Comparative Life Cycle Assessment of different fabrication processes for Perovskite solar mini-modules

Federico Rossi [1, §], Leonardo Rotondi [1, §], Maurizio Stefanelli[2], Adalgisa Sinicropi[1,3,4], Luigi Vesce[2, *], and Maria Laura Parisi [1, 3, 4, *]

[1] University of Siena, R²ES Lab, Department of Biotechnology, Chemistry and Pharmacy, Via Aldo Moro, 2, Siena, Italy
[2] CHOSE – Centre for Hybrid and Organic Solar Energy, Department of Electronic Engineering, University of Rome "Tor Vergata", Via del Politecnico 1, 00133 Rome, Italy
[3] CSGI, Center for Colloid and Surface Science, Via della Lastruccia 3, 50019 Sesto Fiorentino, Italy
[4] ICCOM-CNR, Institute of Chemistry of Organometallic Compounds, Consiglio Nazionale delle Ricerche, Via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy
§ These authors contributed equally to this work.
*Correspondence: vesce@ing.uniroma2.it; marialaura.parisi@unisi.it

Supporting Information

1. Materials and methods

The following description presents how the PSK deposition layer is performed for every technology, and the assumptions made to build the inventory presented in Table S1.

Focusing on the PSK layer deposition, which is the most characteristic material of the PSK solar cells, the LCI has been modelled as following:

- Spin Coating [1]: Firstly, there is the deposition of the PSK precursor solution composed of PbI_2, $PbBr_2$, CsI, MABr and FAI in DMF/DMSO; secondly, the anti-solvent, hence chlorobenzene (CBZ) gets deposited. Subsequently, an annealing step is performed on a hot plate. Energy consumptions come from the use of the spin coater in N_2 glovebox environment, in order to perform depositions, and the hot plate, used to dry the PSK film.

- Blade Coating [1]: this line employs the same reagents, but in smaller quantities, as the spin coating one; the only change is the use of isopropanol as anti-solvent instead of CBZ. Depositions of both PSK precursor solution and anti-solvent are performed exploiting the blade coating techniques in ambient air. Annealing step in order to dry the PSK film is in this case carried out with an oven instead of an hot plate.

- Spin Coating + Press [2]: in this line PSK film is produced performing a one-step approach. The characteristic part of this manufacturing line is the synthesis of the PSK solution. The process exploits two different reactions, one between methylamine and lead iodide leading to $PbI_2*CH_3NH_2$, and the other one between methylamine and ammonium iodide leading to $CH_3NH_3I*3CH_3NH_2$. These two products are then mixed in a 1:1 molar ratio leading to $CH_3NH_3I*3CH_3NH_2 + PbI_2*CH_3NH_2$ in form of a viscous paste. This paste is dropped onto the glass substrate and spread evenly applying pressure with a Kapton sheet. During the subsequently Kapton removal, excess methylamine evaporates leaving on the glass only the PSK crystal; this is assisted by a thermal step using a hot plate. In order to determine the quantity of raw materials (PbI_2, CH_3NH_3I and CH_3NH_2) used in this synthesis some assumptions have been necessary. The article describing the process does not show any reaction yield, nor density or mass of the precursor solution. It was then assumed that the solution in the vial (showed in Figure 1 in the SI of the article, related to $CH_3NH_3I*3CH_3NH_2$) corresponds to the total solution synthetized with the reagents listed in the article. The volume of that solution was calculated measuring the dimensions of the vial using an image manipulation software (IrfanView[3]). The image used should have been the one related to ($CH_3NH_3I*3CH_3NH_2$) + ($PbI_2*CH_3NH_2$), hence the PSK solution, but the presence of a stir bar in the vial vanished all possibilities of evaluating the volume, so it was also assumed that the addition of the lead precursor ($PbI_2*CH_3NH_2$) does not change the volume of the $CH_3NH_3I*3CH_3NH_2$ solution. Moreover, the production of the Kapton sheet employed in the process "Spin Coating + Press" has been modelled using the Ecoinvent process "Market for pthalimide-compound {GLO} – Cut-off". It is assumed that the consumption of each Kapton is allocated to the production of a mini-module and then it goes wasted as "Market for waste plastic, mixture {IT} – Cut-off". Energy consumptions are related to the press and the hot plate.

- Blade Coating in Glovebox [4]: in this manufacturing line the PSK precursor solution is deposited onto the glass substrate exploiting a blade coating technique in N_2 glovebox environment. The substrate is then dipped in diethyl ether, the anti-solvent, and heated using a hot plate. The PSK solution is composed of PbI_2, FAI and MAI in DMF/NMP (N-methyl-2-pyrrolidine). These reagents are the ones named in the reference paper as "For mixed cations".

In addition to the information provided in the above-listed bullet points, among the materials consumed to produce the mini-modules, solvents are often used for the deposition of certain layers of the mini-modules. Accordingly, all solvents are considered to evaporate quantitatively from the cell. Therefore, they are considered in the output as “Spent solvent mixture {Europe without Switzerland} Cut-off, S” in the EcoInvent database. The energy consumed along with the fabrication of mini-modules was considered as the Italian energy mixture medium voltage, using the EcoInvent “Market for electricity, medium voltage {IT} – Cut-off” process. Furthermore, PSK deposition processes in Spin Coating, Blade Coating and Blade Coating in Glovebox lines are considered having a 70% yield.

