

Article

Life Cycle Assessment of classic and innovative batteries for Solar Home Systems in Europe – Supporting Information

Federico Rossi¹ Maria Laura Parisi², Sarah Greven³, Riccardo Basosi⁴, Adalgisa Sinicropi⁵

¹ University of Siena, R2ES Lab, Department of Biotechnology, Chemistry and Pharmacy, Via A. Moro,2, Siena, Italy. University of Florence, Department of Industrial Engineering, Via Santa Marta,3, Florence, Italy,

² University of Siena, R2ES Lab, Department of Biotechnology, Chemistry and Pharmacy, Via A. Moro,2, Siena, Italy. CSGI, Center for colloid and surface science, via della Lastruccia 3, 50019, Sesto Fiorentino, Italy. Institute of Chemistry of Organometallic Compounds (CNR-ICCOM), Via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy.

³ ENSICAEN, Chimie Matériaux, 6 bd Maréchal Juin – CS 45053, F-14050 CAEN Cedex 4- France

⁴ University of Siena, R2ES Lab, Department of Biotechnology, Chemistry and Pharmacy, Via A. Moro,2, Siena, Italy. CSGI, Center for colloid and surface science, via della Lastruccia 3, 50019, Sesto Fiorentino, Italy. Institute of Chemistry of Organometallic Compounds (CNR-ICCOM), Via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy.

⁵ University of Siena, R2ES Lab, Department of Biotechnology, Chemistry and Pharmacy, Via A. Moro,2, Siena, Italy. CSGI, Center for colloid and surface science, via della Lastruccia 3, 50019, Sesto Fiorentino, Italy. Institute of Chemistry of Organometallic Compounds (CNR-ICCOM), Via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy.

* Correspondence: adalgisa.sinicropi@unisi.it

1. Results of the modelling phase

In this section, all the results obtained by the simulation of Solar Home Systems (SHSs) performances are collected in Table S1. Particularly, the battery energy storage system lifespan (L_{BESS}) the missing amount of energy (E_{miss}) and the exceeding one (E_{exc}) are collected for all the installation sites: Denmark (DK), Spain (ES), France (FR), Greece (GR), Hungary (HU), Italy (IT), Portugal (PT) and Romania (RO).

Table S1: Complete results of the SHS modelling phase.

	Bauer (LTO, SSLTO)	Bauer (NCA, SSNCA)	Eli (NCM, SSNCM)	M-B (LFP, SSLFP)	M-B (NCM, SSNCM)	Notter (LMO, SSLMO)	Zack (LFP, SSLFP)	Peters (SIB)	Deng (LiSB)	Eco. (ZEBRA)	Weber (VRFB)	
DK												
L_{BESS}	8.04	6.81	4.63	7.13	5.63	3.31	5.63	4.81	1.63	8.31	20.00	yr
E_{miss}	11.85	11.44	11.31	11.78	11.77	11.75	11.77	11.33	12.80	11.40	13.93	MWh
E_{exc}	354.83	360.22	355.22	352.56	351.75	361.58	351.50	361.76	337.73	359.50	347.26	MWh
ES												
L_{BESS}	8.21	7.05	5.00	7.38	5.98	3.58	5.98	5.07	1.89	8.95	20.00	yr
E_{miss}	8.22	8.30	7.30	8.03	8.09	9.29	8.09	8.38	13.02	8.03	11.50	MWh
E_{exc}	11.00	11.06	12.59	11.31	11.18	9.47	11.18	10.99	19.28	11.20	7.52	MWh
FR												
L_{BESS}	7.79	6.57	4.48	6.85	5.35	3.11	5.35	4.48	1.60	8.13	20.00	yr

E_{miss}	9.28	9.43	8.30	9.22	9.12	11.67	9.12	9.12	10.48	9.29	11.35	MWh
E_{exc}	100.11	98.96	103.48	101.10	101.44	66.55	101.44	100.19	89.64	98.91	86.95	MWh
GR												
L_{BESS}	8.21	6.99	4.99	7.36	5.96	3.51	5.96	5.00	1.86	8.86	20.00	yr
E_{miss}	10.90	10.85	10.16	10.65	10.83	12.18	10.83	10.84	10.91	10.67	13.54	MWh
E_{exc}	33.58	33.56	36.24	34.00	33.75	30.97	33.75	33.50	32.94	33.93	26.74	MWh
HU												
L_{BESS}	8.02	6.79	4.79	7.12	5.72	3.31	5.72	4.79	1.72	8.52	20.00	yr
E_{miss}	4.02	3.89	3.64	4.00	3.92	3.98	3.92	3.85	4.11	3.98	4.90	MWh
E_{exc}	71.59	72.29	75.35	70.99	71.57	71.03	71.57	72.56	68.52	71.73	62.16	MWh
IT												
L_{BESS}	8.29	7.13	5.13	7.48	6.06	3.63	6.06	5.13	1.97	9.06	20.00	yr
E_{miss}	6.19	6.24	5.75	6.20	6.23	6.90	6.23	6.21	6.59	6.24	8.31	MWh
E_{exc}	12.92	12.62	13.64	12.80	12.70	11.54	12.70	12.58	12.04	12.73	9.60	MWh
PT												
L_{BESS}	8.02	6.79	7.14	4.77	5.69	3.29	5.69	4.79	1.71	8.52	20.00	yr
E_{miss}	4.86	4.81	4.91	4.45	4.89	5.17	4.89	4.81	5.44	4.84	6.30	MWh
E_{exc}	15.49	15.60	15.36	16.57	15.35	14.62	15.35	15.64	14.07	15.48	11.23	MWh
RO												
L_{BESS}	8.23	7.04	5.04	7.36	5.96	3.54	5.96	5.04	1.86	8.88	20.00	yr
E_{miss}	3.00	3.05	2.94	2.94	2.99	3.26	2.99	3.06	2.93	2.93	3.67	MWh
E_{exc}	33.06	33.04	34.15	33.63	33.40	31.92	33.40	32.99	33.84	33.58	29.86	MWh

In this section, the full version of the SHSs life cycle inventory (LCI) is proposed for every installation site (Table S2 to Table S9).

[illegible]

[illegible]

[illegible]

[illegible]

Table S4: Complete Life Cycle Inventory of SHSs in France.

Process	Bauer (LTO, SSLTO)	Bauer (NCA, SSNCA)	Eli (NCM, SSNCM)	M-B (LFP, SSLFP)	M-B (NCM, SSNCM)	Notter (LMO, SSLMO)	Zack (LFP, SSLFP)	Peters (SIB)	Deng (LiSB)	Eco. (ZEBRA)	Weber (VRFB)	Unit
<i>Inputs</i>												
market for photovoltaic slanted-roof installation, 3kWp, single-Si, panel, mounted, on roof – GLO (inverter considered separately)	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	items
market for cable, unspecified cable, unspecified - GLO	24.79	24.79	24.79	24.79	24.79	24.79	24.79	24.79	24.79	24.79	24.79	kg
market for tube insulation, elastomere - GLO	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	kg
market for inverter, 2.5kW - GLO	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	items
market for charger, electric passenger car - GLO	64.49	64.49	64.49	64.49	64.49	64.49	64.49	64.49	64.49	64.49	64.49	kg
BESS	78.80	93.41	137.05	89.61	114.76	197.50	114.76	137.05	361.98	75.48	25.83	kWh
VRFB stack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	517.69	kg
VRFB periphery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	265.04	kg
market for electricity, low voltage (on-grid)	29.80	35.89	46.36	33.66	42.64	93.92	42.64	50.91	164.17	28.56	14.19	MWh

[illegible]

Table S5: Complete Life Cycle Inventory of SHSs in Greece.

Process	Bauer (LTO, SSLTO)	Bauer (NCA, SSNCA)	EII (NCM, SSNCM)	M-B (LFP, SSLFP)	M-B (NCM, SSNCM)	Notter (LMO, SSLMO)	Zack (LFP, SSLFP)	Peters (SIB)	Deng (LiSB)	Eco. (ZEBRA)	Weber (VRFB)	Unit
<i>Inputs</i>												
market for photovoltaic slanted-roof installation, 3kWp, single-Si, panel, mounted, on roof – GLO (inverter considered separately)	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	items
market for cable, unspecified cable, unspecified - GLO	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	kg
market for tube insulation, elastomere - GLO	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	kg
market for inverter, 2.5kW - GLO	5.64	5.64	5.64	5.64	5.64	5.64	5.64	5.64	5.64	5.64	5.64	items
market for charger, electric passenger car - GLO	24.94	24.94	24.94	24.94	24.94	24.94	24.94	24.94	24.94	24.94	24.94	kg
BESS	58.02	68.13	95.44	64.67	79.94	135.74	79.94	95.22	240.41	53.73	20.05	kWh
VRFB stack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	401.89	kg
VRFB periphery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	205.76	kg
market for electricity, low voltage (on-grid)	33.20	38.82	50.87	36.17	45.46	86.76	45.46	54.16	146.22	30.09	16.92	MWh

[illegible]

Table S6: Complete Life Cycle Inventory of SHSs in Hungary.

Process	Bauer (LTO, SSLTO)	Bauer (NCA, SSNCA)	EII (NCM, SSNCM)	M-B (LFP, SSLFP)	M-B (NCM, SSNCM)	Notter (LMO, SSLMO)	Zack (LFP, SSLFP)	Peters (SIB)	Deng (LiSB)	Eco. (ZEBRA)	Weber (VRFB)	Unit
<i>Inputs</i>												
market for photovoltaic slanted-roof installation, 3kWp, single-Si, panel, mounted, on roof – GLO (inverter considered separately)	2.74	2.74	2.74	2.74	2.74	2.74	2.74	2.74	2.74	2.74	2.74	items
market for cable, unspecified cable, unspecified - GLO	12.09	12.09	12.09	12.09	12.09	12.09	12.09	12.09	12.09	12.09	12.09	kg
market for tube insulation, elastomere - GLO	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	kg
market for inverter, 2.5kW - GLO	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	items
market for charger, electric passenger car - GLO	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	kg
BESS	35.67	42.16	59.79	40.18	50.00	86.35	50.00	59.77	156.26	33.58	12.05	kWh
VRFB stack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	241.50	kg
VRFB periphery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	123.64	kg
market for electricity, low voltage (on-grid)	12.52	14.31	19.02	14.03	17.11	30.02	17.11	20.10	59.63	11.68	6.12	MWh

[illegible]

Table S7: Complete Life Cycle Inventory of SHSs in Italy.

Process	Bauer (LTO, SSLTO)	Bauer (NCA, SSNCA)	EII (NCM, SSNCM)	M-B (LFP, SSLFP)	M-B (NCM, SSNCM)	Notter (LMO, SSLMO)	Zack (LFP, SSLFP)	Peters (SIB)	Deng (LiSB)	Eco. (ZEBRA)	Weber (VRFB)	Unit
<i>Inputs</i>												
market for photovoltaic slanted-roof installation, 3kWp, single-Si, panel, mounted, on roof – GLO (inverter considered separately)	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	items
market for cable, unspecified cable, unspecified - GLO	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	kg
market for tube insulation, elastomere - GLO	3.37	3.37	3.37	3.37	3.37	3.37	3.37	3.37	3.37	3.37	3.37	kg
market for inverter, 2.5kW - GLO	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	items
market for charger, electric passenger car - GLO	14.61	14.61	14.61	14.61	14.61	14.61	14.61	14.61	14.61	14.61	14.61	kg
BESS	32.86	38.19	53.09	36.42	44.96	75.03	44.96	53.09	130.31	30.07	11.46	kWh
VRFB stack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	229.73	kg
VRFB periphery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	117.61	kg
market for electricity, low voltage (on-grid)	18.68	21.90	28.01	20.74	25.71	47.55	25.71	30.25	83.81	17.23	10.39	MWh

[illegible]

Table S8: Complete Life Cycle Inventory of SHSs in Portugal.

