0.01	0.02	New Zealand	0.01	0.02	Morocco	0.01	0.03
Israel	0.01	0.02	Slovak Republic	0.01	0.02	Denmark	0.01	0.03	New Zealand	0.01	0.03
Denmark	0.01	0.02	Denmark	0.01	0.03	Israel	0.01	0.03	Portugal	0.01	0.03
Singapore	0.00	0.02	Singapore	0.00	0.03	Portugal	0.02	0.03	Israel	0.01	0.03
Portugal	0.02	0.03	Switzerland	0.02	0.03	Singapore	0.01	0.03	Greece	0.01	0.03
Hungary	0.01	0.03	Portugal	0.02	0.04	Switzerland	0.02	0.03	Switzerland	0.02	0.03
Switzerland	0.02	0.03	Norway	0.02	0.04	Hungary	0.01	0.04	Hungary	0.02	0.03

	2000			2005			2010			2015	
Country	P [TW]	Win [TW]	Country	P [TW]	Win [TW]	Country	P [TW]	Win [TW]	Country	P [TW]	Win [TW]
Chile	0.02	0.03	Hungary	0.02	0.04	Greece	0.02	0.04	Singapore	0.01	0.04
Norway	0.02	0.03	Chile	0.02	0.04	Norway	0.02	0.04	Norway	0.01	0.04
Greece	0.02	0.04	Greece	0.02	0.04	Chile	0.02	0.04	Finland	0.02	0.04
Austria	0.02	0.04	Austria	0.03	0.04	Austria	0.03	0.04	Austria	0.03	0.04
Finland	0.02	0.04	Finland	0.02	0.05	Finland	0.02	0.05	Chile	0.02	0.05
Czech Republic	0.02	0.05	Czech Republic	0.02	0.06	Czech Republic	0.02	0.06	Czech Republic	0.02	0.06
Sweden	0.03	0.06	Sweden	0.03	0.07	Sweden	0.03	0.07	Sweden	0.03	0.06
Belgium	0.03	0.08	Belgium	0.03	0.08	Belgium	0.03	0.08	Belgium	0.03	0.07
Thailand	0.04	0.10	Netherlands	0.04	0.11	Netherlands	0.04	0.11	Netherlands	0.03	0.10
Netherlands	0.04	0.10	Turkey	0.06	0.11	Poland	0.06	0.13	Poland	0.05	0.13
Turkey	0.05	0.10	Poland	0.05	0.12	Turkey	0.06	0.14	Spain	0.06	0.16
Poland	0.04	0.12	Thailand	0.04	0.13	Thailand	0.05	0.16	Australia	0.06	0.17
Australia	0.05	0.14	Australia	0.05	0.15	Australia	0.05	0.17	Turkey	0.08	0.17
Spain	0.06	0.16	Spain	0.08	0.19	Spain	0.08	0.17	Thailand	0.06	0.18
Mexico	0.07	0.20	Indonesia	0.11	0.24	Italy	0.12	0.23	Italy	0.11	0.20
Indonesia	0.10	0.21	Mexico	0.07	0.24	Mexico	0.09	0.24	United Kingdom	0.10	0.24
Italy	0.11	0.23	Italy	0.13	0.25	United Kingdom	0.11	0.27	Mexico	0.09	0.25
Brazil	0.14	0.25	Korea	0.08	0.28	Indonesia	0.11	0.27	Indonesia	0.15	0.30
Korea	0.07	0.25	Brazil	0.16	0.29	Korea	0.08	0.33	France	0.10	0.33
United Kingdom	0.12	0.30	United Kingdom	0.11	0.30	Canada	0.14	0.35	Korea	0.08	0.36
France	0.11	0.33	France	0.11	0.36	France	0.11	0.35	Canada	0.14	0.37
Canada	0.15	0.34	Canada	0.15	0.36	Brazil	0.19	0.35	Brazil	0.20	0.39
Germany	0.17	0.45	Germany	0.17	0.45	Germany	0.17	0.43	Germany	0.17	0.41
India	0.25	0.59	India	0.28	0.68	Japan	0.20	0.66	Japan	0.21	0.57
Japan	0.22	0.69	Japan	0.22	0.69	India	0.38	0.93	India	0.41	1.11
People's Republic of China	0.61	1.50	People's Republic of China	0.97	2.37	United States	1.14	2.94	United States	1.15	2.90

