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A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies

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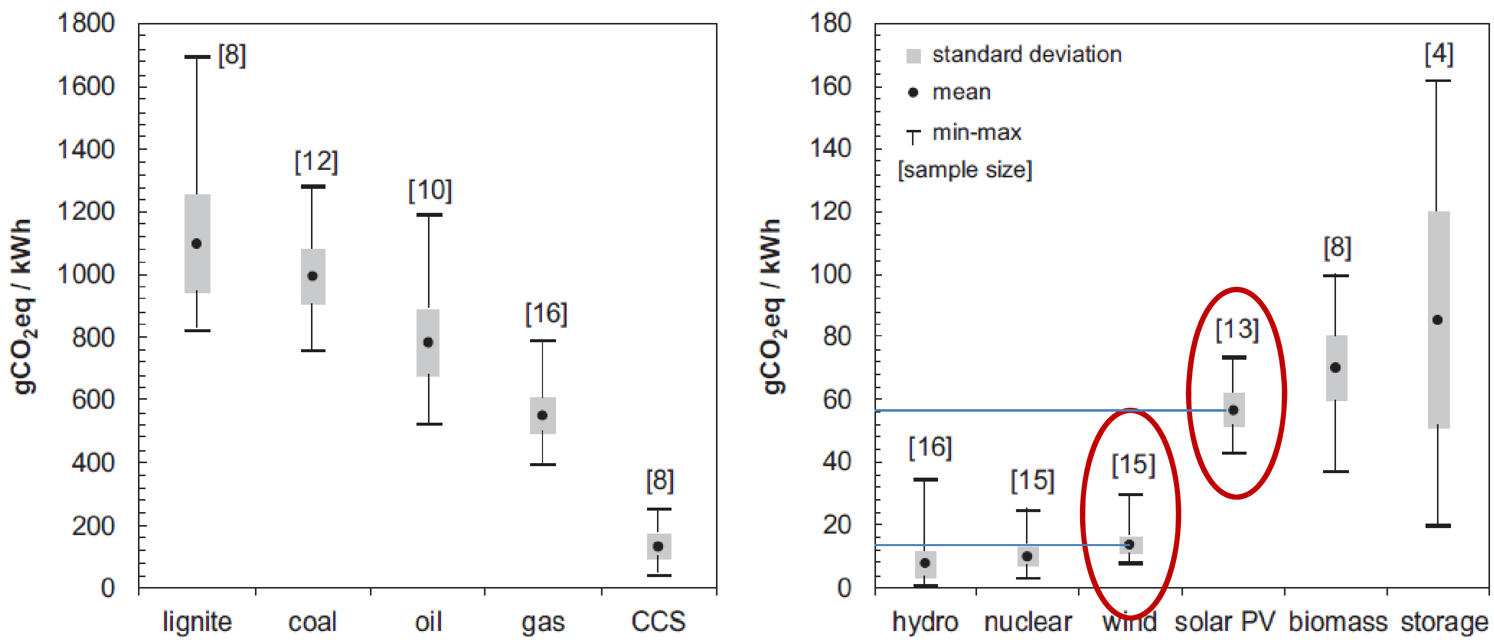

Fig. 5. Summary of life-cycle GHG emissions for selected power plants (*source*: Lignite [10,17,26], coal [10,17,25–28], oil [10,17,20,25,28], natural gas [10,12,17,25–30], carbon capture and storage (CCS) and energy storage systems [23,31,32], nuclear [10,12,17,20,27,28,33,34], solar PV [17,26,28,35,36], wind [17,18,26,28,37–40], hydro [28,41–43], biomass [26,41,44]).

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Review

Life Cycle Assessment of Renewable Energy Generation Technologies

Yohji Uchiyama*

Keywords: renewable energy, generation technology, life cycle assessment, energy balance, carbon-dioxide emission

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Table I. Basic unit of CO_2 emission for each power generation system (Unit : g-C/kWh)

Power generation system	Manufacture of facility	Maintenance	Combustion	Methane leakage	Total
Coal fired power	1.09	9.78	246.33	12.69	269.89
Oil fired power	0.62	7.21	188.41	3.10	200.06
LNG burning power	0.55	24.10	137.27	16.05	177.67
Nuclear power generation	1.00	4.46	—	0.24	5.70
Hydropower generation	4.63	0.07	—	0.11	4.81
Geothermal power generation	1.39	4.63	—	0.27	6.29
Wind power generation	6.73	2.41	—	0.37	9.51
Photovoltaic power (dwelling house)	11.91	3.57	—	0.53	16.01
Photovoltaic power (on the ground)	26.24	6.82	—	1.25	34.31

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Dynamic life cycle assessment (LCA) of renewable energy technologies

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Table 3
Selected inventory and impact assessment results of renewable electricity systems

