

Appendix A

Calculation of Indicators

Santa Catarina					
Collected data		HPP ^{d,e}	WPP ^{b,c}		PSPP ^f
Name		Garibaldi	Complexo Eólico Água Doce		Tubarão
Location		Abdon Batista/Cerro Negro (SC)	Água Doce (SC)		Tubarão (SC)
Details		3 Francis turbines	86 wind turbines		19,424 panels
Installed power (MW)		191.9	129.0		3.0
Assured energy (MWh/year)		728,000.0	359,042.0		14,560.0
Occupied area (km ²)		26.7	200.0		0.1
Cost of investment (R\$)		950,000,000.0	750,000,000.0		56,300,000.0
Supply capability (population)		500,000	380,000		10,000
Sustainability indicators		Unit	Garibaldi	Água Doce	Tubarão
Economic	Implementation cost	USD/kW	1,547.00	1,816.90	5,864.60
	Price of generated energy ^g	R\$/MWh	227,00	223,00	249,00
	Payback time	Years	5.7	9.4	15.5
Technical	Occupied area	MW/km ²	7.2	0.6	30.0
	Lifetime	Years	100.0	20.0	20.0
	Generation efficiency	%	Not relevant	Not relevant	Not relevant

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Sustainability indicators		Unit	Garibaldi	Agua Doce	Tubarão
Environmental	GHG emissions	kg CO ₂ eq	9,245,600.0	4,261,828.5	1,368,640.0
	Emissions of other gases	kg NO _x	13,104.0	19,567.8	3,145.0
		kg SO ₂	11,648.0	19,029.2	3,028.5
	Annual water consumption	t/year	26,208,000.0	359,042.0	145,600.0

Ceará

Collected data	HPP ^a	WPP ^h	PSPP ⁱ
Name	Açude Castanhão	Usina de Geração Eólica de Praia Formosa	Grupo Telles
Location	Jaguaribara (CE)	Camocim (CE)	Pindoretama (CE)
Details	Not found	50 wind turbines	9223 panels
Installed power (MW)	5.0	105.0	3.0
Assured energy (MWh/year)	31,500.0	416,678.0	14,560.0
Area utilization (km ²)	325.0		0.05
Cost of investment (R\$)	12.000.000,00	500.000.000,00	20.000.000,00
Supply capability (population)	13,000.0	310,000.0	5721.0

Sustainability indicators		Unit	Açude Castanhão	Praia Formosa	Grupo Telles
Economic	Implementation cost	USD/kW	750.00	1488.10	2083.30
	Price of generated energy ^e	R\$/MWh	227,00	223,00	249,00
	Payback time	Years	1.7	5.4	5.5
Technical	Occupied area	MW/km ²	0.02		60.0
	Lifetime	Years		20.0	20.0
	Generation efficiency	%	Not relevant	Not relevant	Not relevant
Environmental	GHG emissions	kg CO ₂ eq	400,050.0	4,945,967.9	1,368,640.0
	Emissions of other gases	kg NO _x	567.0	22,709.0	3145.0
		kg SO ₂	504.0	22,083.9	3028.5
	Annual water consumption	t/year	1,134,000.0	416,678.0	145,600.0

^aSEINFRA (2017)^bPrefeitura de água doce (2017)^cIMPSA (2017)^dAgência Nacional de Águas (ANA) (2010)^eFilippim et al. (2013)^fTractebel Energia (2014)^gAgência Nacional de Energia Elétrica (ANEEL) (2016)^hFundação Getúlio Vargas (FGV) (2009)ⁱSENAI (2016)