| Country | 2000 | | Country | 2005 | | Country | 2010 | | Country | 2015 | |
	P [TW]	Win [TW]		P [TW]	Win [TW]		P [TW]	Win [TW]		P [TW]	Win [TW]
United States	1.13	3.02	United States	1.13	3.08	People's Republic of China	1.20	3.37	People's Republic of China	1.44	3.97

Table S3. Total World power production (in [W]), world GDP (in USD), and energy efficiency (as energy intensity, according to IEA definition)

Year	Total production [TW]	GDP [billion USD] (year 2011 values)	Energy efficiency (as energy intensity) [W/USD]
1990	11.68	38.13	306.26
1991	11.70	38.97	300.28
1992	11.64	39.82	292.26
1993	11.81	40.66	290.50
1994	11.98	42.05	284.90
1995	12.28	43.42	282.78
1996	12.57	45.05	279.09
1997	12.74	46.88	271.86
1998	12.89	48.08	267.99
1999	12.91	49.83	259.12
2000	13.29	52.22	254.54
2001	13.51	53.42	252.82
2002	13.60	54.95	247.60
2003	14.16	56.94	248.76
2004	14.85	59.71	248.65

2005	15.31	62.44	245.24
2006	15.76	65.73	239.70
2007	16.02	69.31	231.17
2008	16.34	71.24	229.38
2009	16.20	70.77	228.86
2010	16.97	74.38	228.07
2011	17.39	77.21	225.23

Table S4. World Total Primary Energy Production, sectorial energy consumption (for: (i) industry, agriculture and fishing; (ii) services, excluding residential sector; (iii) residential sector) and power plant losses. Values, expressed in terawatts, refer to years 1973-2015 (DATA source: IEA).

Year	Total Primary Energy Production [TW]	Energy Consumption [TW]			Power plant losses (TS) [TW]
		Industry, agriculture and fisheries (pV)	Services (excl. residential sector) (E)	Residential (N)	
1973	8.10	2.21	2.15	1.45	1.05
1974	8.15	1.65	2.14	1.44	1.08
1975	8.21	2.18	2.14	1.55	1.12
1976	8.66	2.30	2.25	1.56	1.21
1977	9.32	2.42	2.31	1.58	1.29
1978	9.60	2.48	2.41	1.63	1.33
1979	9.57	2.60	2.46	1.65	1.38
1980	9.50	2.56	2.40	1.69	1.42
1981	9.50	2.52	2.40	1.70	1.44
1982	9.61	2.46	2.38	1.73	1.45
1983	9.61	2.45	2.40	1.75	1.51
1984	9.99	2.57	2.45	1.83	1.61

Year	Total Primary Energy Production [TW]	Energy Consumption [TW]			Power plant losses (TS) [TW]
		Industry, agriculture and fisheries (pV)	Services *(excl. residential sector)* (E)	Residential (ωN)	
1985	10.26	2.56	2.48	1.91	1.69
1986	10.47	2.59	2.56	1.93	1.75
1987	10.86	2.67	2.64	1.98	1.84
1988	11.24	2.75	2.75	2.01	1.94
1989	11.43	2.72	2.81	2.04	2.06
1990	11.65	2.62	3.03	2.04	2.11
1991	11.73	2.61	3.07	2.07	2.18
1992	11.74	2.55	3.08	2.08	2.22
1993	11.86	2.53	2.97	2.27	2.23
1994	11.94	2.53	3.02	2.25	2.28
1995	12.25	2.61	3.06	2.29	2.36
1996	12.56	2.57	3.19	2.34	2.49
1997	12.69	2.61	3.21	2.34	2.52
1998	12.75	2.60	3.26	2.32	2.57
1999	13.02	2.60	3.37	2.36	2.59
2000	13.31	2.68	3.44	2.40	2.68
2001	13.46	2.67	3.47	2.42	2.76
2002	13.74	2.69	3.57	2.44	2.80
2003	14.21	2.79	3.67	2.50	2.92
2004	14.85	3.00	3.82	2.52	3.05
2005	15.27	3.13	3.93	2.53	3.16
2006	15.72	3.28	4.01	2.54	3.25