Process	Bauer (LTO, SSLTO)	Bauer (NCA, SSNCA)	EII (NCM, SSNCM)	M-B (LFP, SSLFP)	M-B (NCM, SSNCM)	Notter (LMO, SSLMO)	Zack (LFP, SSLFP)	Peters (SIB)	Deng (LiSB)	Eco. (ZEBRA)	Weber (VRFB)	Unit
<i>Inputs</i>												
market for photovoltaic slanted-roof installation, 3kWp, single-Si, panel, mounted, on roof – GLO (inverter considered separately)	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	items
market for cable, unspecified cable, unspecified - GLO	6.28	6.28	6.28	6.28	6.28	6.28	6.28	6.28	6.28	6.28	6.28	kg
market for tube insulation, elastomere - GLO	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	kg
market for inverter, 2.5kW - GLO	4.44	4.44	4.44	4.44	4.44	4.44	4.44	4.44	4.44	4.44	4.44	items
market for charger, electric passenger car - GLO	16.33	16.33	16.33	16.33	16.33	16.33	16.33	16.33	16.33	16.33	16.33	kg
BESS	40.53	47.89	45.51	68.13	57.10	98.84	57.10	67.93	178.62	38.15	13.69	kWh
VRFB stack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.33	kg
VRFB periphery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	140.45	kg
market for electricity, low voltage (on-grid)	15.15	17.71	17.19	23.29	21.47	39.32	21.47	25.12	79.43	14.21	7.88	MWh

[illegible]

Table S9: Complete Life Cycle Inventory of SHSs in Romania.

Process	Bauer (LTO, SSLTO)	Bauer (NCA, SSNCA)	EII (NCM, SSNCM)	M-B (LFP, SSLFP)	M-B (NCM, SSNCM)	Notter (LMO, SSLMO)	Zack (LFP, SSLFP)	Peters (SIB)	Deng (LiSB)	Eco. (ZEBRA)	Weber (VRFB)	Unit
<i>Inputs</i>												
market for photovoltaic slanted-roof installation, 3kWp, single-Si, panel, mounted, on roof – GLO (inverter considered separately)	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	items
market for cable, unspecified cable, unspecified - GLO	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	kg
market for tube insulation, elastomere - GLO	3.54	3.54	3.54	3.54	3.54	3.54	3.54	3.54	3.54	3.54	3.54	kg
market for inverter, 2.5kW - GLO	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	items
market for charger, electric passenger car - GLO	15.34	15.34	15.34	15.34	15.34	15.34	15.34	15.34	15.34	15.34	15.34	kg
BESS	19.07	22.27	31.10	21.30	26.33	44.27	26.33	31.10	70.93	17.67	7.38	kWh
VRFB stack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	147.92	kg
VRFB periphery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	75.73	kg
market for electricity, low voltage (on-grid)	9.12	10.82	14.58	9.99	12.55	22.97	12.55	15.18	39.36	8.26	4.58	MWh

[illegible]

3. Life Cycle Impact Assessment

In this section, the results concerning the midpoint environmental impact indicators are collected and illustrated with histograms for all the batteries and installation sites (excluding IT that is available in the main manuscript). Particularly, three impact categories have been considered because they represent the highest contribution to the overall SHS eco-profile: Climate Change, Human Toxicity, Fossil Depletion. These results have been collected from Figure S1 to Figure S21.

Figure S1: Climate change SHSs environmental impact indicator in Denmark.

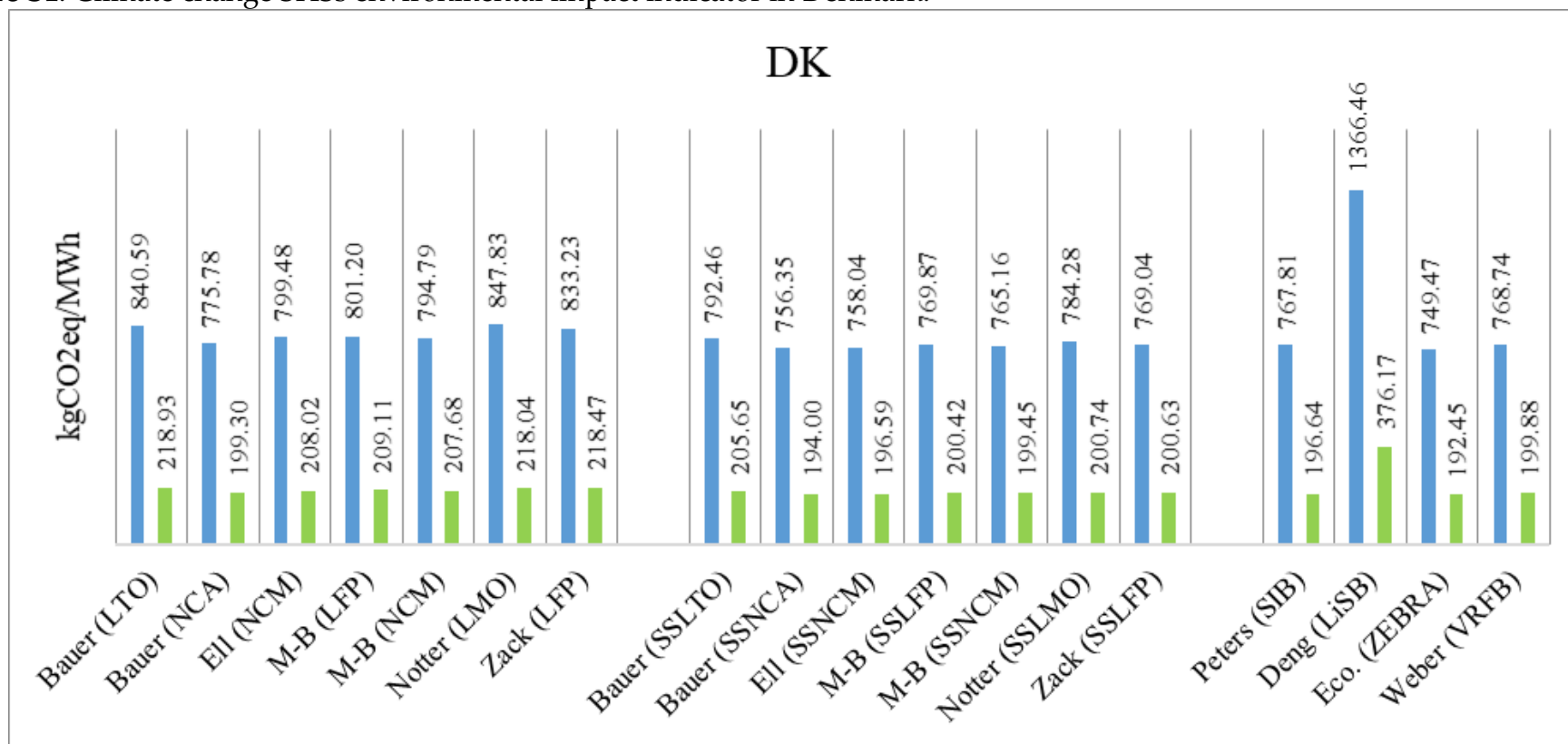


Figure S2: Climate change SHSs environmental impact indicator in Spain.

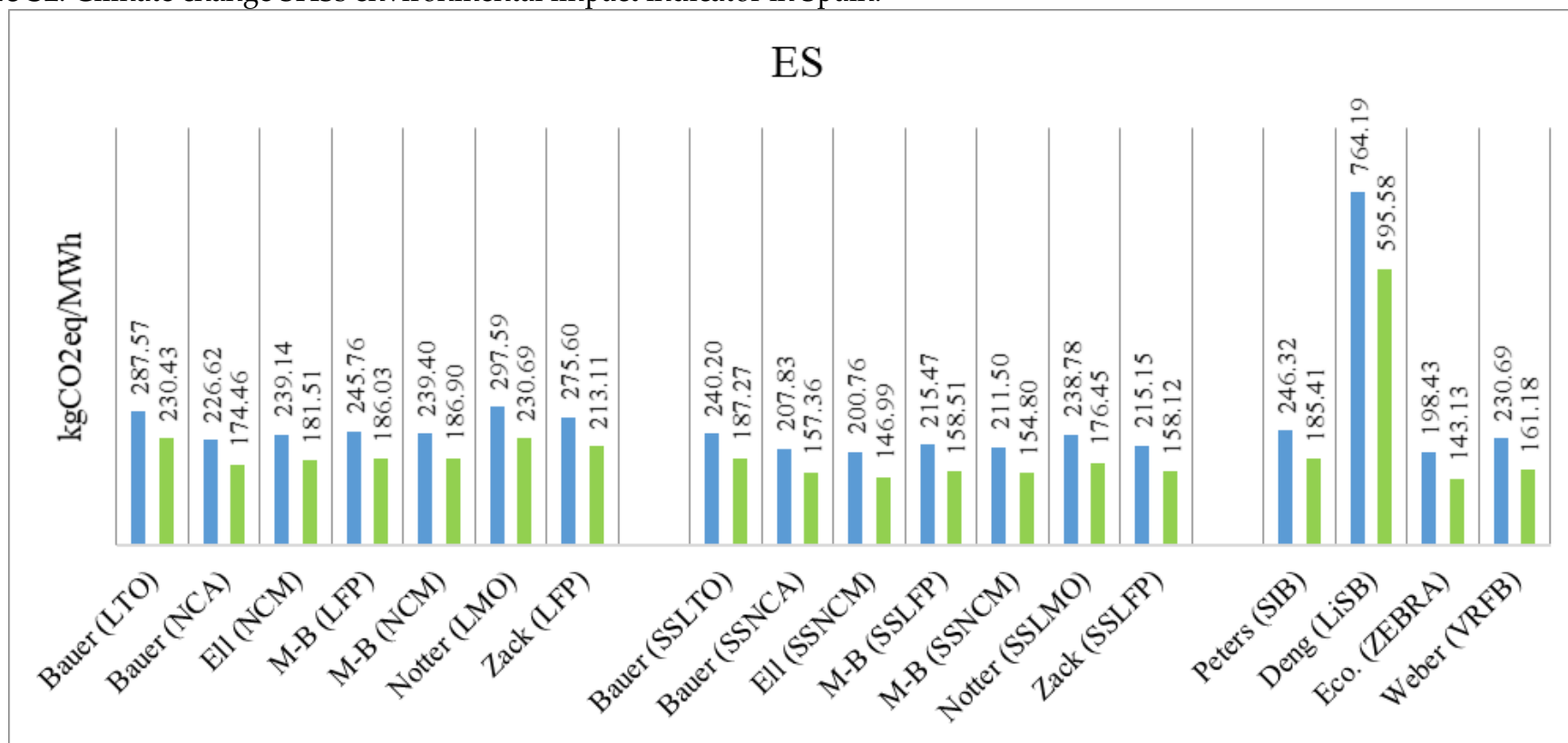


Figure S3: Climate change SHSs environmental impact indicator in France.