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Appendix B

Calculation of AIS

Santa Catarina Sustainability indicators		Weight											
Type	Indicator	Unit	UHE	WPP	PSPP	Average	NP	HPP	WPP	PSPP	MON	ECO	SUS
Economic	Implementation cost	USD/kW	1,547.00	1,817.00	5,865.00	3,076.00	-0.50	-0.59	-1.91	0.45	0.07	0.25	
	Price of energy generated	R\$/MWh	70.93	69.69	77.8	72.81	0.97	0.96	1.07	0.45	0.07	0.25	
	Payback time	Years	5.75	9.38	15.53	10.22	-0.56	-0.92	-1.52	0.45	0.07	0.25	
Technical	Assured energy	MWh asstd./MW	3,794	2,783	4,242	3,606	1.05	0.77	1.18	0.45	0.10	0.25	
	Resource availability	Qualitative	3	3	1	2.33	1.29	1.29	0.43	0.45	0.10	0.25	
	Area utilization	MW/km ²	7.18	7.5	30	14.89	0.48	0.50	2.01	0.45	0.10	0.25	
Quantitative environmental	Lifetime	Years	100	20	20	46.67	2.14	0.43	0.43	0.45	0.10	0.25	
	Greenhouse gases emission	kg CO ₂ eq/MWh	12.7	11.87	94	39.52	-0.32	-0.30	-2.38	0.05	0.41	0.25	
	SO ₂ emissions	kg NO _x /MWh	0.018	0.055	0.216	0.10	-0.19	-0.57	-2.25	0.05	0.41	0.25	
	NO _x emissions	kg SO ₂ /MWh	0.016	0.053	0.208	0.09	-0.17	-0.57	-2.25	0.05	0.41	0.25	
	Annual water consumption	t/MWh	36	1	10	15.67	-2.30	-0.06	-0.64	0.05	0.41	0.25	
Qualitative environmental	Biodiversity loss		5	1	1	2.33	-2.14	-0.43	-0.43	0.05	0.41	0.25	
	Dismantling conservation units		5	2	1	2.67	-1.88	-0.75	-0.38	0.05	0.41	0.25	

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Santa Catarina		Sustainability indicators		Average		NP		Weight	
Type	Indicator	UHE	WPP	PSPP	HPP	WPP	PSPP	MON	SUS
	Unit								
Social	Interaction of structure with fauna	3	2	1				0.05	0.41
	Toxins		1	3	-1.00	-0.50	-1.50	0.05	0.41
	Population removal	5	1	1	-2.14	-0.43	-0.43	0.05	0.41
	Land-use impact	5	2	1	-1.88	-0.75	-0.38	0.05	0.41
	Visual impact	1	3	1	-0.60	-1.80	-0.60	0.05	0.41
	Noise	2	3	1	-1.00	-1.50	-0.50	0.05	0.41
								AIS	

Santa Catarina

Sustainability indicators		CN-MON			CN-ECO			CN-SUST			
Type	Indicator	Unit	HPP	WPP	PSPP	HPP	WPP	PSPP	HPP	WPP	PSPP
Economic	Implementation cost	USD/kW	-0.23	-0.27	-0.86	-0.04	-0.04	-0.13	-0.13	-0.15	-0.48
	Price of energy generated	RS/MWh	0.44	0.43	0.48	0.07	0.07	0.07	0.24	0.24	0.27
	Payback time	Years	-0.25	-0.41	-0.68	-0.04	-0.06	-0.11	-0.14	-0.23	-0.38
Technical	Assured energy	MWh assur./MW	0.47	0.35	0.53	0.11	0.08	0.12	0.26	0.19	0.29
	Resource availability	Qualitative	0.58	0.58	0.19	0.13	0.13	0.04	0.32	0.32	0.11
	Area utilization	MW/km ²	0.22	0.23	0.91	0.05	0.05	0.20	0.12	0.13	0.50
Quantitative environmental	Lifetime	Years	0.96	0.19	0.19	0.21	0.04	0.04	0.54	0.11	0.11
	Greenhouse gases emission	kg CO ₂ eq/MWh	-0.02	-0.02	-0.12	-0.13	-0.12	-0.98	-0.08	-0.08	-0.59
	SO ₂ emissions	kg NO _x /MWh	-0.01	-0.03	-0.11	-0.08	-0.23	-0.92	-0.05	-0.14	-0.56
	NO _x emissions	kg SO ₂ /MWh	-0.01	-0.03	-0.11	-0.07	-0.24	-0.92	-0.04	-0.14	-0.56
	Annual water consumption	t/MWh	-0.11	0.00	-0.03	-0.94	-0.03	-0.26	-0.57	-0.02	-0.16
Qualitative environmental	Biodiversity loss		-0.11	-0.02	-0.02	-0.88	-0.18	-0.18	-0.54	-0.11	-0.11
	Dismantling conservation units		-0.09	-0.04	-0.02	-0.77	-0.31	-0.15	-0.47	-0.19	-0.09

