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Life cycle assessment of New Jersey offshore wind

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Supplementary Material

S1. Explanation of impact categories

Table S1. Description of ReCiPe 2016 midpoint and endpoint impact categories

Midpoint impact categories	Represents the environmental effects at an earlier stage in the cause-effect chain, focusing on specific, measurable impacts. These categories provide more detailed, robust indicators for specific environmental problems, making them useful for understanding the direct contributions of a process to various environmental issues.
Global warming	Reflects the potential for climate change due to greenhouse gas emissions, expressed in kg CO2 eq (kilograms carbon dioxide equivalent).
Stratospheric ozone depletion	Reflects the depletion of the ozone layer caused by substances like CFCs, expressed in kg CFC-11 eq (kilograms chloroflourocarbon-11 equivalent).
Ionizing radiation	Reflects potential health effects from exposure to ionizing radiation, expressed in kBq Co-60 eq (kilobecquerel Cobalt-60 equivalent).
Ozone formation, Human health	Reflects the formation of ground-level ozone and its impact on respiratory health, expressed in kg NOx eq (kilograms nitrogen oxides equivalent).
Fine particulate matter formation	Reflects the impact of fine particulate matter on human health, expressed in kg PM2.5 eq (kilograms particulate matter 2.5 equivalent).
Ozone formation, Terrestrial ecosystems	Reflects the damage from ozone formation on plant life and growth, expressed in kg NOx eq (kilograms nitrogen oxides equivalent).
Terrestrial acidification	Reflects the acidification of soils due to emissions like SO2, expressed in kg SO2 eq (kilograms sulfur dioxide equivalent).
Freshwater ecotoxicity	Reflects nutrient pollution in freshwater systems leading to excessive plant growth, expressed in kg P eq (kilograms phosphorus equivalent).
Marine ecotoxicity	Reflects nutrient pollution in marine ecosystems, expressed in kg N eq (kilograms nitrogen equivalent).
Human carcinogenic toxicity	Reflects cancer risks from chemical exposure, expressed in kg 1,4-DCB (1,4-dichlorobenzene).
Human non-carcinogenic toxicity	Reflects non-cancer health impacts from chemicals, expressed in kg 1,4-DCB (1,4-dichlorobenzene).
Land use	Reflects the impact of land occupation and transformation on biodiversity, expressed in m2a crop eq (square meters of land used annually for crops equivalent).
Mineral resource scarcity	Reflects the depletion of mineral resources, expressed in kg Cu eq (kilograms copper equivalent).
Fossil resource scarcity	Reflects the depletion of fossil fuel resources, expressed in kg oil eq (kilograms oil equivalent).
Water consumption	Reflects freshwater usage impacts, expressed in m3 (cubic meters).
Endpoint impact categories	
Human health	Reflects the overall health damage due to pollutants, expressed in DALYs (disability-adjusted life years).
Ecosystems	Reflects biodiversity loss and ecosystem damage, expressed in species.year (species per year).
Resources	Reflects long-term economic impact due to depletion of resources, expressed in USD2013 (United States Dollar 2013).