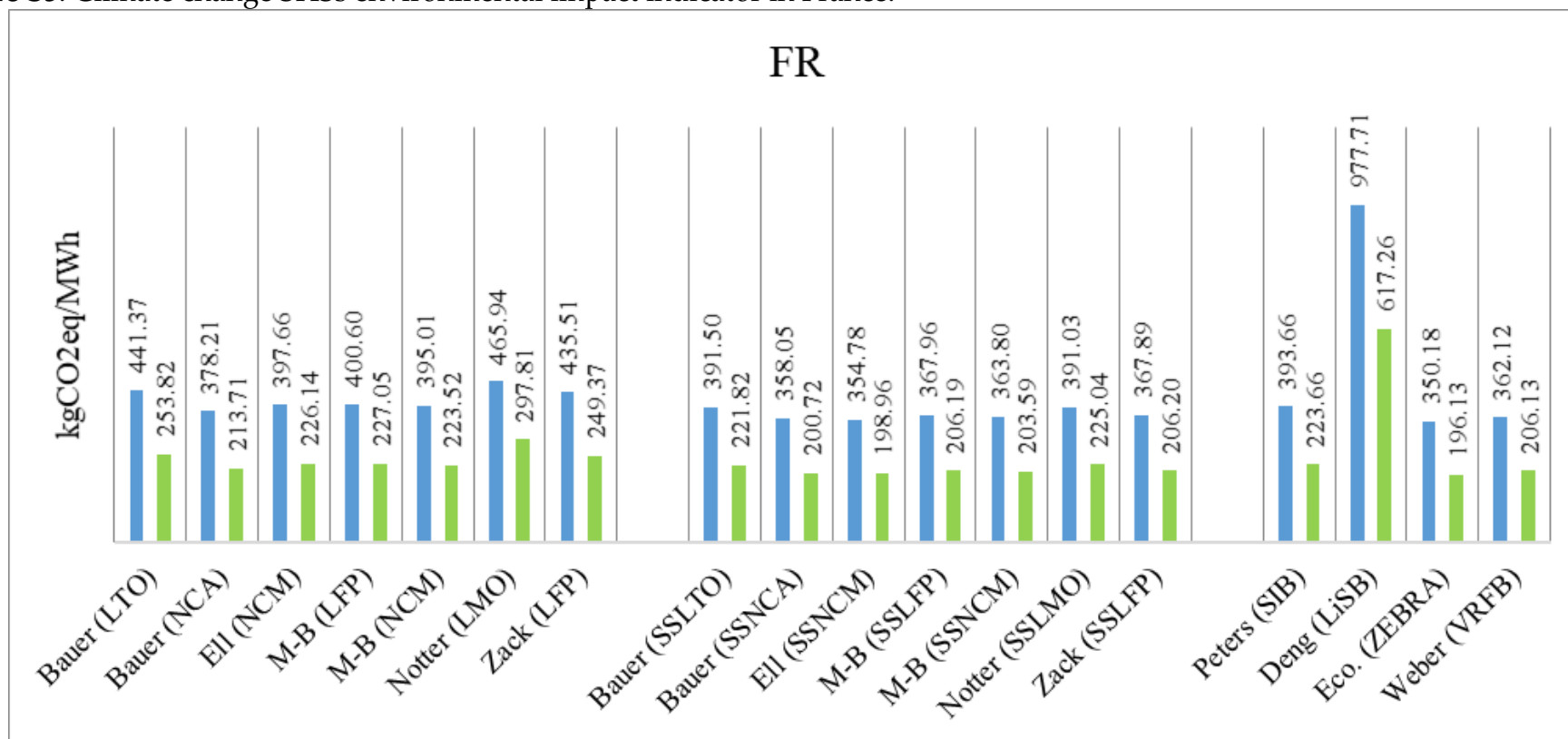


Figure S4: Climate change SHSs environmental impact indicator in Greece.

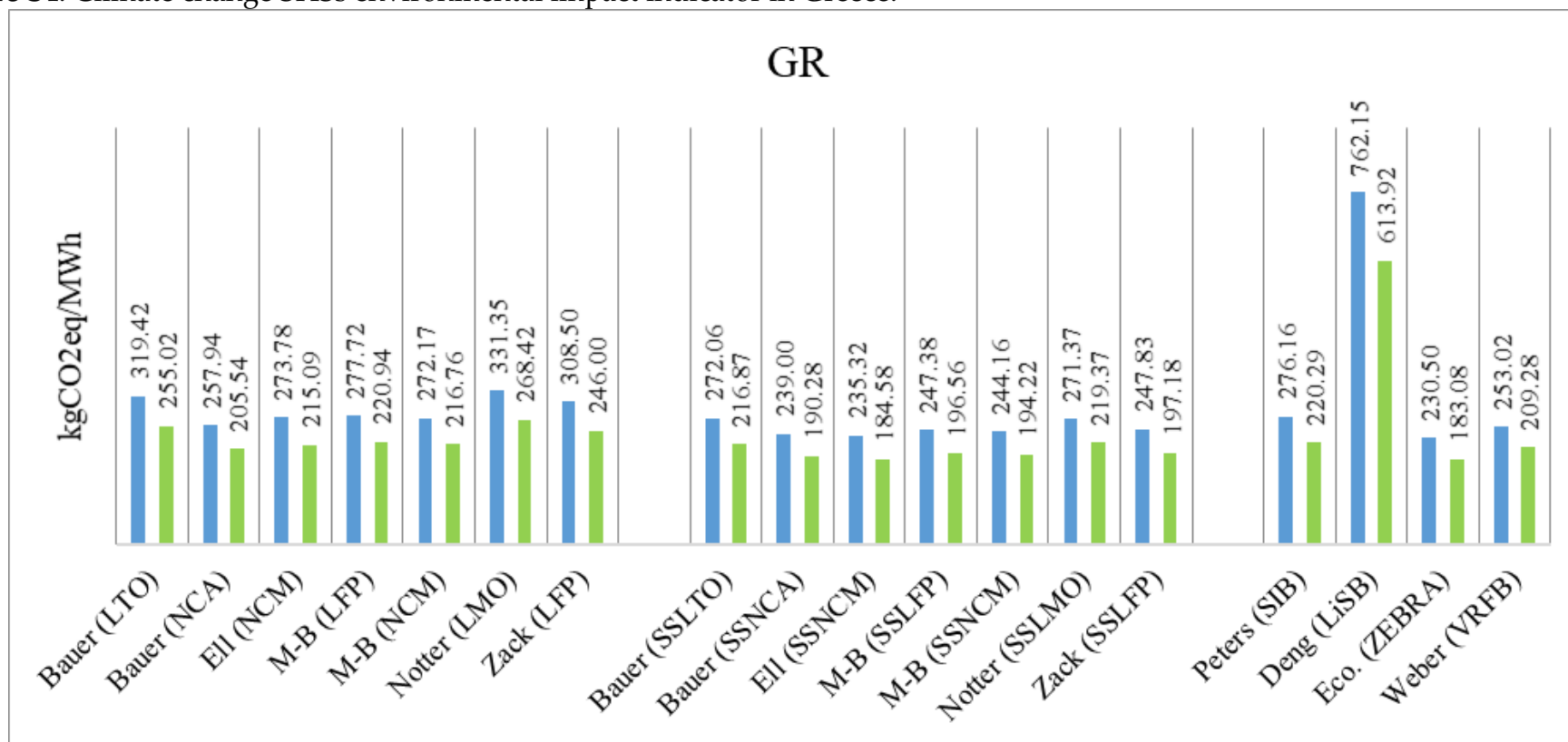


Figure S5: Climate change SHSs environmental impact indicator in Hungary.

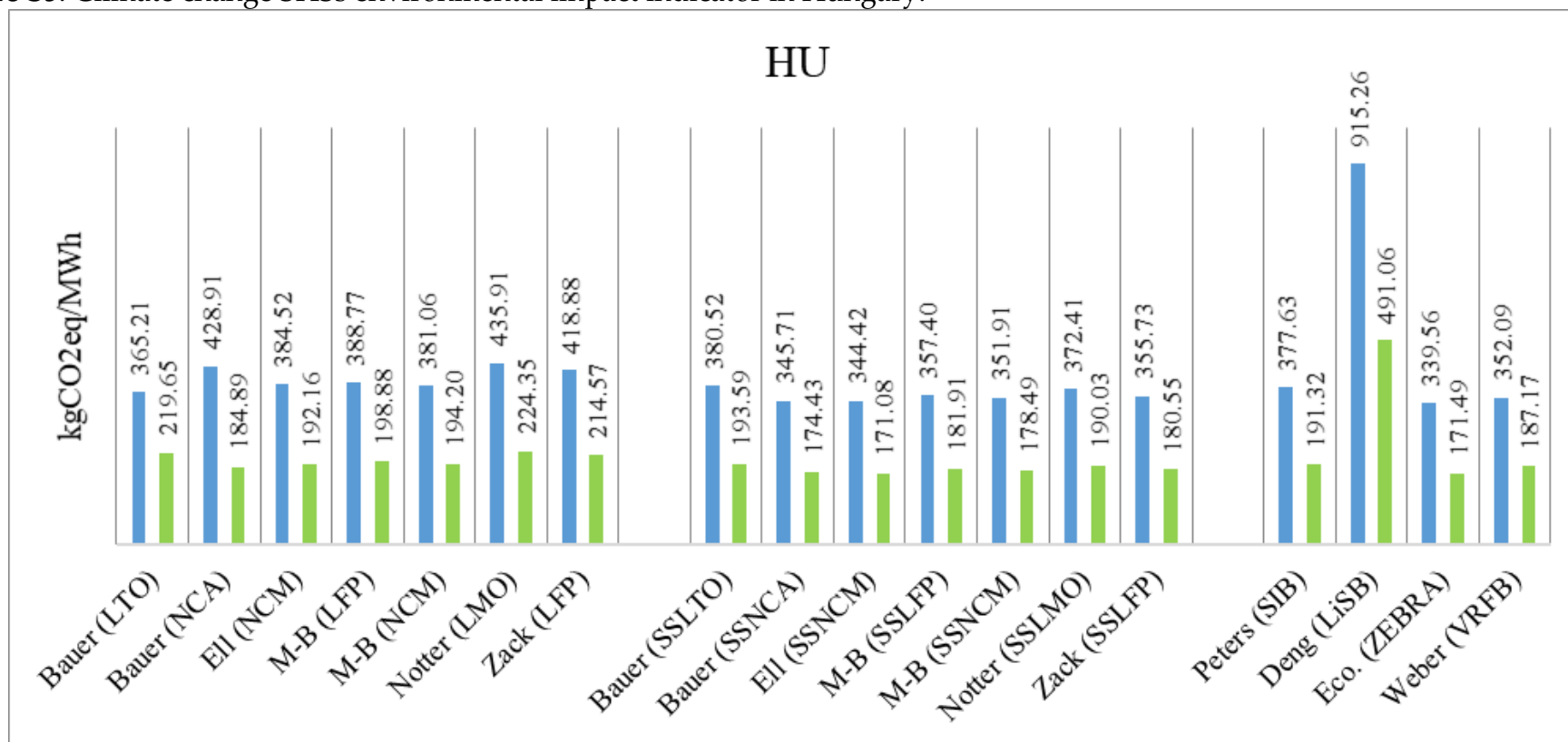


Figure S6: Climate change SHSs environmental impact indicator in Portugal.