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Santa Catarina		CN-MON			CN-ECO			CN-SUST			
Type	Indicator	Unit	HPP	WPP	PSPP	HPP	WPP	PSPP	HPP	WPP	PSPP
Social	Interaction of structure with fauna										
	Toxins		-0.05	-0.03	-0.08	-0.41	-0.21	-0.62	-0.25	-0.13	-0.38
	Population removal		-0.11	-0.02	-0.02	-0.88	-0.18	-0.18	-0.54	-0.11	-0.11
	Land-use impact		-0.09	-0.04	-0.02	-0.77	-0.31	-0.15	-0.47	-0.19	-0.09
	Visual impact		-0.03	-0.09	-0.03	-0.25	-0.74	-0.25	-0.15	-0.45	-0.15
	Noise		-0.05	-0.08	-0.03	-0.41	-0.62	-0.21	-0.25	-0.38	-0.13
			1.44	0.67	0.15	-5.71	-3.29	-4.77	-2.56	-1.56	-2.63
Ceará											
Type	Indicator	Unit	UHE	WPP	PSPP	Average	NP	WPP	PSPP	Weight	SUS
Economic	Implementation cost	USD/kW	750	1,488	2,083	1,440	-0.52	-1.03	-1.45	0.45	0.25
	Price of energy generated	RS/MWh	70,94	69,69	77,81	72,81	0.97	0.96	1.07	0.45	0.25
Technical	Payback time	Years	1.68	5.38	5.52	4.19	-0.40	-1.28	-1.32	0.45	0.25
	Assured energy	MWh assrd./MW	6,300	3,968	4,242	4,837	1.30	0.82	0.88	0.45	0.25
	Resource av.	Qualitative	1.00	3.00	3.00	2.33	0.43	1.29	1.29	0.45	0.25

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Sustainability Indicators		UHE	WPP	PSPP	Average	NP	Weight					
Type	Indicator	Unit	WPP	PSPP	WPP	HPP	WPP	PSPP	MON	ECO	SUS	
Quantitative Environmental	Area utilization	MW/km ²	7.50		22.51	0.00	0.33	2.67	0.45	0.10	0.25	
	Lifetime	Years	20	20	24	1.33	0.83	0.83	0.45	0.10	0.25	
	Greenhouse gases emission	kg CO ₂ eq/MWh	11.87	94.00	39.52	-0.32	-0.30	-2.38	0.05	0.41	0.25	
	SO ₂ emissions	kg NO _x /MWh	0.05	0.22	0.10	-0.19	-0.57	-2.25	0.05	0.41	0.25	
	NO _x emissions	kg SO ₂ /MWh	0.02	0.05	0.21	0.09	-0.17	-0.57	-2.25	0.05	0.41	0.25
Qualitative Environmental	Annual water consumption	t/MWh	1.00	10.00	15.67	-2.30	-0.06	-0.64	0.05	0.41	0.25	
	Biodiversity loss		5	1.00	1.00	1.67	-1.80	-0.60	-0.60	0.05	0.41	
	Dismantling conservation units		5	2.00	1.00	2.00	-1.50	-1.00	-0.50	0.05	0.41	
	Interaction of structure with fauna		3	2.00	1.00	2.00	-1.50	-1.00	-0.50	0.05	0.41	
	Toxins		2	2.00	1.00	3.00	2.00	-1.00	-0.50	-1.50	0.05	0.41
Social	Population removal		5	1.00	1.00	1.67	-1.80	-0.60	-0.60	0.05	0.41	
	Land-use impact		5	2.00	1.00	2.00	-1.50	-1.00	-0.50	0.05	0.41	
	Visual impact		1	750	1488	2083	1440.48	-0.52	-1.03	-1.45	0.45	0.07
	Noise		2	70.94	69.69	77.81	72.81	0.97	0.96	1.07	0.45	0.07
Ceará										AIS		
Sustainability Indicators			CN-MON			CN-ECO			CN-SUST			
Type	Indicator	Unit	HPP	WPP	PSPP	HPP	WPP	PSPP	HPP	WPP	PSPP	
Economic	Implementation cost	USD/kW	-0.23	-0.46	-0.65	-0.04	-0.07	-0.10	-0.13	-0.26	-0.36	