S2. Life Cycle Inventory

S2.1. Raw material supply

Table S2. LCI – IEA Wind 15-MW Turbine

Units for OSWF	Component	Weight per unit (tons)	Process
105	Tower + monopile	2178	
	Low-alloyed steel	2069.1	Steel, low-alloyed, hot rolled {GLO}| market for steel, low-alloyed, hot rolled | Cut-off, U
	Aluminum	30.492	Aluminium, primary, ingot {IAI Area, North America}| market for aluminium, primary, ingot | Cut-off, U
	Copper	8.712	Copper, cathode {GLO}| market for copper, cathode | Cut-off, U
	Plastic (PET)	30.492	Polyethylene, high density, granulate {US}| polyethylene, high density, granulate, recycled to generic market for high density PE granulate | Cut-off, U
	Electronics for control units	30.492	Electronics, for control units {GLO}| market for electronics, for control units | Cut-off, U
	Lubricating oil	8.712	Lubricating oil {RoW}| market for lubricating oil | Cut-off, U
105	Nacelle	449.20	
	Yaw system, ball bearing	95.00	Steel, low-alloyed, hot rolled {GLO}| market for steel, low-alloyed, hot rolled | Cut-off, U
	Yaw system, drive + brake	5.00	Steel, low-alloyed, hot rolled {GLO}| market for steel, low-alloyed, hot rolled | Cut-off, U
	Hub	190.00	Steel, chromium steel 18/8, hot rolled {GLO}| market for steel, chromium steel 18/8, hot rolled | Cut-off, U
	Electronics for control units	5.00	Electronics, for control units {GLO}| market for electronics, for control units | Cut-off, U
	Copper	5.00	Copper, cathode {GLO}| market for copper, cathode | Cut-off, U
	Transformer LV	40.00	Transformer, low voltage use {GLO}| market for transformer, low voltage use | Cut-off, U
	Cast iron	109.20	Cast iron {GLO}| market for cast iron | Cut-off, U
105	Generator	371.50	
	Iron	181.00	Cast iron {GLO}| market for cast iron | Cut-off, U
	Copper	9.00	Copper, cathode {GLO}| market for copper, cathode | Cut-off, U
	Magnet	24.20	Permanent magnet, for electric motor {GLO}| market for permanent magnet, for electric motor | Cut-off, U
	Rotor	86.20	Reinforcing steel {GLO}| market for reinforcing steel | Cut-off, U
	Stator	71.10	Reinforcing steel {GLO}| market for reinforcing steel | Cut-off, U
105	Rotor	196.00	
	Chromium steel	98.00	Steel, chromium steel 18/8, hot rolled {GLO}| market for steel, chromium steel 18/8, hot rolled | Cut-off, U
	Cast iron	98.00	Cast iron {GLO}| market for cast iron | Cut-off, U
315	Blade	65.00	
	Carbon-fiber	5.5	Carbon fibre reinforced plastic, injection moulded {GLO}| market for carbon fibre reinforced plastic, injection moulded | Cut-off, U

	Fiberglass	52	Glass fibre reinforced plastic, polyamide, injection moulded {GLO}| market for glass fibre reinforced plastic, polyamide, injection moulded | Cut-off, U
	PVC foam	4.55	Polyvinylchloride, bulk polymerised {GLO}| market for polyvinylchloride, bulk polymerised | Cut-off, U
	Steel	3.25	Reinforcing steel {GLO}| market for reinforcing steel | Cut-off, U

Table S3. LCI - Power Transmission

Component	**Total Weight (tons)**	**Process**
Offshore substation	10,900	
Steel	10,900	Steel, chromium steel 18/8 {GLO}| market for steel, chromium steel 18/8 | Cut-off, U
Inter-array submarine cables	15,400	
Copper	6,160	Copper, cathode {GLO}| market for copper, cathode | Cut-off, U
Polyethylene	4,620	Polyethylene terephthalate, granulate, amorphous {US}| polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | Cut-off, U
Polypropylene	770	Polypropylene, granulate {GLO}| market for polypropylene, granulate | Cut-off, U
Galvanized steel	3,850	Steel, chromium steel 18/8 {GLO}| market for steel, chromium steel 18/8 | Cut-off, U
Inter-link submarine cables	1,500	
Copper	675	Copper, cathode {GLO}| market for copper, cathode | Cut-off, U
Polyethylene	375	Polyethylene terephthalate, granulate, amorphous {US}| polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | Cut-off, U
Polypropylene	75	Polypropylene, granulate {GLO}| market for polypropylene, granulate | Cut-off, U
Galvanized steel	375	Steel, chromium steel 18/8 {GLO}| market for steel, chromium steel 18/8 | Cut-off, U
Export HVDC cables (offshore substation to landfall point)	5,040	
Copper	2,772	Copper, cathode {GLO}| market for copper, cathode | Cut-off, U
Polyethylene	1,260	Polyethylene terephthalate, granulate, amorphous {US}| polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | Cut-off, U
Polypropylene	252	Polypropylene, granulate {GLO}| market for polypropylene, granulate | Cut-off, U
Galvanized steel	756	Steel, chromium steel 18/8 {GLO}| market for steel, chromium steel 18/8 | Cut-off, U
Export cables (landfall point to onshore substation)	800	
Copper	400	Copper, cathode {GLO}| market for copper, cathode | Cut-off, U
Polyethylene	240	Polyethylene terephthalate, granulate, amorphous {US}| polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | Cut-off, U
Polypropylene	40	Polypropylene, granulate {GLO}| market for polypropylene, granulate | Cut-off, U
Galvanized steel	120	Steel, chromium steel 18/8 {GLO}| market for steel, chromium steel 18/8 | Cut-off, U