Concerning the consumption of raw materials, some of them are not available in the Ecoinvent library. Therefore, ad-hoc datasets developed by the authors [5] were used for the following compounds: TiO_2 paste; the titanium complex (Titanium diisopropoxide bis (acetylacetonate)) solution; acetylacetonate solution; lithium (lithium bis(trifluoromethanesulfonyl)imide) and cobalt (Cobalt FK209) salts; Spiro-OMeTAD; 4-tert-Butylpyridine; perovskite solution for the Spin Coating + Press process; lead bromide ($PbBr_2$); cesium iodide (CsI_2); lead iodide (PbI_2); methylammonium bromide (MABr); formamidinium iodide (FAI); fullerens and FTO-glass.

The electricity consumption of the glovebox alone was estimated considering the electricity use of the spin coater with and without the glovebox, both present in the “Spin Coating” process. In this production line, the TiO_2 deposition was performed using only the spin coater, while other depositions (PSK and Spiro) were performed using the spin coater in the glovebox. Accordingly, the energy consumption of the glovebox was numerically evaluated by subtraction. These assumptions lead to an estimated energy consumption of the glovebox approximately equal to 0.04kWh related to a cell area of 31.36 cm^2. The electricity consumed by the glovebox is then employed to estimate the additional energy demanded by the process “Blade Coating in Glovebox” compared to “Blade Coating”.

Table S1: LCI of the techniques referred to 1 cm^2 as functional unit

Flow	Process	Spin Coating	Blade Coating	Spin Coating + Press	Blade Coating in Glovebox	Unit	Comment
Glass substrate							
Inputs							
FTO Glass sheet	See ref[ESPResSO]	0.87	0.87	0.87	0.87	g	
Outputs							
Glass substrate	FTO Glass production	0.87	0.87	0.87	0.87	g	
Laser Scribing (P1)							
Inputs							
Glass substrate	Glass substrate	0.87	0.87	0.87	0.87	g	

Electricity	Market for electricity, medium voltage - {IT}	0.096	0.096	0.096	0.096	Wh	
Outputs							
Scribed Glass substrate	Glass substrate scribing	0.87	0.87	/	0.87	g	
			Cleaning				
Inputs							
Scribed Glass substrate	Laser Scribing (P1)	0.87	0.87	0.87	0.87	g	
Acetone	Market for acetone, liquid - {RER}	0.25	0.25	0.25	0.25	g	
Isopropanol	Market for isopropanol - {RER}	0.25	0.25	0.25	0.25	g	
Ethanol	Market for ethanol, without water, in 99,7% solution state, from ethylene - {RER}	/	/	/	1.26	g	
NaOH	Market for sodium hydroxide, without water, in 50% solution state - {GLO}	/	/	/	0.026	g	
Electricity	Market for electricity, medium voltage - {IT}	0.34	0.34	0.34	/	Wh	
Outputs							
Cleaned Glass substrate	Glass substrate cleaning	0.87	0.87	0.87	0.87	g	
Waste solvents	Market for spent solvent mixture - {Europe without Switzerland}	0.50	0.50	0.50	1.29	g	
			Compact Layer Deposition				

Inputs							
Cleaned Glass substrate	Cleaning	0.87	0.87	/	0.87	g	
Ti(acac)$_2$OiPr$_2$	See ref[ESPResSO]	0.0095	0.0095	0.0095	0.0095	g	
Acetylacetone	See ref[ESPResSO]	0.0062	0.0062	0.0062	0.0062	g	
1-butanol	Market for 1-butanol - {GLO}	/	/	/	0.12	g	
Ethanol	Market for ethanol, without water, in 99,7% solution state, from ethylene - {RER}	0.11	0.11	0.11	/	g	
Electricity	Market for electricity, medium voltage - {IT}	13	13	13	13	Wh	
Outputs							
CLD Glass	CLD	0.87	0.87	0.87	0.87	g	
Waste solvents	Market for spent solvent mixture - {Europe without Switzerland}	0.13	0.13	0.13	0.13	g	
ETL Deposition							
Inputs							
CLD Glass	CLD	0.87	0.87	0.87	0.87	g	
TiO_2 paste with ethanol	see Table S2	0.043	0.0030	0.041	/	g	
C_{60}	see ref[ESPResSO]	/	/	/	0.0029	mg	
Monochlorobenzene	Market for monochlorobenzene - {RER}	/	/	/	1.1	mg	
Tetrahydrofuran	Market for tetrahydrofuran - {GLO}	/	/	/	0.85	mg	

Electricity	Market for electricity, medium voltage - {IT}	0.64	1.4	0.64	2.7	Wh	
Outputs							
HTL Glass	HTL Deposition	0.91	0.87	0.91	0.87	g	
Waste solvents	Market for spent solvent mixture - {Europe without Switzerland}	/	/	/	1.91	mg	
ETL Sintering							
Inputs							
HTL Glass	HTL Deposition	0.91	0.87	0.91	/	g	
Electricity	Market for electricity, medium voltage - {IT}	2.3	2.3	2.3	/	Wh	
Outputs							
Sintered HTL Glass	HTL Sintering	0.87	0.87	0.87	/	g	
Waste solvents	Market for spent solvent mixture - {Europe without Switzerland}	0.042	0.0029	0.040	/	g	
UV Treatment							
Inputs							
Sintered HTL Glass	HTL Sintering	0.87	0.87	0.87	/	g	
Electricity	Market for electricity, medium voltage - {IT}	0.11	0.11	0.11	/	Wh	
Outputs							
UV Treated Glass	UV Treatment	0.87	0.87	0.87	/	g	
Perovskite Deposition							
Inputs							
UV Treated Glass	UV Treatment	0.87	0.87	0.87	0.87	g	
PbI_2	see ref[ESPResSO]	5.2	1.0	/	1.0	mg	
$PbBr_2$	see ref[ESPResSO]	0.83	0.16	/	/	mg	