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(continued)		Ceará											
Sustainability Indicators		CN-MON			CN-ECO			CN-SUST					
Type	Indicator	Unit	HPP	WPP	PSPP	HPP	WPP	PSPP	HPP	WPP	PSPP		
Technical	Price of energy generated	R\$/MWh	0.44	0.43	0.48	0.07	0.07	0.07	0.24	0.24	0.27		
	Payback time	Years	-0.18	-0.58	-0.59	-0.03	-0.09	-0.09	-0.10	-0.32	-0.33		
	Assured energy	MWh assur./ MW	0.59	0.37	0.39	0.13	0.08	0.09	0.33	0.21	0.22		
Quantitative Environmental	Resource av.	Qualitative	0.19	0.58	0.58	0.04	0.13	0.13	0.11	0.32	0.32		
	Area utilization	MW/km ²	0.00	0.15	1.20	0.00	0.03	0.27	0.00	0.08	0.67		
	Lifetime	Years	0.60	0.38	0.38	0.13	0.08	0.08	0.33	0.21	0.21		
	Greenhouse gases emission	kg CO ₂ eq/MWh	-0.02	-0.02	-0.12	-0.13	-0.12	-0.98	-0.08	-0.08	-0.59		
	SO ₂ emissions	kg NO _x /MWh	-0.01	-0.03	-0.11	-0.08	-0.23	-0.92	-0.05	-0.14	-0.56		
	NO _x emissions	kg SO ₂ /MWh	-0.01	-0.03	-0.11	-0.07	-0.24	-0.92	-0.04	-0.14	-0.56		
Qualitative Environmental	Annual water consumption	t/MWh	-0.11	0.00	-0.03	-0.94	-0.03	-0.26	-0.57	-0.02	-0.16		
	Biodiversity loss		0.25	-0.09	-0.03	-0.03	-0.74	-0.25	-0.25	-0.45	-0.15		
	Dismantling conservation units		0.25	-0.08	-0.05	-0.03	-0.62	-0.41	-0.21	-0.38	-0.25		
	Interaction of structure with fauna		0.25	-0.08	-0.05	-0.03	-0.62	-0.41	-0.21	-0.38	-0.25		
	Toxins		0.25	-0.05	-0.03	-0.08	-0.41	-0.21	-0.62	-0.25	-0.13		
Social	Population removal		0.25	-0.09	-0.03	-0.03	-0.74	-0.25	-0.25	-0.45	-0.15		
	Land-use impact		0.25	-0.08	-0.05	-0.03	-0.62	-0.41	-0.21	-0.38	-0.25		
	Visual impact		0.25	-0.23	-0.46	-0.65	-0.04	-0.07	-0.10	-0.13	-0.26		
	Noise		0.25	0.44	0.43	0.48	0.07	0.07	0.07	0.24	0.24		
			0.72	0.39	1.15	-5.30	-3.67	-4.81	-2.64	-1.90	-2.21		

Appendix C

Summary of Results' Radar Charts

See Figs. C.1, C.2, C.3, C.4, C.5 and C.6.