S2.2. Assembly, transportation, and installation

Table S4. LCI - Assembly, transportation, and installation

Component	Amount	Process
Land transformation from	219.2 km2	Transformation, from seabed, unspecified
Land transformation to	219.2 km2	Transformation, to unspecified, used
Land occupation	6.58E6 m2y	Occupation, seabed, infrastructure
Fuel consumption	55,000 ton	Diesel {GLO}| market group for diesel | Cut-off, U
Electricity consumption	5,410,534.72 MJ	PJM electricity generation mix
Natural gas	47.02%	Electricity, high voltage {WECC, US only}| electricity production, natural gas, combined cycle power plant | Cut-off, U
Coal	9.64%	Electricity, high voltage {WECC, US only}| electricity production, hard coal | Cut-off, U
Hydro	1.42%	Electricity, high voltage {WECC, US only}| electricity production, hydro, reservoir, alpine region | Cut-off, U
Nuclear	29.44%	Electricity, high voltage {WECC, US only}| electricity production, nuclear, pressure water reactor | Cut-off, U
Onshore wind	6.33%	Electricity, high voltage {WECC, US only}| electricity production, wind, >3MW turbine, onshore | Cut-off, U
Solar	4.16%	Electricity, low voltage {WECC, US only}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, U
Oil	0.32%	Electricity, high voltage {WECC, US only}| electricity production, oil | Cut-off, U
Geothermal	0.57%	Electricity, high voltage {WECC, US only}| electricity production, deep geothermal | Cut-off, U
Other	1.1%	Electricity, high voltage {WECC, US only}| electricity production, natural gas, combined cycle power plant | Cut-off, U
Transport – suppliers to NJWP		
Transport, freight, sea	1.41E8 tkm	Transport, freight, sea, bulk carrier for dry goods {GLO}| market for transport, freight, sea, bulk carrier for dry goods | Cut-off, U
Transport, freight, lorry	4.72E4 tkm	Transport, freight, lorry >32 metric ton, EURO6 {RoW}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off, U
Fuel consumption	58.5 tons	Diesel {GLO}| market group for diesel | Cut-off, U
Transport – NJWP to OSW farm		
Transport, freight, sea	8.18E7 tkm	Transport, freight, sea, bulk carrier for dry goods {GLO}| market for transport, freight, sea, bulk carrier for dry goods | Cut-off, U
Fuel consumption	38.4 tons	Diesel {GLO}| market group for diesel | Cut-off, U

S2.3. Operation and maintenance

Table S5. LCI - Operation and maintenance

Component	Amount	Process
Lubricating oil	8.71 ton	Lubricating oil {RoW}| market for lubricating oil | Cut-off, U
Transport, freight, sea	1.22E3 tkm	Transport, freight, sea, tanker for liquid goods other than petroleum and liquefied natural gas {GLO}| market for transport, freight, sea, tanker for liquid goods other than petroleum and liquefied natural gas | Cut-off, U

S2.4. Dismantling, transportation, and end-of-life.