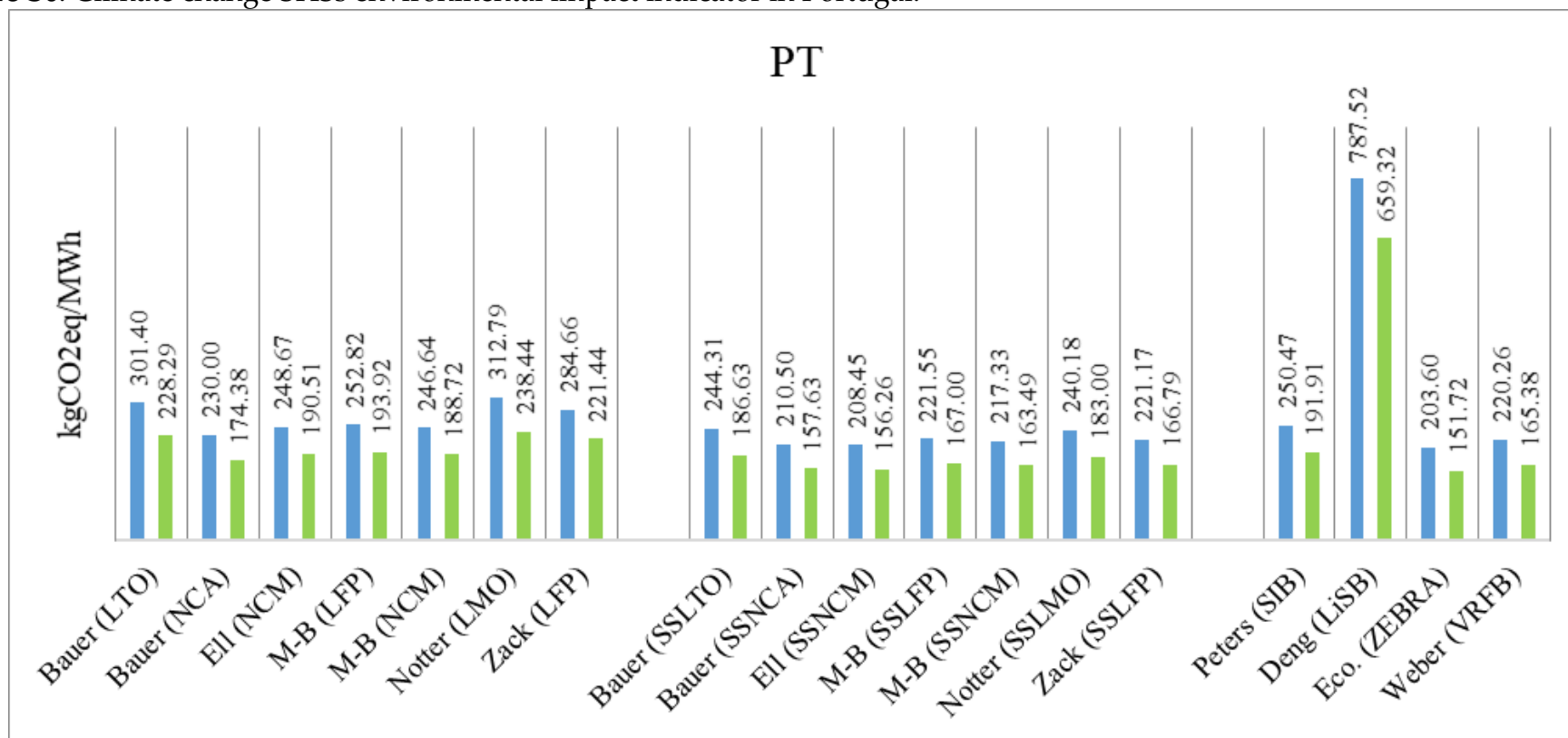


Figure S7: Climate change SHSs environmental impact indicator in Romania.

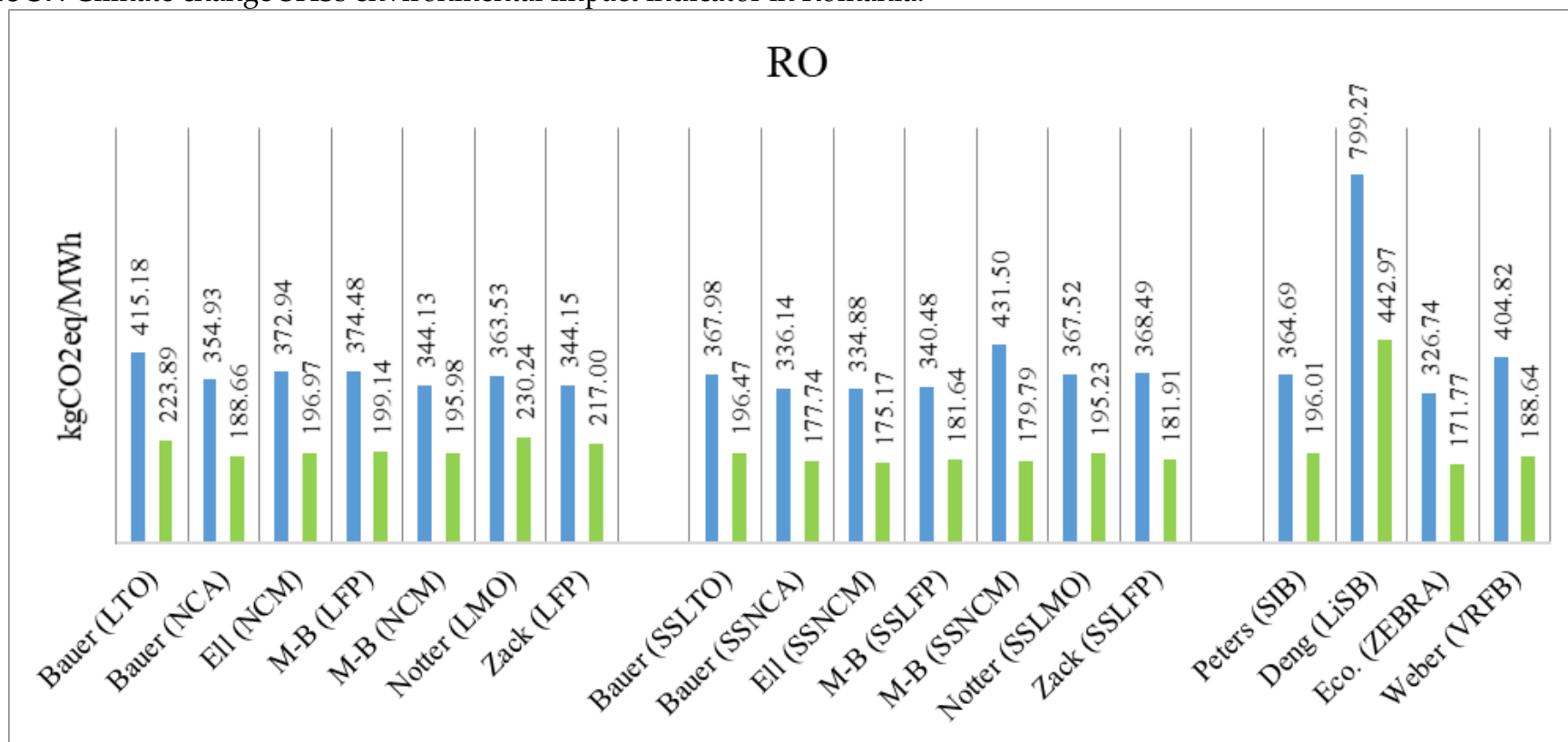


Figure S8: Human Toxicity SHSs environmental impact indicator in Denmark.

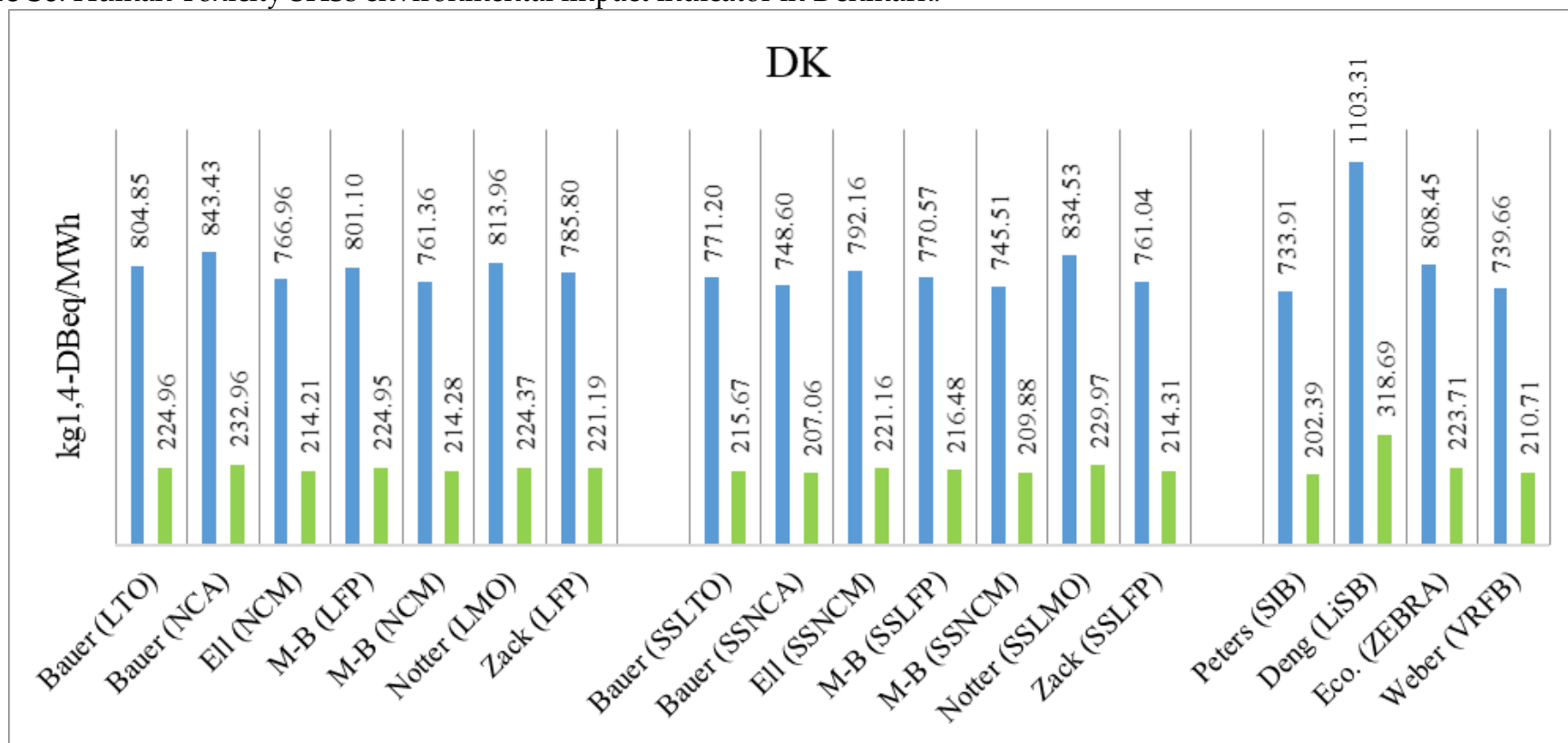


Figure S9: Human Toxicity SHSs environmental impact indicator in Spain.