Product	Unit	Hydro-power 3.1 MW_{el}	Hydro-power 300 kW_{el}	Wind 1.5 MW (On-shore)	Wind 2.5 MW (Off-shore)	PV (polyc. SOG-Si)	Geother-mal (Hot Dry Rock	Solar ther-mal (Para-bolic trough 80 MW_{el})	Forest wood steam turbine[a]	SRF steam turbine[a]	Waste wood steam turbine[a,b]	Forest wood Co-com-bustion	SRF co-combus-tion	Forest wood recipro-cating engine[a]	SRF reci-procating engine[a]	Biogas[a]
		1 kW h_{el}	1 kW h_{el}	1 kW h_{el}	1 kW h_{el}	1 kW h_{el}	1 kW h_{el}	1 kW h_{el}	1 kW h_{el}	1 kW h_{el}	1 kW h_{el}	1 kW h_{el}	1 kW h_{el}	1 kW h_{el} and 1.7 kW h_{th}	1 kW h_{el} and 1.7 kW h_{th}	1 kW h_{el} and 0.39 kW h_{th}
Ressources																
CED	MJ	0.10	0.14	0.12	0.11	1.5	0.54	0.14	0.28	0.46	0.36	0.18	0.29	0.36	0.53	0.09
Iron ore	g	1.7	2.0	3.3	5.1	3.3	3.2	2.78	1.0	2.8	3.7	0.7	1.8	1.5	3.5	2.5
Bauxite	mg	4	16	4.8		1200	4.7	7.15	29	20	27	19	13	93	81	34
Emissions in air																
CO_2	g	10	13	10.2	8.9	99	37.8	13.4	22	35	31	14	23	27	41	11
CH_4	mg	21	29	24.1	9.8	220	103.4	35.2	17	58	63	21	47	77	124	−19,763
N_2O	mg	0.4	0,7	0.2		1.9	2.6	0.2	73	161	14	41	98	29	130	−743
SO_2	mg	17	28	39.5	35.4	288	61.6	46.7	72	198	315	26	67	74	111	368
CO	mg	59	74	96.8		141	208	85.4	757	820	405	185	226	829	898	723
NO_x	mg	36	49	31.1	20.9	340	188.9	72.9	1064	1192	1320	258	330	1360	1349	575
NMHC[c]	mg	6	11	26.1	2.4	20		2.1	45	40	123	30	27	157	149	166
Particles/dust	mg	26	31	42.2	10.9	119	35.4	40.1	60	95	109	86	109	87	125	38
HCl	mg	0.1	0.2	0.2		2.9	1.1	0.4	41	42	55	5	5	0.2	1	0.1
NH_3	mg	0.04	0.06	0.03		0.71	0.7	0.14	0.1	119	0.1	14	91	0.1	137	1619
Benzene	mg	0.03	0.05	0.02		0.09	0.05	0.22	2.7	2.6	44.9	2.1	2.0	0.5	0.4	0.02
Benzo(a)-pyrene	μg	0.2	0.3	0.48		1.4	0.3	0.36	251	447	502	122	248	272	489	0.4
Impact assessment																
Global warming	g	10	13	11	9	104	41	14	45	86	37	27	54	38	84	−580
Acidifca-tion	mg	42	61	61	50	528	190	98	853	1294	1288	237	473	1026	1313	3814
Eutrophi-cation	mg	5	6	4	2.7	44	24.8	10	138	196	172	38	74	177	223	609

CED, cumulative (non-renewable) energy demand; co-combustion in hard coal power plant; reciprocating engine, gasified wood in Otto engine; SRF, short rotation forestry.
[a] Without allocation/credit.
[b] Incineration plant fired with wood.
[c] Incl. benzene + benzo(a)pyrene.

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The lifetime pollution implications of various types of electricity generation

An input–output analysis

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Table 9 Wind: pollution output changes by type and phase

	Effect	CO_2 (kt/TWh)	SO_2 (kt/TWh)	NO_x (kt/TWh)
Construction	Direct	22.58	0.27	0.08
	Indirect	11.94	0.10	0.05
	Total	34.51	0.27	0.13
Operating	Fuel	–1113.55	–13.90	–4.50
	Structural	–16.65	–0.15	–0.08
	Total	–1130.20	–14.05	–4.58
Decommissioning	Direct	0.01	0.00	0.00
	Indirect	0.12	0.00	0.00
	Total	0.12	0.00	0.00
Total		–1095.56	–13.68	–4.45