CsI	see ref[ESPResSO]	0.19	0.036	/	/	mg	
MABr	see ref[ESPResSO]	0.21	0.040	/	/	mg	
MAI	see ref[ESPResSO]	/	/	/	0.25	mg	
FAI	see ref[ESPResSO]	1.6	0.31	/	0.12	mg	
PSK precursor solution	see Table S3	/	/	4.75	/	mg	
DMF	Market for N,N-dimethylformamide - {GLO}	6.8	1.7	/	1.5	mg	
DMSO	Market for dimethyl sulfoxide - {GLO}	2.6	0.49	/	/	mg	
NMP	Market for N-methyl-2-pyrrolidone - {GLO}	/	/	/	0.69	mg	
Monochlorobenzene	Market for monochlorobenzene - {RER}	21	/	/	/	mg	
Isopropanol	Market for isopropanol - {RER}	/	7.5	/	/	g	
Diethyl ether	Market for diethyl ether, without water, in 99,95% solution state - {RER}	/	/	/	9.1	g	Dipping
Kapton sheet	Market for phtalimide compound - {GLO}	/	/	0.28	/	mg	
Electricity	Market for electricity, medium voltage - {IT}	1.9	1.4	1.1	2.7	Wh	Deposition
Electricity	Market for electricity, medium voltage - {IT}	13	0.54	13	13	Wh	Annealing
Outputs							
PSK Glass substrate	Perovskite Deposition	0.88	0.87	0.88	0.87	g	

Waste solvents	Market for spent solvent mixture - {Europe without Switzerland}	33	10	0.79	9100	mg	
Waste Kapton sheet	Market for waste plastic, mixture - {IT}	/	/	0.28	/	mg	
Spiro Deposition							
Inputs							
PSK Glass substrate	Perovskite Deposition	0.88	0.87	0.88	0.87	g	
Spiro-OMeTAD	see ref[ESPResSO]	0.47	0.18	0.47	0.16	mg	
Monochlorobenzene	Market for monochlorobenzene - {RER}	7.1	2.7	7.1	2.5	mg	
Tert-butylpiridine	see ref[ESPResSO]	0.15	0.044	0.15	0.072	mg	
Lithium salt	see ref[ESPResSO]	0.053	0.057	0.053	0.023	mg	
Cobalt Salt	see ref[ESPResSO]	/	/	/	0.13	µg	
Acetonitrile	Market for acetonitrile - {GLO}	0.12	0.044	0.12	0.070	mg	
Electricity	Market for electricity, medium voltage - {IT}	1.9	1.4	1.9	2.7	Wh	
Outputs							
Spiro Glass substrate	Spiro Deposition	0.88	0.87	0.88	0.87	g	
Waste solvents	Market for spent solvent mixture - {Europe without Switzerland}	7.21	2.70	7.21	2.55	mg	
Laser Ablation (P2)							
Inputs							
Spiro Glass substrate	Spiro Deposition	0.88	0.87	0.88	0.87	g	

Electricity	Market for electricity, medium voltage - {IT}	0.41	0.41	0.41	0.41	Wh	
Outputs							
P2 Glass substrate	Laser Ablation (P2)	0.88	0.87	0.88	0.87	g	
Gold Deposition							
Inputs							
P2 Glass substrate	Laser Ablation (P2)	0.88	0.87	0.88	0.87	g	
Gold	Market for gold - {GLO}	0.013	0.013	0.013	0.013	mg	
Electricity	Market for electricity, medium voltage - {IT}	0.014	0.014	0.014	0.014	kWh	
Outputs							
Gold Glass substrate	Gold Deposition	0.89	0.88	0.89	0.88	g	
Laser Ablation (P3)							
Inputs							
Gold Glass substrate	Gold Deposition	0.89	0.88	0.89	0.88	g	
Electricity	Market for electricity, medium voltage {IT}	0.22	0.22	0.22	0.22	Wh	
Outputs							
PSK mini-module	Laser Ablation (P3)	0.89	0.88	0.89	0.88	g	

Table S2: LCI of the material TiO_2 paste with ethanol based on [43] and [45]

Flow	Process	Spin coating	Blade coating	Spin coating + Press	Unit	Comment
Inputs						
TiO_2 paste	see ref[ESPResSO]	1	1	1	kg	
Ethanol	Market for ethanol, without water, in 99,7% solution state, from ethylene-{RER}	5	8	6	kg	
Outputs						
TiO_2 paste with ethanol	TiO_2 paste for PSK	6	9	7	kg	Density assumed as: $\frac{(d_{TiO_2} * 1) + (dEtOH * x)}{y}$ with: $x = quantity\ of\ EtOH$ $y = quantity\ of\ solution$ according to relative mixing ratios