Table S6. LCI – Dismantling, transportation, and end-of-life

Component	Amount	Process
Land transformation from	219.2 km2	Transformation, from seabed, infrastructure
Land transformation to	219.2 km2	Transformation, to seabed, unspecified
Land occupation	6.58E6 m2y	Occupation, sea and ocean
Fuel consumption	55,000 ton	Diesel {GLO}| market group for diesel | Cut-off, U
Electricity consumption	5,410,534.72 MJ	PJM electricity generation mix (see table 3 for breakdown)
Transport – NJWP to OSW farm	1p	See table 3 for breakdown

S2.5. Conventional and renewable electricity generation sources for comparison analysis

Table S7. LCI – Conventional and renewable electricity generation sources for comparison analysis

Source	Process
Coal	Electricity, high voltage {WECC, US only}| electricity production, hard coal | Cut-off, U
Natural gas	Electricity, high voltage {WECC, US only}| electricity production, natural gas, conventional power plant | Cut-off, U
Oil	Electricity, high voltage {WECC, US only}| electricity production, oil | Cut-off, U
Nuclear, PWR	Electricity, high voltage {WECC, US only}| electricity production, nuclear, pressure water reactor | Cut-off, U
Nuclear, BWR	Electricity, high voltage {WECC, US only}| electricity production, nuclear, boiling water reactor | Cut-off, U
Solar	Electricity, low voltage {WECC, US only}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, U
Hydro, flow	Electricity, high voltage {WECC, US only}| electricity production, hydro, run-of-river | Cut-off, U
Hydro, reservoir	Electricity, high voltage {WECC, US only}| electricity production, hydro, reservoir, alpine region | Cut-off, U
Onshore wind	Electricity, high voltage {WECC, US only}| electricity production, wind, >3MW turbine, onshore | Cut-off, U

S3. Results

Table S8 . Midpoint and endpoint combined results – functional unit 1kWh – Offshore Wind Farm

Phase			1										2	3	4
Impact category	Unit	Total	Blade	Tower + Monopile	Rotor	Nacelle	Generator	Cables - landfall to substation	Export submarine cables	Inter-array submarine cables	Inter-link submarine cables	Offshore substation	Assembly, transit, install	O&M	Disassembly, transit, EOL
Global warming	kg CO2 eq	1.27E-02	2.14E-03	4.68E-03	5.33E-04	1.40E-03	1.19E-03	2.78E-05	1.85E-04	5.13E-04	5.30E-05	7.97E-04	3.64E-04	1.11E-07	7.73E-04
Stratospheric ozone depletion	kg CFC11 eq	4.60E-09	1.24E-09	1.13E-09	1.24E-10	4.47E-10	4.71E-10	2.57E-11	1.76E-10	4.17E-10	4.49E-11	2.04E-10	8.99E-11	2.72E-14	2.30E-10
Ionizing radiation	kBq Co-60 eq	5.99E-04	9.37E-05	1.98E-04	2.46E-05	7.51E-05	9.14E-05	2.20E-06	1.46E-05	3.88E-05	4.00E-06	4.14E-05	6.13E-06	3.85E-09	9.53E-06
Ozone formation, Human health	kg NOx eq	3.62E-05	4.22E-06	1.29E-05	1.36E-06	4.37E-06	3.36E-06	2.08E-07	1.43E-06	3.41E-06	3.67E-07	2.02E-06	1.23E-06	5.45E-10	1.39E-06
Fine particulate matter formation	kg PM2.5 eq	3.75E-05	3.05E-06	1.00E-05	1.62E-06	5.59E-06	3.05E-06	4.02E-07	2.77E-06	6.47E-06	7.00E-07	2.84E-06	4.65E-07	1.63E-10	5.37E-07
Ozone formation, Terrestrial ecosystems	kg NOx eq	3.83E-05	4.36E-06	1.37E-05	1.43E-06	4.57E-06	3.52E-06	2.13E-07	1.46E-06	3.50E-06	3.76E-07	2.10E-06	1.46E-06	7.29E-10	1.62E-06
Terrestrial acidification	kg SO2 eq	8.11E-05	7.07E-06	1.86E-05	1.83E-06	1.04E-05	6.80E-06	1.21E-06	8.37E-06	1.89E-05	2.07E-06	2.99E-06	1.31E-06	3.80E-10	1.44E-06
Freshwater ecotoxicity	kg 1,4-DCB	9.71E-06	4.62E-07	3.26E-06	2.07E-07	1.27E-06	7.89E-07	1.32E-07	9.12E-07	2.08E-06	2.26E-07	3.14E-07	2.27E-08	2.36E-11	5.10E-08
Marine ecotoxicity	kg 1,4-DCB	5.00E-06	2.51E-07	1.93E-07	1.53E-08	5.23E-08	4.33E-06	2.60E-09	1.72E-08	4.41E-08	4.52E-09	2.36E-08	3.19E-08	5.58E-12	3.65E-08