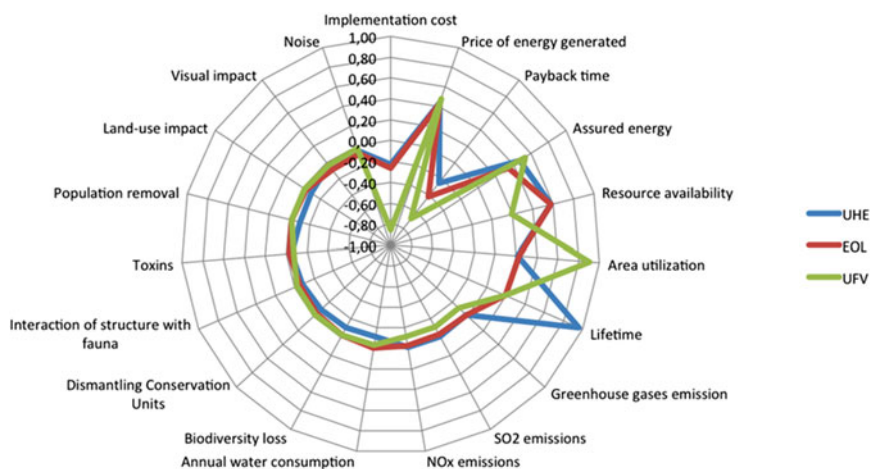


Fig. C.1 Sustainability radar chart for Scenario 1, SC. *Source* The author

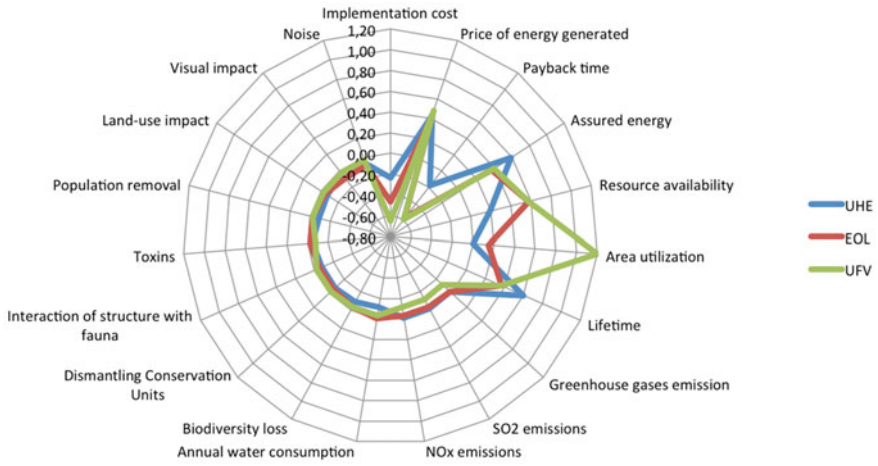


Fig. C.2 Sustainability radar chart for Scenario 1, CE. *Source* The author

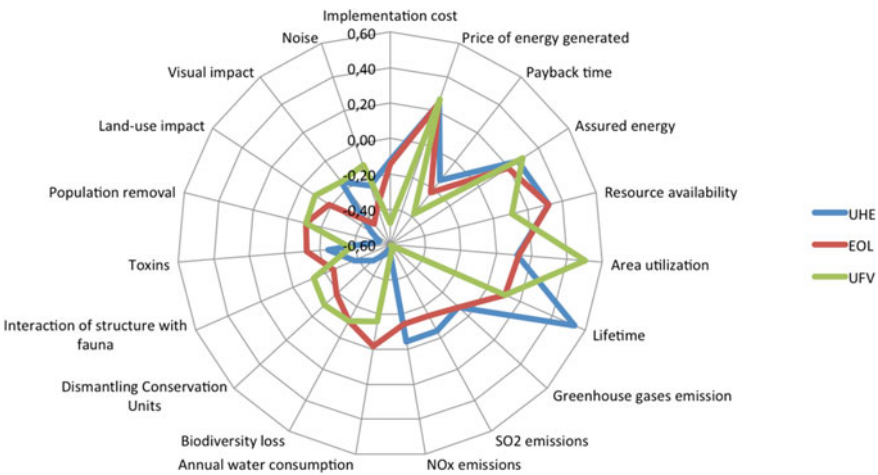


Fig. C.3 Sustainability radar chart for Scenario 2, SC. *Source* The author