Table S3: LCI of the material perovskite precursor solution based on [44]

Flow	Process	Amount	Unit	Comment
Inputs				
PbI_2	see ref[ESPResSO]	922	mg	
MAI	see ref[ESPResSO]	318	mg	
Methylamine	Market for methylamine - {RER}	37.2	g	Calculated from flowrate
Outputs				
Perovskite precursor solution	PSK precursor solution for Spin Coating + Press	1.49	g	Density assumed as $\frac{1.4884g}{0.98mL} = 1.52\frac{g}{mL}$ with: Calculated mass from the reaction = 1.4884g Estimated volume ≈ 0.98mL
Waste solvents	Market for spent solvent mixture - {Europe without Switzerland}	37	g	

2. Results and Discussions

Table S4: Environmental impact in percentage values of the process Spin Coating

Etichetta	Step01 Glass Substrate	Step03 Cleaning	Step04 Compact Layer Deposition	Step05 TiO_2 Spin Coating Deposition	Step08 Perovskite Spin Coating Deposition	Step09 Spiro Spin Coating Deposition	Step11 Gold Deposition	Others
Climate change	*Others*	7.95	25.06	1.38	27.75	3.65	26.51	7.71
Ozone depletion	*Others*	*Others*	26.54	1.34	30.62	3.98	27.76	9.75
Ionising radiation	*Others*	*Others*	23.55	1.19	35.67	3.48	26.50	9.62
Photochemical ozone formation	6.67	8.95	22.33	1.47	24.83	3.31	27.46	4.98
Particulate matter	9.76	10.07	20.56	1.42	23.20	3.18	27.22	4.58
Human toxicity, non-cancer	25.43	*Others*	14.41	0.87	17.88	2.28	33.06	6.07
Human toxicity, cancer	8.65	6.48	16.61	1.47	32.29	6.90	23.81	3.80
Acidification	6.45	5.30	23.36	1.39	26.58	3.41	28.06	5.44
Eutrophication, freshwater	*Others*	*Others*	18.29	1.11	20.32	2.69	46.39	11.19
Eutrophication, marine	7.85	5.20	22.29	1.27	25.56	3.30	29.35	5.18
Eutrophication, terrestrial	8.77	*Others*	22.07	1.25	25.03	3.22	29.67	9.99
Ecotoxicity, freshwater	9.72	*Others*	13.23	0.76	19.32	2.64	48.31	6.02
Land use	5.89	*Others*	22.92	1.27	27.24	3.50	31.46	7.72
Water use	*Others*	*Others*	25.85	1.56	29.65	3.74	26.25	12.96
Resource use, fossils	*Others*	8.88	24.88	1.62	28.33	3.55	25.93	6.81
Resource use, minerals and metals	12.31	*Others*	*Others*	0.12	2.13	0.21	82.93	2.31

Table S5: Environmental impact in percentage values of the process Blade Coating

Etichetta	Step01 Glass Substrate	Step03 Cleaning	Step04 Compact Layer Deposition	Step05 TiO_2 Blade Coating Deposition	Step06 TiO_2 Sintering	Step08 Perovskite Blade Coating Deposition	Step09 Spiro Blade Coating Deposition	Step11 Gold Deposition	Others
Climate change	*Others*	10.51	33.11	3.36	5.48	4.91	3.48	34.74	4.40
Ozone depletion	*Others*	*Others*	36.13	3.82	6.24	5.45	3.94	37.48	6.95
Ionising radiation	*Others*	*Others*	33.78	3.60	5.87	7.49	3.67	37.71	7.89
Others Photochemical ozone formation	8.55	11.47	28.63	2.88	*Others*	4.20	3.01	34.93	6.33
Particulate matter	12.31	12.71	25.95	2.57	*Others*	3.97	2.77	34.07	5.65
Human toxicity, non-cancer	30.26	*Others*	17.15	1.67	*Others*	2.88	1.85	39.03	7.16
Human toxicity, cancer	12.93	9.68	24.82	2.55	*Others*	4.05	5.11	35.30	5.55
Acidification	8.40	6.90	30.41	3.18	5.17	4.59	3.24	36.23	1.87
Eutrophication, freshwater	Others	Others	22.35	2.25	*Others*	3.27	2.35	56.23	13.54
Eutrophication, marine	10.11	6.69	28.69	2.97	*Others*	4.42	3.07	37.48	6.57
Eutrophication, terrestrial	11.22	6.22	28.23	2.93	*Others*	4.25	3.00	37.65	6.49
Ecotoxicity, freshwater	11.81	*Others*	16.07	1.62	*Others*	3.07	2.01	58.23	7.18
Land use	7.72	*Others*	30.05	3.15	5.12	4.80	3.29	40.92	4.96
Water use	*Others*	6.29	34.89	3.57	5.78	5.31	3.66	35.14	5.38
Resource use, fossils	*Others*	11.81	33.07	3.37	5.44	5.12	3.43	34.19	3.58
Resource use, minerals and metals	12.62	*Others*	1.45	0.14	*Others*	0.33	0.15	84.39	0.92

Table S6: Environmental impact percentage values of the process Spin Coating + Press