Human carcinogenic toxicity	kg 1,4-DCB	4.50E-01	2.63E-03	5.56E-02	1.26E-02	7.37E-02	3.04E-02	9.80E-03	6.78E-02	1.53E-01	1.67E-02	2.51E-02	7.54E-04	4.15E-07	1.32E-03
Human non-carcinogenic toxicity	kg 1,4-DCB	5.09E-03	4.54E-05	1.03E-03	4.04E-05	6.80E-04	3.35E-04	1.06E-04	7.34E-04	1.64E-03	1.79E-04	6.74E-05	3.40E-06	4.11E-09	2.30E-04
Land use	m2a crop eq	6.60E-03	5.93E-05	1.37E-03	5.93E-05	8.90E-04	4.36E-04	1.36E-04	9.39E-04	2.10E-03	2.30E-04	9.88E-05	5.72E-06	5.56E-09	2.80E-04
Mineral resource scarcity	kg Cu eq	1.15E-02	8.01E-05	4.97E-03	1.01E-03	2.50E-03	9.43E-04	1.91E-05	1.27E-04	4.18E-04	4.28E-05	1.34E-03	1.33E-05	5.75E-09	2.40E-05
Fossil resource scarcity	kg oil eq	7.37E-02	9.40E-04	1.53E-02	6.34E-04	1.01E-02	5.62E-03	1.58E-03	1.09E-02	2.44E-02	2.67E-03	1.06E-03	1.01E-04	8.71E-08	3.92E-04
Water consumption	m3	4.73E-04	3.70E-05	1.15E-04	1.49E-05	5.35E-05	1.19E-04	3.43E-06	2.36E-05	5.55E-05	5.99E-06	2.62E-05	9.39E-06	2.71E-09	1.01E-05
Human health	DALY	9.04E-08	4.45E-09	3.06E-08	5.00E-09	1.54E-08	7.44E-09	7.02E-10	4.83E-09	1.15E-08	1.24E-09	7.23E-09	7.00E-10	1.23E-09	2.46E-13
Ecosystems	species.yr	7.86E-11	9.14E-12	2.36E-11	2.55E-12	9.55E-12	7.47E-12	6.87E-13	4.73E-12	1.10E-11	1.19E-12	3.99E-12	1.61E-12	3.04E-12	5.41E-16
Resources	USD2013	1.26E-03	1.74E-04	2.73E-04	3.49E-05	9.84E-05	1.08E-04	2.96E-06	1.99E-05	5.22E-05	5.46E-06	5.63E-05	2.16E-04	2.19E-04	3.76E-08