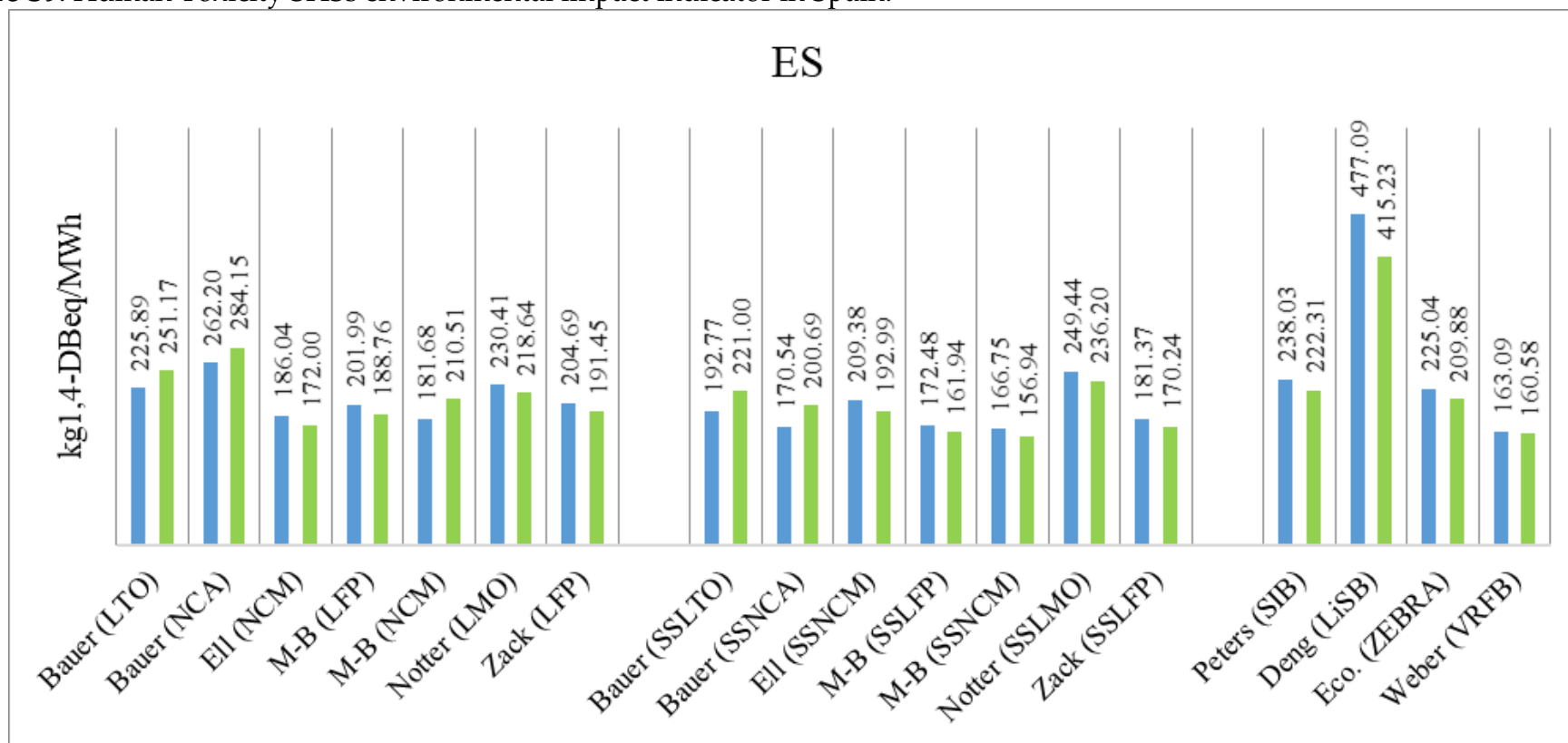


Figure S10: Human Toxicity SHSs environmental impact indicator in France.

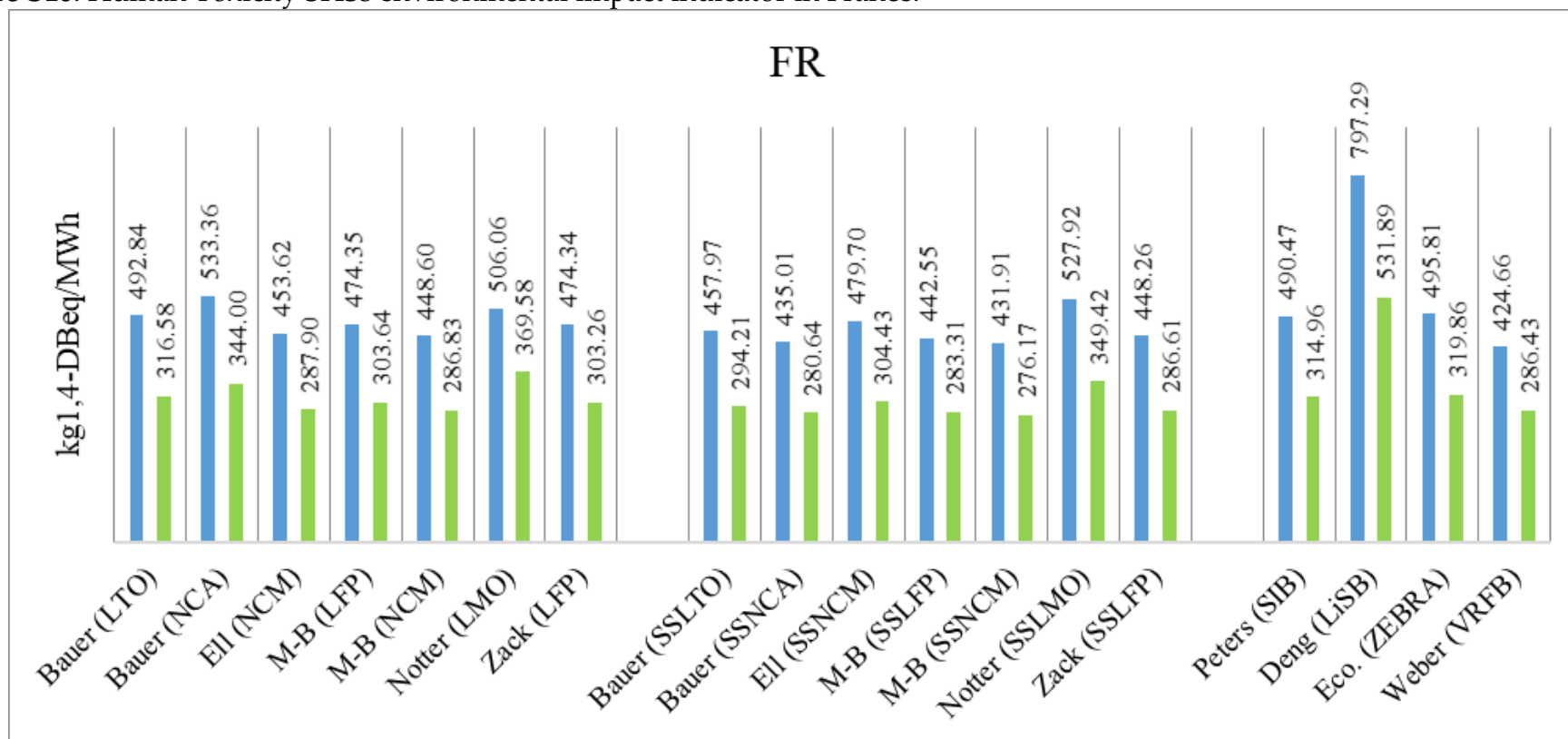


Figure S11: Human Toxicity SHSs environmental impact indicator in Greece.

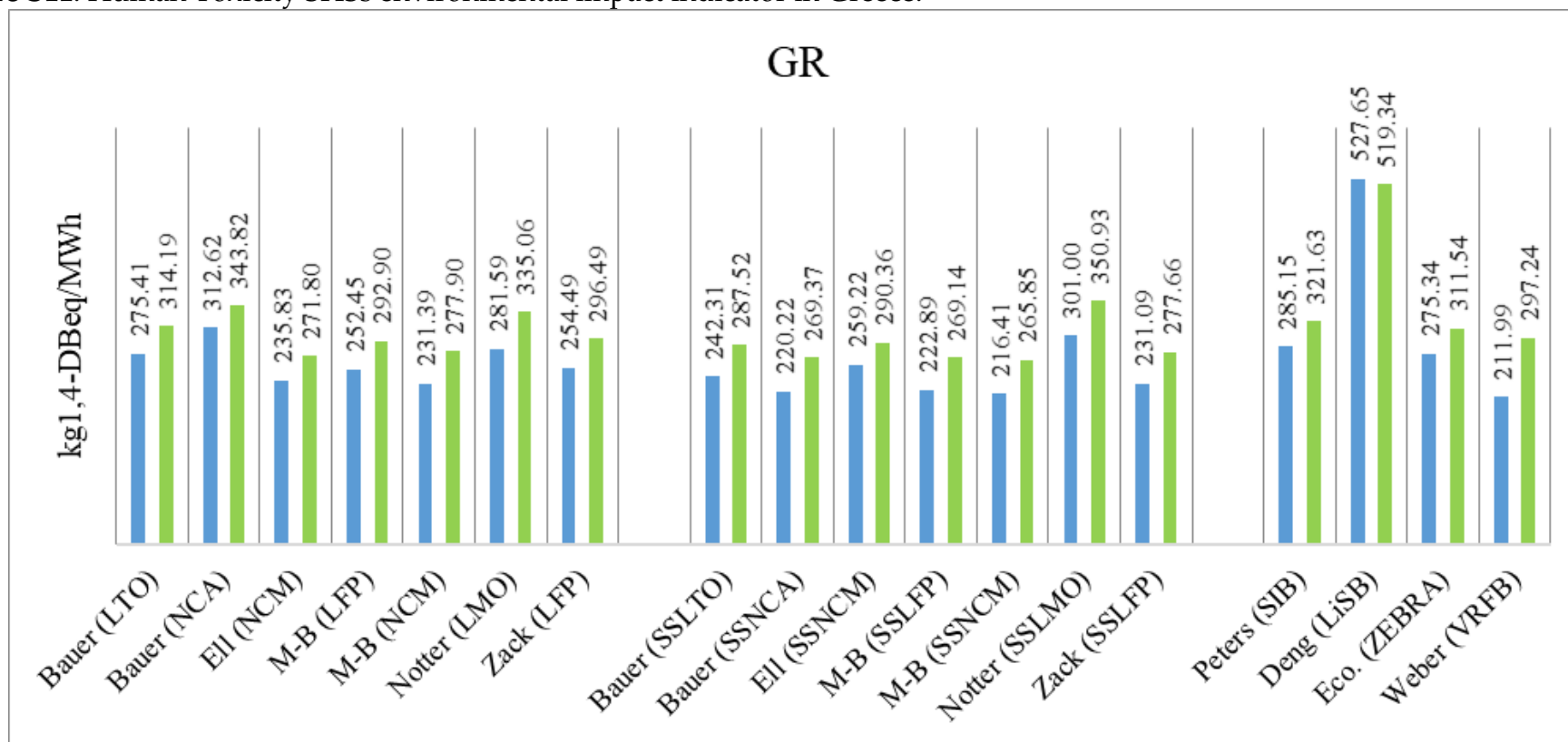


Figure S12: Human Toxicity SHSs environmental impact indicator in Hungary.