Etichetta	Step01 Glass Substrate	Step02 Cleaning	Step03 Compact Layer Deposition	Step05 TiO_2 Spin Coating Deposition	Step08 Perovskite Press Deposition	Step09 Spiro Spin Coating Deposition	Step11 Gold Deposition	Others
Climate change	*Others*	7.96	25.28	1.36	27.70	3.65	26.33	7.71
Ozone depletion	*Others*	*Others*	26.83	1.33	30.45	4.00	27.62	9.77
Ionising radiation	*Others*	*Others*	25.30	1.25	31.46	3.71	28.02	10.25
Photochemical ozone formation	6.75	9.06	22.76	1.44	24.04	3.35	27.56	5.04
Particulate matter	9.87	10.19	20.96	1.38	22.44	3.22	27.32	4.62
Human toxicity, non-cancer	25.97	*Others*	14.83	0.86	16.32	2.33	33.50	6.20
Human toxicity, cancer	10.00	7.48	19.33	1.57	21.97	7.97	27.29	4.38
Acidification	6.50	5.35	23.74	1.37	26.06	3.44	28.06	5.48
Eutrophication, freshwater	*Others*	*Others*	18.63	1.10	19.71	2.72	46.53	11.31
Eutrophication, marine	7.84	5.19	22.44	1.24	25.74	3.29	29.09	5.16
Eutrophication, terrestrial	8.79	*Others*	22.27	1.23	25.01	3.23	29.47	10.00
Ecotoxicity, freshwater	10.13	*Others*	13.88	0.77	16.29	2.75	49.92	6.27
Land use	5.99	*Others*	23.49	1.27	26.09	3.56	31.75	7.85
Water use	*Others*	*Others*	26.37	1.55	28.82	3.79	26.36	13.11
Resource use, fossils	*Others*	8.94	25.22	1.60	27.96	3.57	25.88	6.84
Resource use, minerals and metals	12.42	*Others*	*Others*	0.11	1.93	0.21	82.99	2.34

Table S7: Environmental impact percentage values of the process Blade Coating in Glovebox

Etichetta	Step01 Glass Substrate	Step03 Cleaning	Step04 Compact Layer Deposition	Step05 C_{60} Blade Coating in Glovebox Deposition	Step06 Perovskite Blade Coating in Glovebox Deposition	Step07 Spiro Blade Coating in Glovebox Deposition	Step09 Gold Deposition	Others
Climate change	*Others*	4.71	8.87	1.64	73.08	1.66	8.97	1.07
Ozone depletion	*Others*	2.84	19.21	3.72	49.63	3.75	19.22	1.62
Ionising radiation	*Others*	1.46	20.35	3.99	45.39	4.01	22.04	2.76
Photochemical ozone formation	*Others*	3.64	6.39	1.15	78.19	1.16	7.36	2.11
Particulate matter	*Others*	4.03	6.54	1.11	76.43	1.13	7.69	3.07
Human toxicity, non-cancer	13.12	2.98	8.26	1.39	55.52	1.43	16.93	0.37
Human toxicity, cancer	*Others*	3.83	7.30	1.60	71.51	1.99	9.82	3.95
Acidification	*Others*	2.80	11.74	2.20	64.17	2.21	13.23	3.66
Eutrophication, freshwater	*Others*	3.78	6.37	1.15	70.85	1.17	15.19	1.49
Eutrophication, marine	*Others*	3.38	10.30	1.91	65.88	1.93	12.69	3.93
Eutrophication, terrestrial	*Others*	3.18	10.44	1.94	64.87	1.95	13.17	4.45
Ecotoxicity, freshwater	5.31	3.58	8.13	1.44	53.48	1.53	26.17	0.37
Land use	*Others*	2.74	13.20	2.47	58.27	2.51	16.95	3.86
Water use	*Others*	3.23	9.22	1.62	74.89	1.59	8.25	1.20
Resource use, fossils	*Others*	3.54	6.26	1.15	81.11	1.15	6.19	0.60
Resource use, minerals and metals	9.02	1.31	*Others*	0.19	27.89	0.19	60.26	1.15

Table S8: Environmental impact percentage values of comparison between all processes

Etichetta	Blade Coating in Glovebox	Blade Coating	Spin Coating	Spin Coating + Press
Climate change	100.00	25.80	33.82	34.05
Ozone depletion	100.00	51.29	69.25	69.60
Ionising radiation	100.00	58.45	83.16	78.64
Photochemical ozone formation	100.00	21.08	26.81	26.71
Particulate matter	100.00	22.57	28.25	28.15
Human toxicity, non-cancer	100.00	43.37	51.20	50.53
Human toxicity, cancer	100.00	27.82	41.25	35.98
Acidification	100.00	36.52	47.15	47.14
Eutrophication, freshwater	100.00	27.01	32.74	32.64
Eutrophication, marine	100.00	33.85	43.22	43.61
Eutrophication, terrestrial	100.00	34.98	44.38	44.68
Ecotoxicity, freshwater	100.00	44.94	54.17	52.42
Land use	100.00	41.41	53.86	53.38
Water use	100.00	23.48	31.43	31.29
Resource use, fossils	100.00	18.10	23.86	23.91
Resource use, minerals and metals	100.00	71.41	72.67	72.62

Figure S1: Environmental impact results obtained with EF/3.0 Single Score of comparison between all processes and single-Si cell.