Table S9. Midpoint results – functional unit 1 kWh – Comparison Analysis

Impact category	**Unit**	**OSW**	**Coal**	**Natural Gas**	**Oil**	**Nuclear, PWR**	**Nuclear, BWR**	**Solar**	**Hydro, flow**	**Hydro, reservoir**	**Onshore wind**
Global warming	kg CO2 eq	1.27E-02	1.02E+00	6.21E-01	2.05E+00	6.83E-03	7.21E-03	5.96E-02	4.60E-03	7.07E-03	2.22E-02
Stratospheric ozone depletion	kg CFC11 eq	4.60E-09	2.81E-07	1.18E-07	1.00E-06	4.04E-09	4.42E-09	2.17E-08	8.68E-10	2.76E-09	8.22E-09
Ionizing radiation	kBq Co-60 eq	5.99E-04	3.77E-03	2.18E-03	4.10E-03	6.93E-01	7.88E-01	4.04E-03	1.04E-04	2.47E-04	8.96E-04

Ozone formation, Human health	kg NOx eq	3.62E-05	2.10E-03	5.67E-04	6.75E-03	3.44E-05	3.63E-05	1.59E-04	1.73E-05	2.05E-05	7.60E-05
Fine particulate matter formation	kg PM2.5 eq	3.75E-05	6.69E-04	9.83E-05	3.83E-03	2.71E-05	2.84E-05	1.22E-04	9.30E-06	1.04E-05	7.30E-05
Ozone formation, Terrestrial ecosystems	kg NOx eq	3.83E-05	2.12E-03	6.64E-04	7.01E-03	3.55E-05	3.75E-05	1.68E-04	1.79E-05	2.12E-05	7.96E-05
Terrestrial acidification	kg SO2 eq	8.11E-05	2.06E-03	2.36E-04	1.21E-02	3.34E-05	3.52E-05	2.57E-04	1.29E-05	1.66E-05	1.83E-04
Freshwater eutrophication	kg P eq	9.71E-06	6.04E-04	1.24E-05	2.90E-05	4.30E-06	4.53E-06	3.19E-05	1.14E-06	1.45E-06	2.20E-05
Marine eutrophication	kg N eq	5.00E-06	4.07E-05	1.22E-06	3.45E-05	1.27E-05	1.35E-05	2.89E-06	1.03E-07	1.35E-07	1.34E-06
Terrestrial ecotoxicity	kg 1,4-DCB	4.50E-01	3.38E-01	2.24E-01	7.17E+00	2.43E-01	2.55E-01	1.45E+00	1.91E-02	2.85E-02	1.10E+00
Freshwater ecotoxicity	kg 1,4-DCB	5.09E-03	2.15E-02	2.73E-03	5.29E-03	1.12E-03	1.17E-03	1.26E-02	2.24E-04	2.12E-04	4.55E-02
Marine ecotoxicity	kg 1,4-DCB	6.60E-03	2.96E-02	3.60E-03	1.24E-02	1.57E-03	1.64E-03	1.65E-02	3.02E-04	2.97E-04	5.55E-02
Human carcinogenic toxicity	kg 1,4-DCB	1.15E-02	5.00E-02	7.55E-03	2.06E-02	2.94E-03	3.02E-03	1.01E-02	1.87E-03	1.89E-03	1.13E-02
Human non-carcinogenic toxicity	kg 1,4-DCB	7.37E-02	8.72E-01	4.90E-02	1.83E-01	8.77E-02	9.30E-02	1.48E-01	3.20E-03	4.88E-03	1.92E-01
Land use	m2a crop eq	4.73E-04	1.11E-02	2.28E-03	1.09E-02	2.66E-04	2.97E-04	2.10E-02	2.09E-04	8.86E-05	1.10E-03
Mineral resource scarcity	kg Cu eq	7.92E-04	4.37E-04	4.32E-04	8.18E-04	6.98E-04	7.35E-04	7.71E-04	8.12E-05	9.45E-05	9.25E-04
Fossil resource scarcity	kg oil eq	3.79E-03	2.70E-01	2.29E-01	5.57E-01	1.82E-03	1.91E-03	1.49E-02	9.21E-04	1.18E-03	5.28E-03
Water consumption	m3	1.11E-04	9.62E-04	3.28E-03	3.34E-03	2.93E-03	2.96E-03	2.00E-03	3.86E-05	2.93E-02	2.34E-04