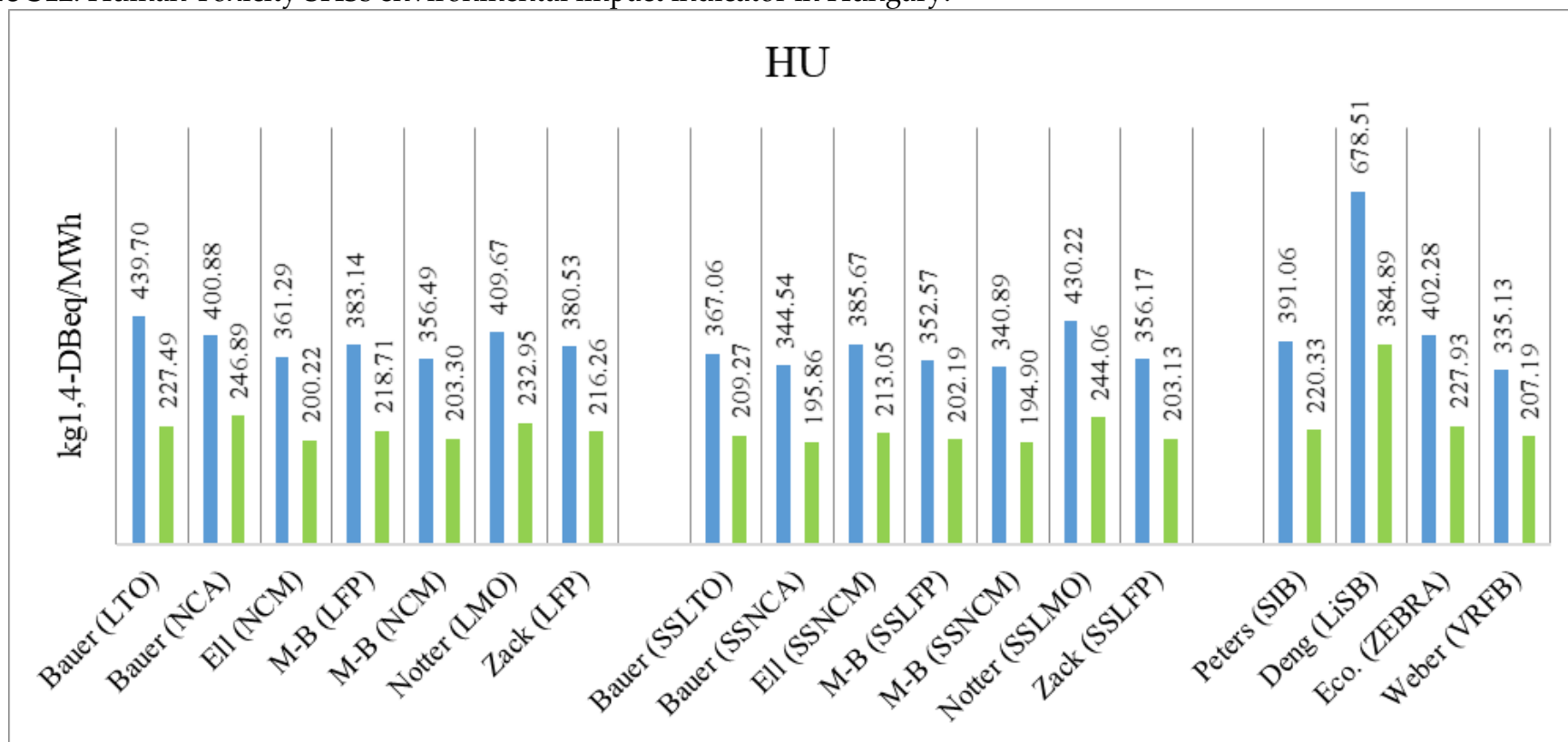


Figure S13: Human Toxicity SHSs environmental impact indicator in Portugal.

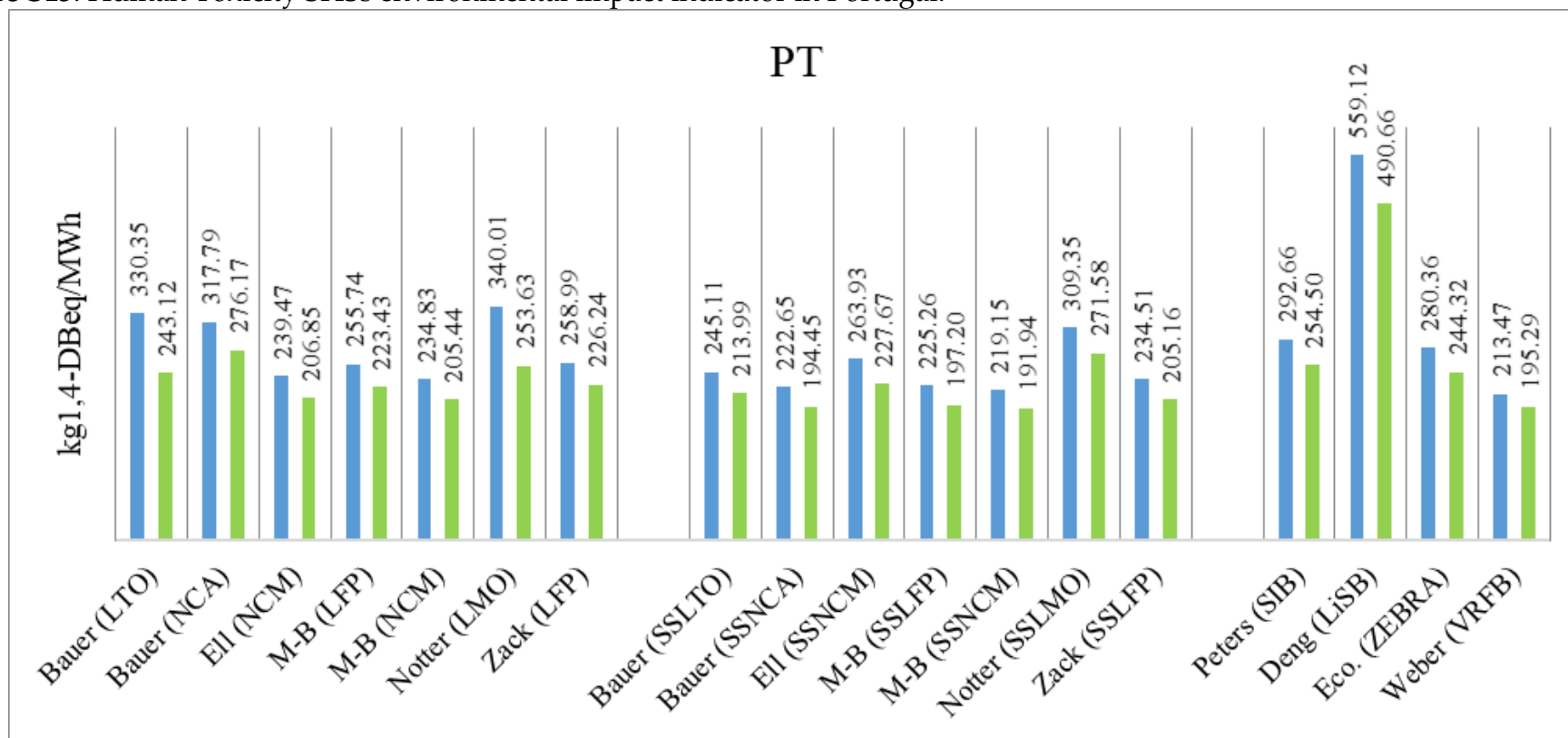


Figure S14: Human Toxicity SHSs environmental impact indicator in Romania.

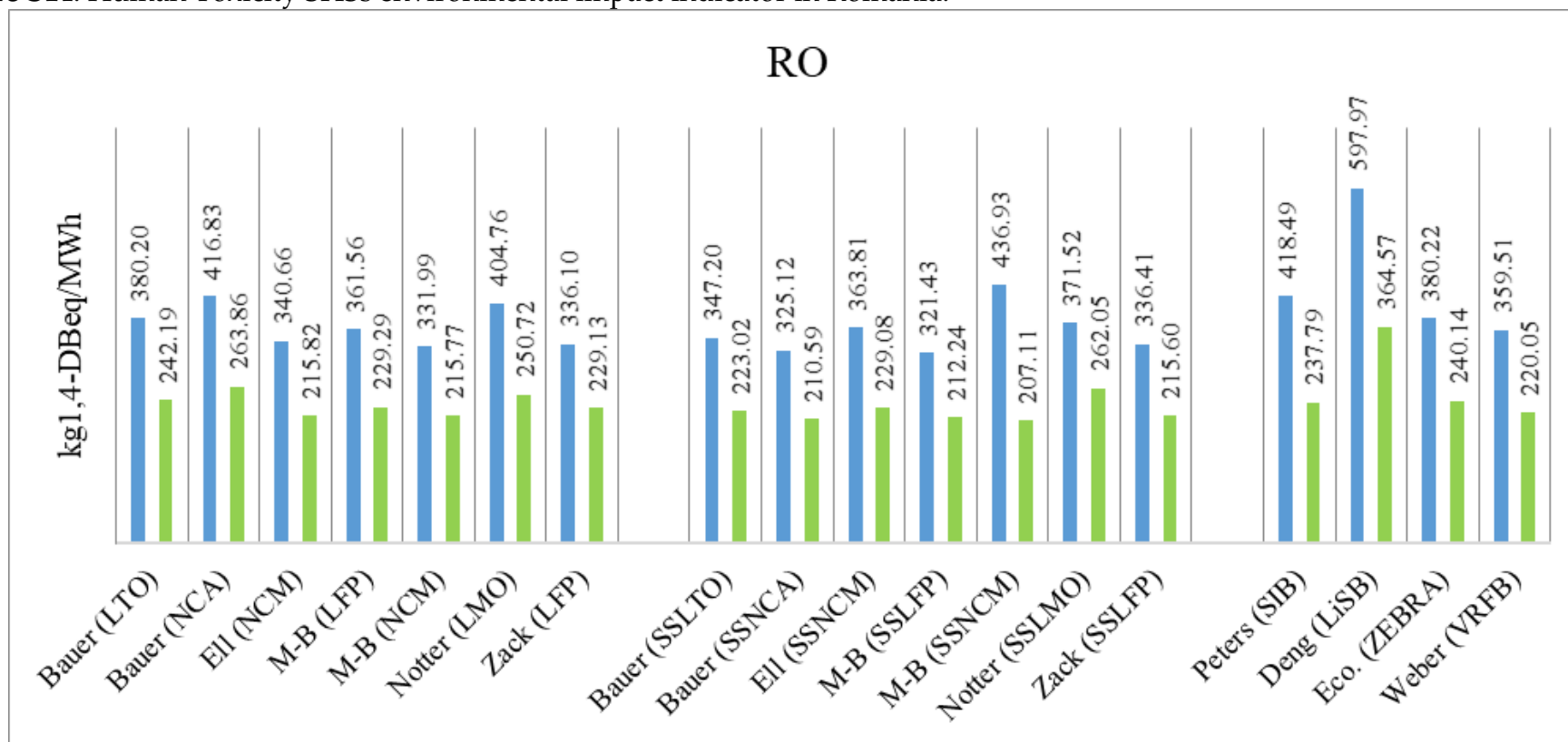


Figure S15: Fossil Depletion SHSs environmental impact indicator in Denmark.