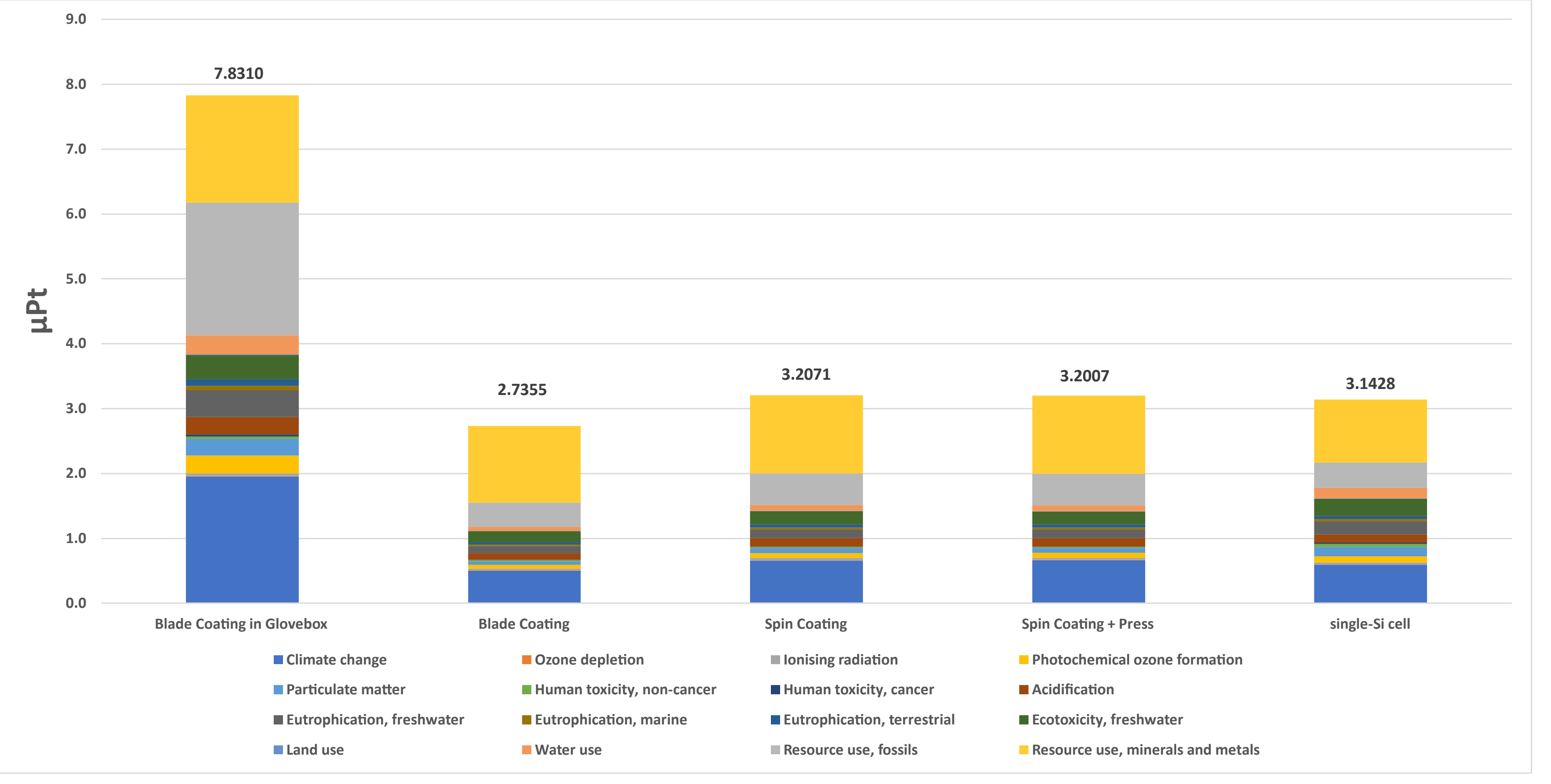


Figure S2: Environmental impact results obtained with EF/3.0 Single Score of comparison between all processes and single-Si cell expressed as percentage changes between all processes and single-Si cell.