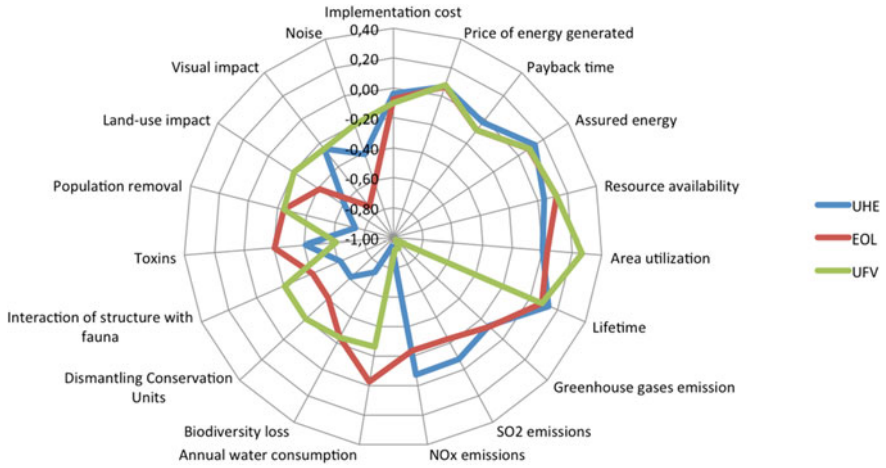


Fig. C.4 Sustainability radar chart for Scenario 2, CE. Source The author

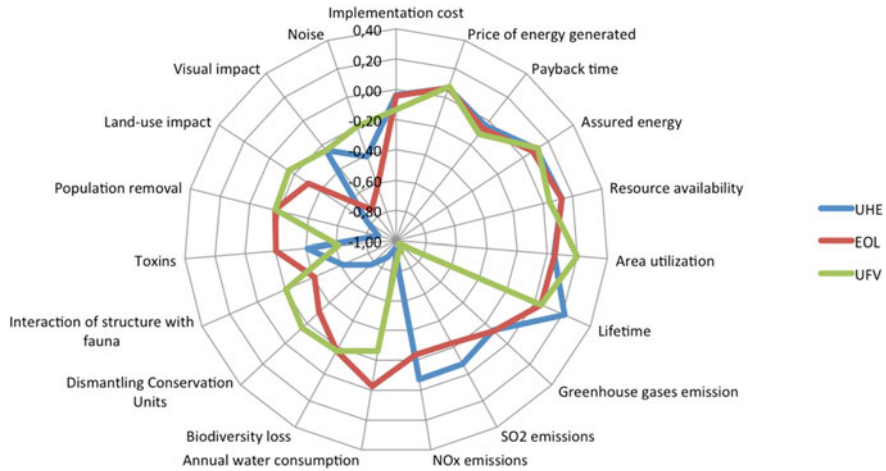


Fig. C.5 Sustainability radar chart for Scenario 3, SC. Source The author

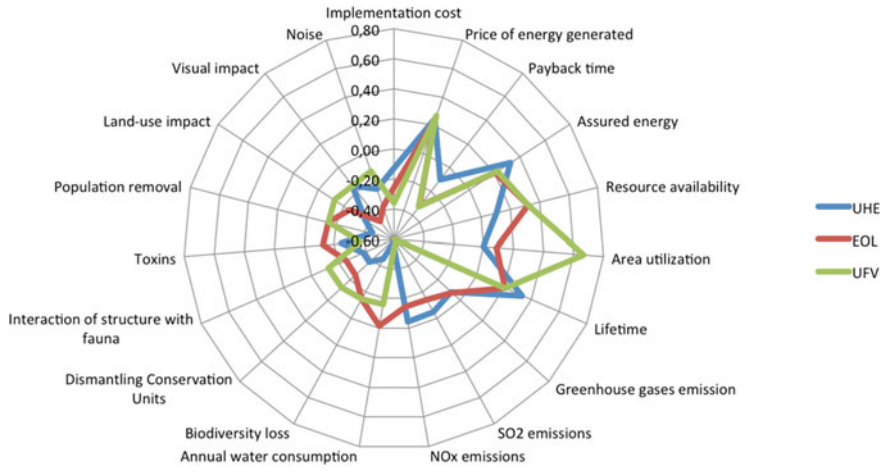


Fig. C.6 Sustainability radar chart for Scenario 3, CE. Source The author