Table 10 Solar: pollution output changes by type and phase

	Effect	CO_2 (kt/TWh)	SO_2 (kt/TWh)	NO_x (kt/TWh)
Construction	Direct	12.43	0.07	0.06
	Indirect	31.28	0.22	0.17
	Total	43.71	0.29	0.23
Operating	Fuel	–1113.55	–13.90	–4.50
	Structural	–36.06	–0.31	–0.18
	Total	–1149.61	–14.21	–4.68
Decommissioning	Direct	0.02	0.00	0.00
	Indirect	0.46	0.00	0.00
	Total	0.48	0.00	0.00
Total		–1105.42	–13.92	–4.45

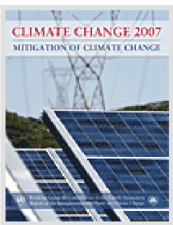
Lenzen, M. (2008) Life cycle energy and greenhouse gas emissions of nuclear energy: A review. *Energy Conversion and Management 49, 2178-2199.*

Case	Energy intensity (kWh_{th}/kWh_{el})	Greenhouse gas intensity (g CO_2-e/kWh)	Lifetime output (GWh_{el})	Comment
Base	0.33	106	4,244	20.0% capacity factor, 25 year lifetime
High	0.67	217	2,850	17.1% capacity factor, 20 year lifetime
Low	0.16	53	6,000	22.8% capacity factor, 30 year lifetime

Table 6.48: Summary of full chain intensities for 100 a MW_{el} nominal PV installation.

Case	Energy intensity (kWh_{th}/kWh_{el})	Greenhouse gas intensity (g CO_2-e/kWh)	Lifetime output (GWh_{el})	Comment
Base	0.066	21	9,378	31.2% capacity factor, 25 year lifetime
High	0.012	40	5,515	23.1% capacity factor, 20 year lifetime
Low	0.041	13	14,637	38.3% capacity factor, 30 year lifetime

Table 6.36: Summary of full chain intensities for 150 MW_{el} nominal wind farm.



Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007
B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)
Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Contents

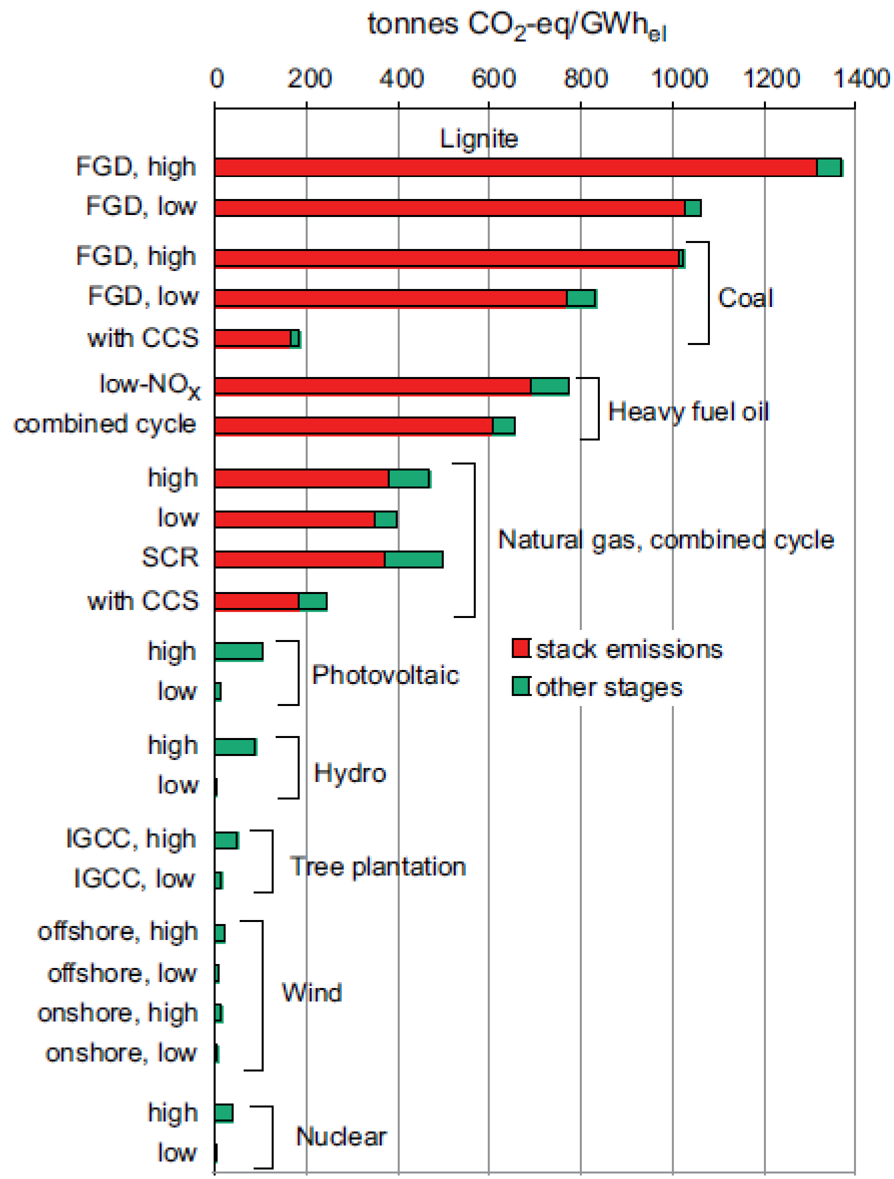


Figure 4.19: *GHG emissions for alternative electricity-generation systems.*

Notes: 1 tCO_2 –eq/GWh = 0.27 tC –eq/GWh. Hydro does not include possible GHG emissions from reservoirs (Section 4.3.3.1)