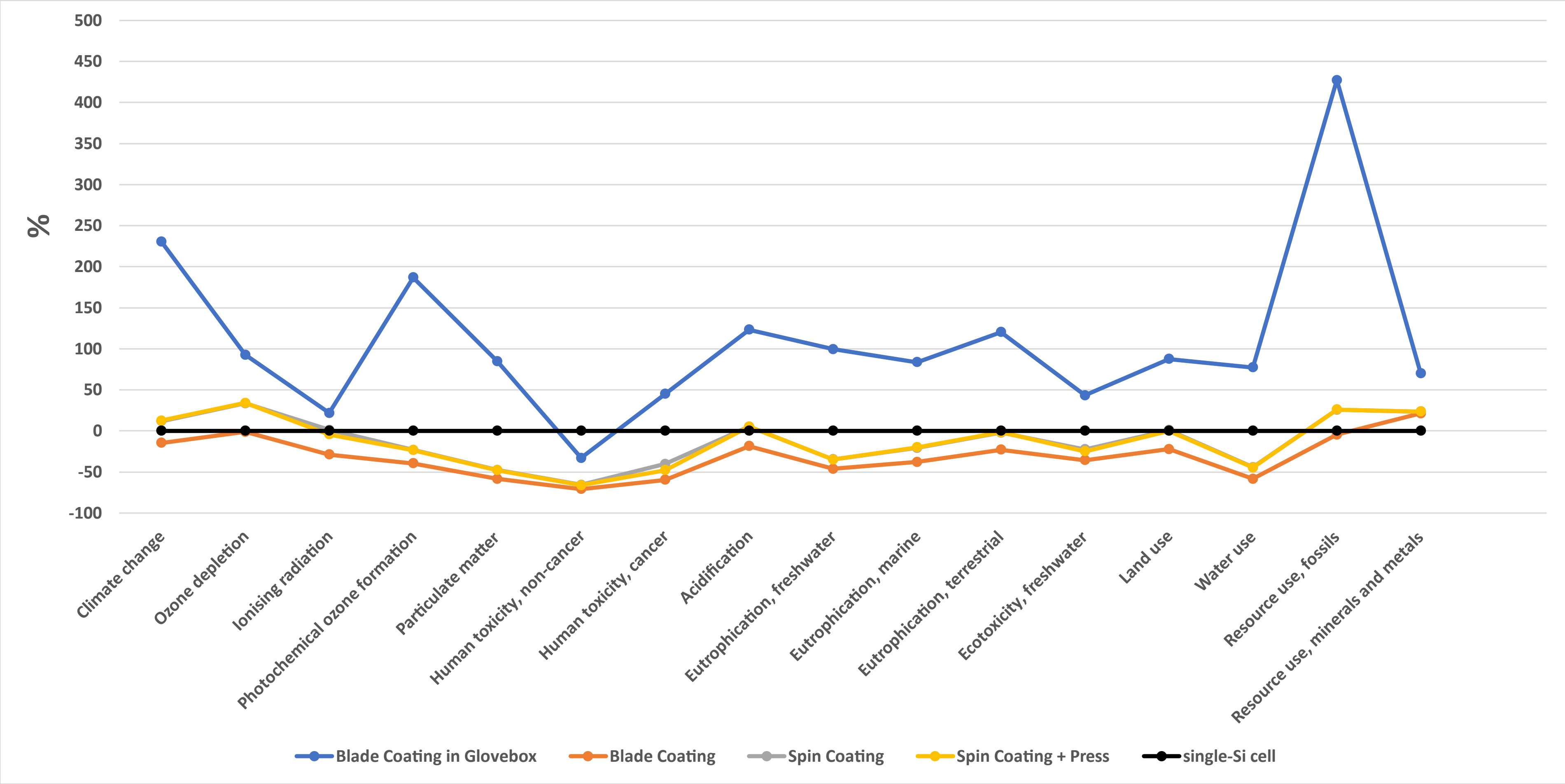


Figure S3: Environmental impact results obtained with EF/3.0 Characterization of comparison between all processes and single-Si cell.