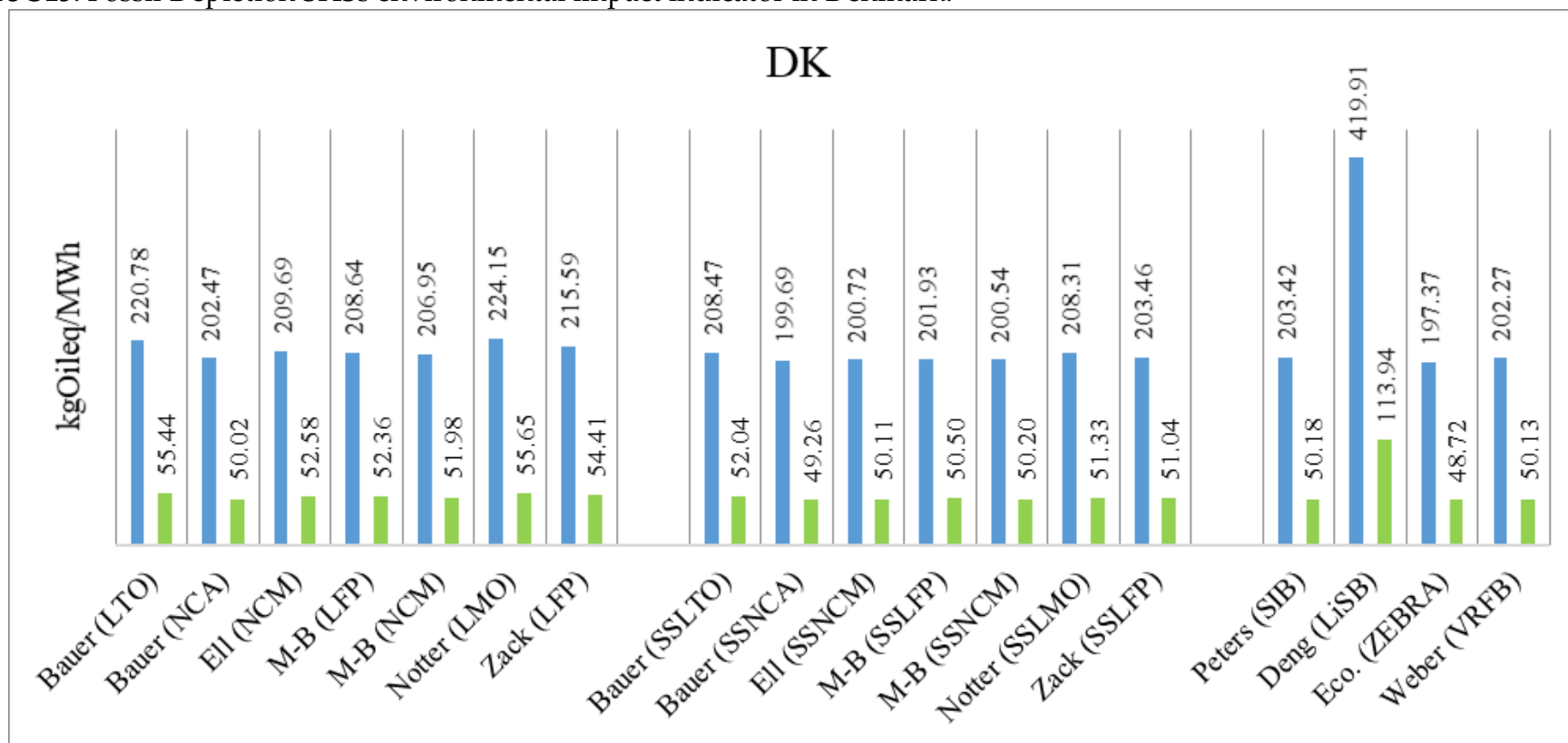


Figure S16: Fossil Depletion SHSs environmental impact indicator in Spain.

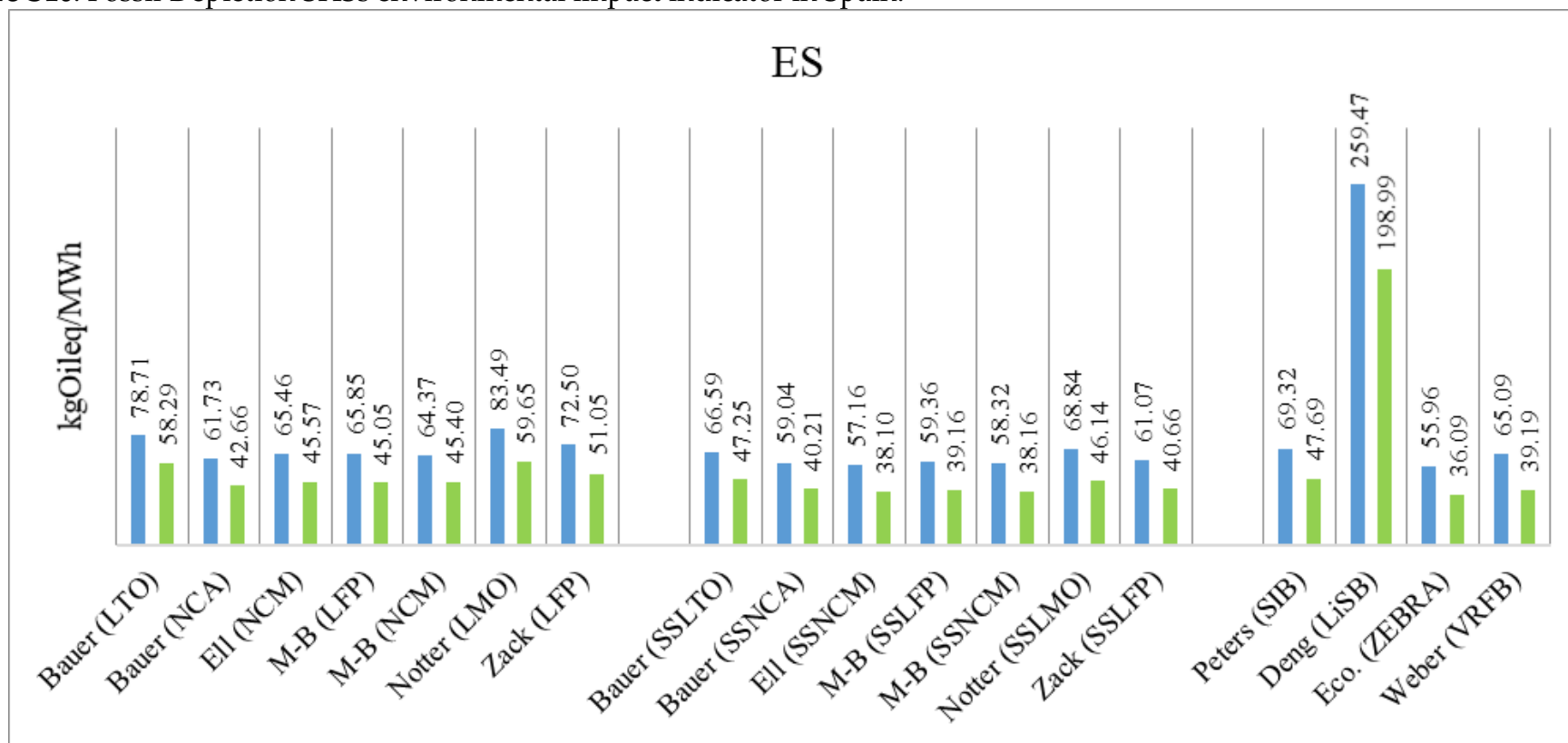


Figure S17: Fossil Depletion SHSs environmental impact indicator in France.

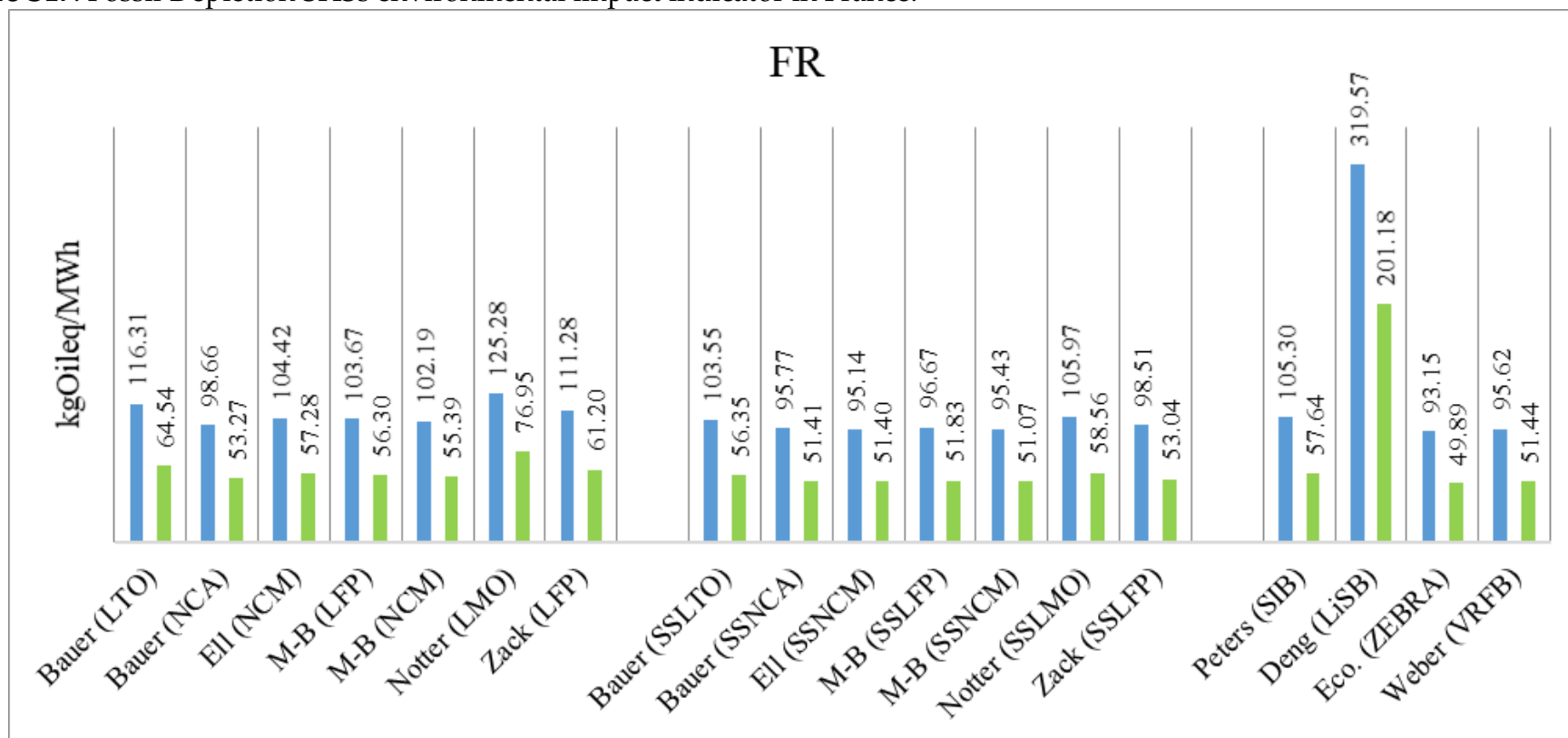


Figure S18: Fossil Depletion SHSs environmental impact indicator in Greece.