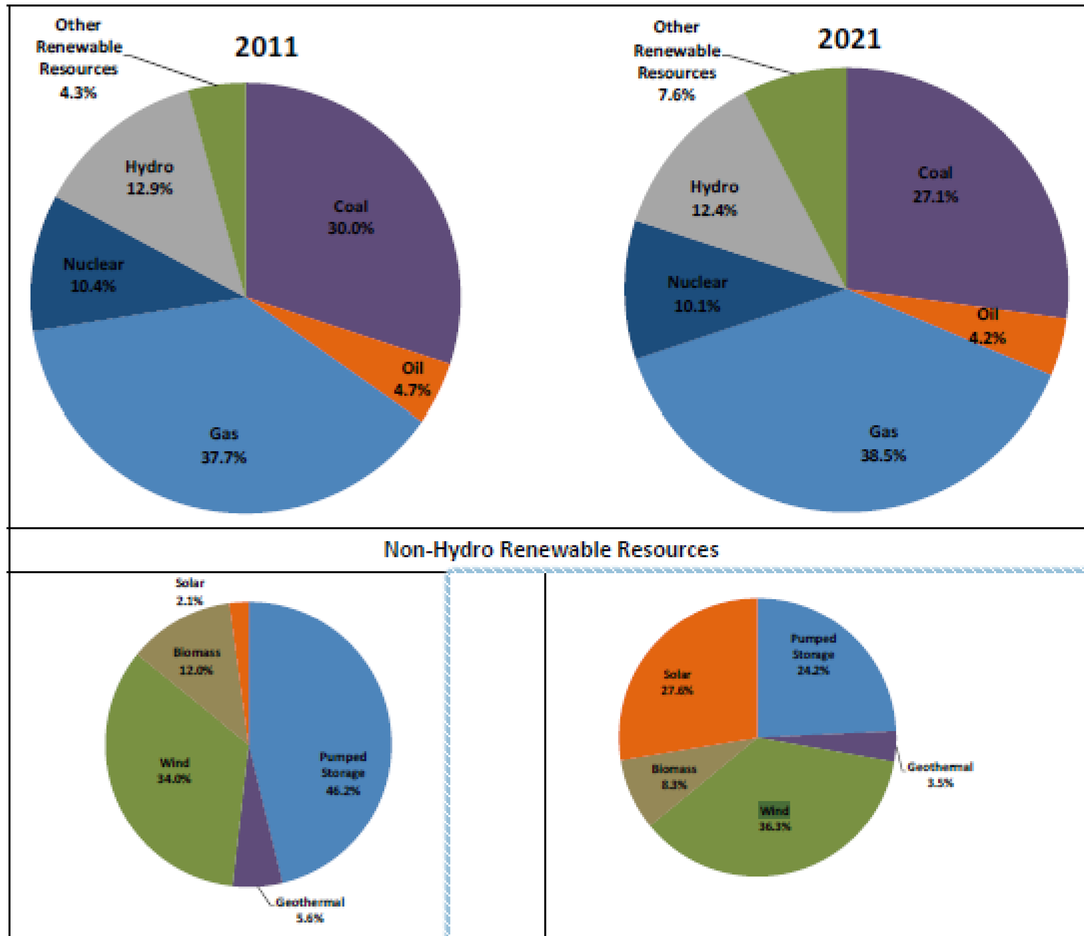
Source: WEC, 2004b

North American Electric Reliability Corporation (NERC), *2011 Long-Term Reliability Assessment*, Nov. 2011

"… the actual capacity output of wind plants during times of peak demand generally amount to a fraction of nameplate capacity. For example, expected on-peak capacity can account for as little as 8% of an Assessment Area's entire nameplate wind capacity. As noted by NERC in prior assessments, consistent methods to determine on-peak wind capacity are needed ensuring uniform measurement and resource adequacy assumptions."

"In certain areas, where large concentrations of wind resources have been added, system lanners must accommodate added variability by increasing the amount of available regulating reserves, and potentially carrying additional Operating Reserves."

Figure 19: NERC-Wide Existing and Future Projected Fuel-Mix



P a g e | 19

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