Year	Total Primary Energy Production [TW]	Energy Consumption [TW]			Power plant losses (TS) [TW]
		Industry, agriculture and fisheries (pV)	Services (excl. residential sector) (E)	Residential (N)	
2007	16.14	3.41	4.15	2.55	3.34
2008	16.33	3.47	4.20	2.58	3.34
2009	16.19	3.37	4.15	2.58	3.30
2010	17.09	3.66	4.32	2.65	3.49
2011	17.34	3.80	4.37	2.63	3.57
2012	17.61	3.81	4.46	2.64	3.61
2013	17.83	3.85	4.57	2.70	3.65
2014	18.06	3.89	4.64	2.70	3.69
2015	18.12	3.87	4.76	2.72	3.67

Table S5. World Total Primary Energy Production, sectorial energy consumption (for: (i) industry, agriculture and fishing; (ii) services, excluding residential sector; (iii) residential sector) and power plant losses. Values, expressed as %, refer to years 1973-2015 (DATA source: IEA).

Year	Energy Consumption [% of TPES]			Power plant losses (TS) [% of TPES]	Differences [%]
	Industry, agriculture and fishing (pV)	Services, excl. residential (E)	Residential (N)		
1973	27%	27%	18%	13%	15%
1974	20%	26%	18%	13%	23%
1975	27%	26%	19%	14%	15%
1976	27%	26%	18%	14%	15%

Year	Energy Consumption [% of TPES]			Power plant losses (TS) [% of TPES]	Differences [%]
	Industry, agriculture and fishing (pV)	Services, excl. residential (E)	Residential (N)		
1977	26%	25%	17%	14%	18%
1978	26%	25%	17%	14%	18%
1979	27%	26%	17%	14%	15%
1980	27%	25%	18%	15%	15%
1981	27%	25%	18%	15%	15%
1982	26%	25%	18%	15%	17%
1983	26%	25%	18%	16%	16%
1984	26%	25%	18%	16%	15%
1985	25%	24%	19%	16%	16%
1986	25%	24%	18%	17%	16%
1987	25%	24%	18%	17%	16%
1988	24%	24%	18%	17%	16%
1989	24%	25%	18%	18%	16%
1990	22%	26%	17%	18%	16%
1991	22%	26%	18%	19%	15%
1992	22%	26%	18%	19%	15%
1993	21%	25%	19%	19%	16%
1994	21%	25%	19%	19%	16%
1995	21%	25%	19%	19%	16%
1996	20%	25%	19%	20%	16%
1997	21%	25%	18%	20%	16%
1998	20%	26%	18%	20%	16%

Year	Energy Consumption [% of TPES]			Power plant losses (TS) [% of TPES]	Differences [%]
	Industry, agriculture and fishing (pV)	Services, excl. residential (E)	Residential (N)		
1999	20%	26%	18%	20%	16%
2000	20%	26%	18%	20%	16%
2001	20%	26%	18%	20%	16%
2002	20%	26%	18%	20%	16%
2003	20%	26%	18%	21%	16%
2004	20%	26%	17%	21%	17%
2005	21%	26%	17%	21%	17%
2006	21%	26%	16%	21%	17%
2007	21%	26%	16%	21%	17%
2008	21%	26%	16%	20%	17%
2009	21%	26%	16%	20%	17%
2010	21%	25%	15%	20%	17%
2011	22%	25%	15%	21%	17%
2012	22%	25%	15%	20%	18%
2013	22%	26%	15%	20%	17%
2014	22%	26%	15%	20%	17%
2015	21%	26%	15%	20%	17%

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