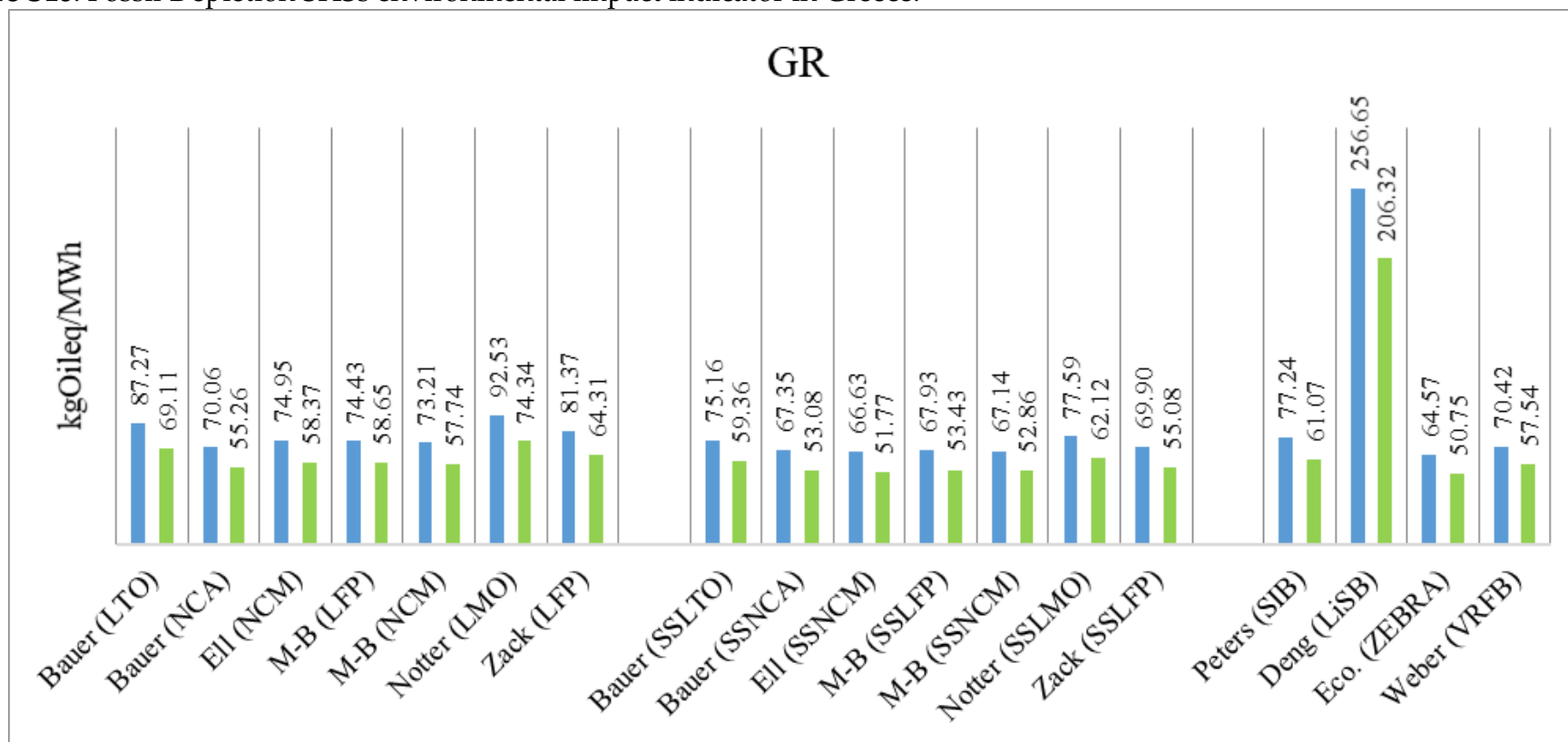


Figure S19: Fossil Depletion SHSs environmental impact indicator in Hungary.

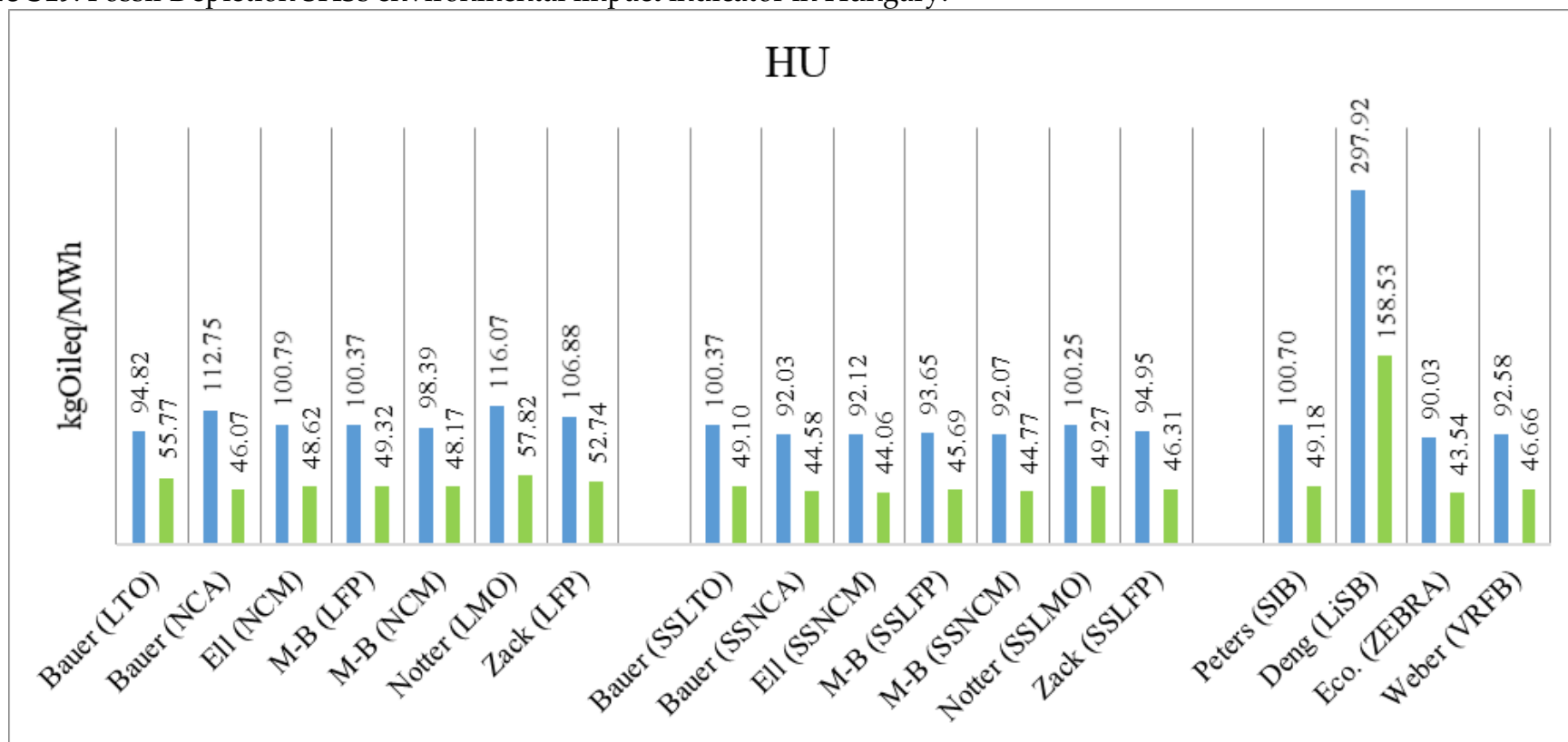


Figure S20: Fossil Depletion SHSs environmental impact indicator in Portugal.

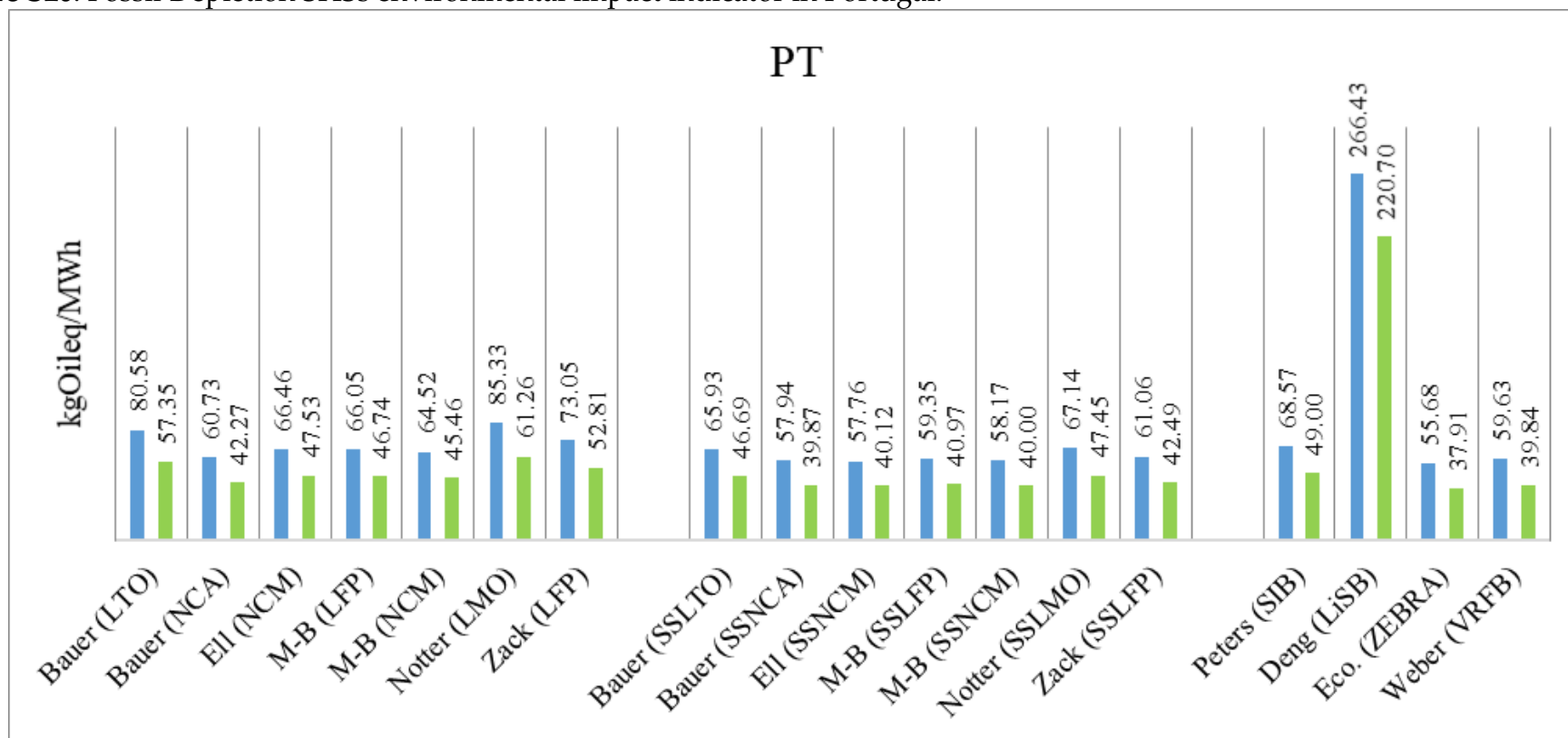


Figure S21: Fossil Depletion SHSs environmental impact indicator in Romania.