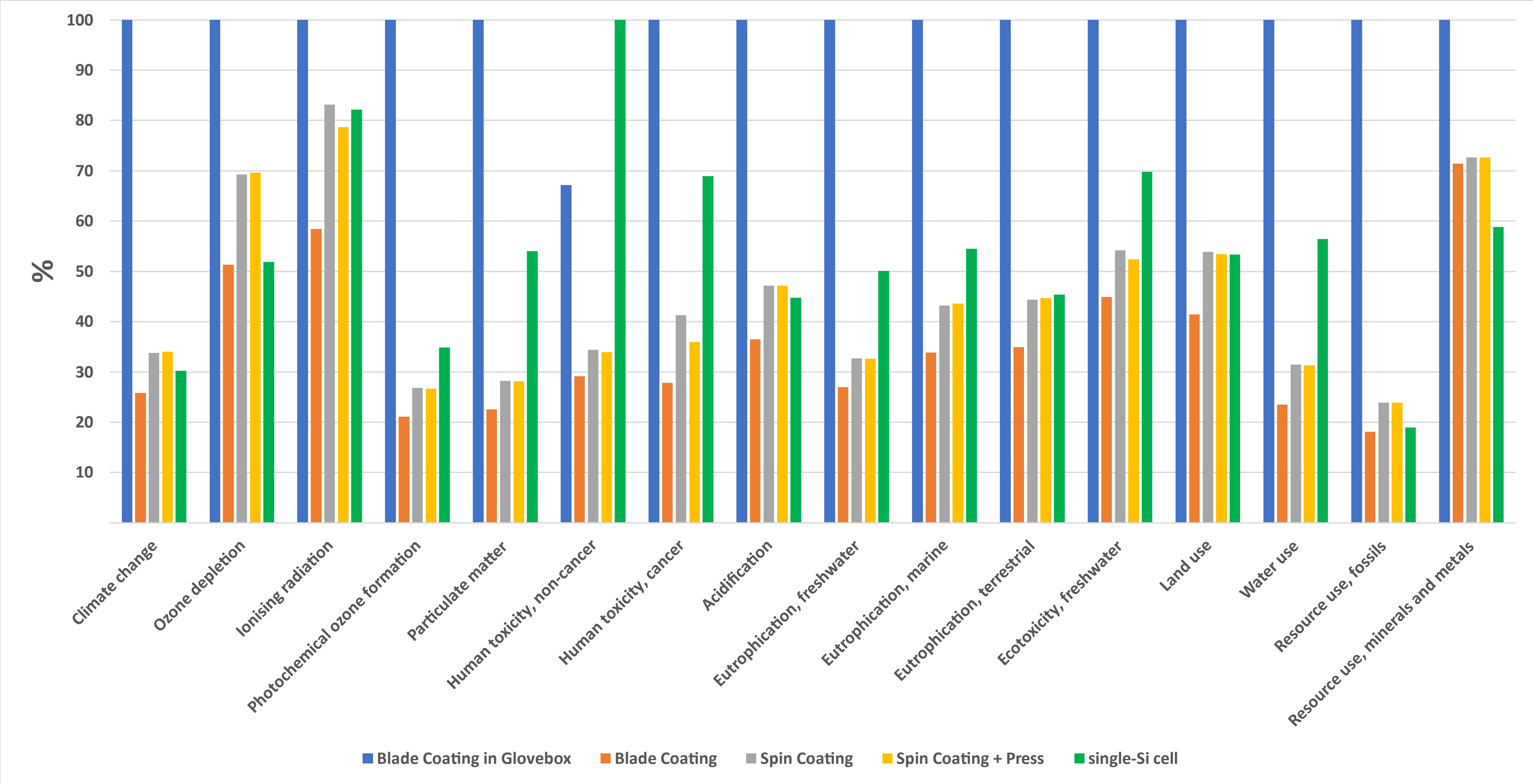


Figure S4: Environmental impact results obtained with EF/3.0 Single Score of comparison between electricity scenarios of Blade Coating

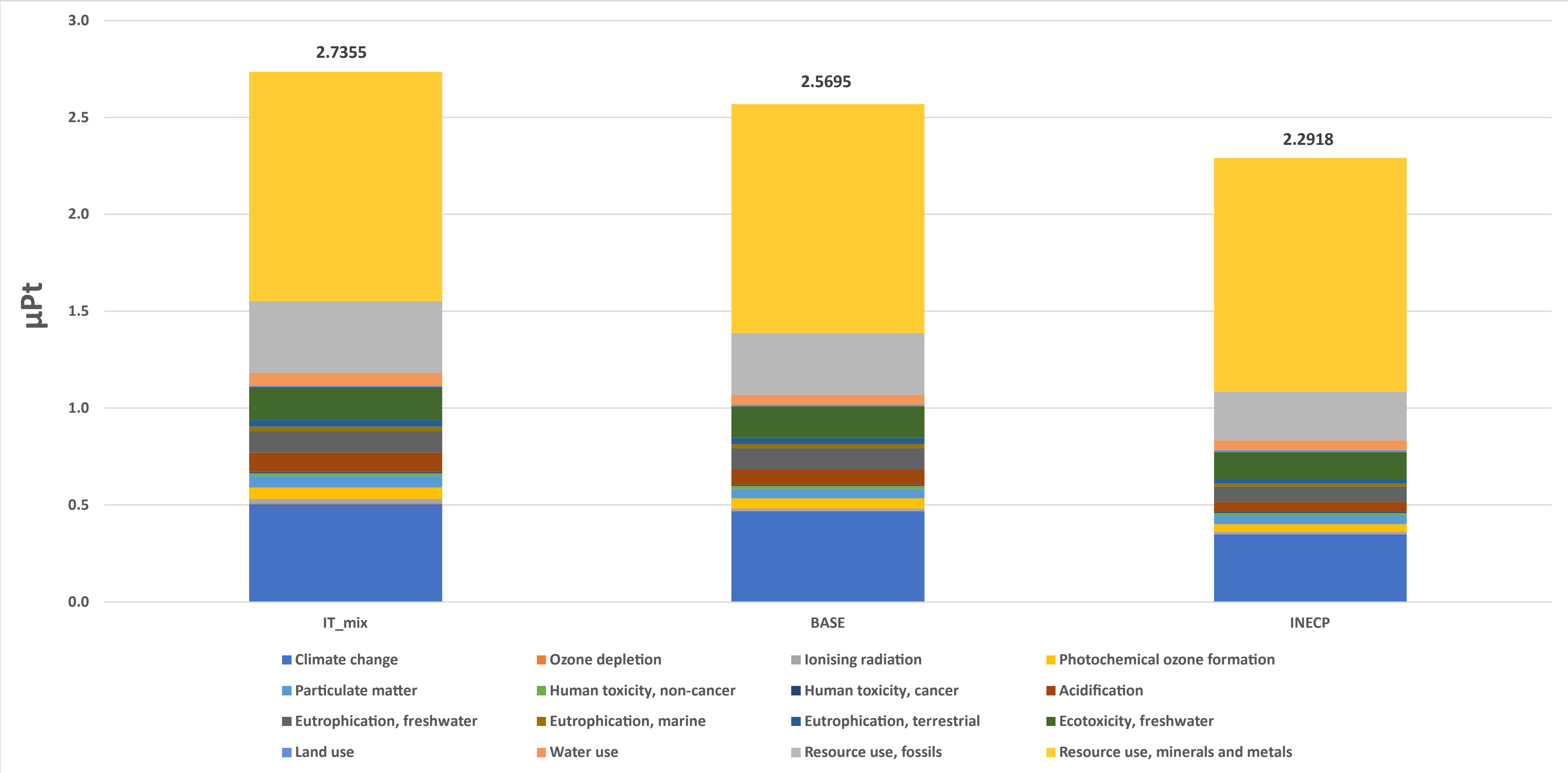


Figure S5: Environmental impact results obtained with EF/3.0 Single Score of comparison between electricity scenarios of Spin Coating

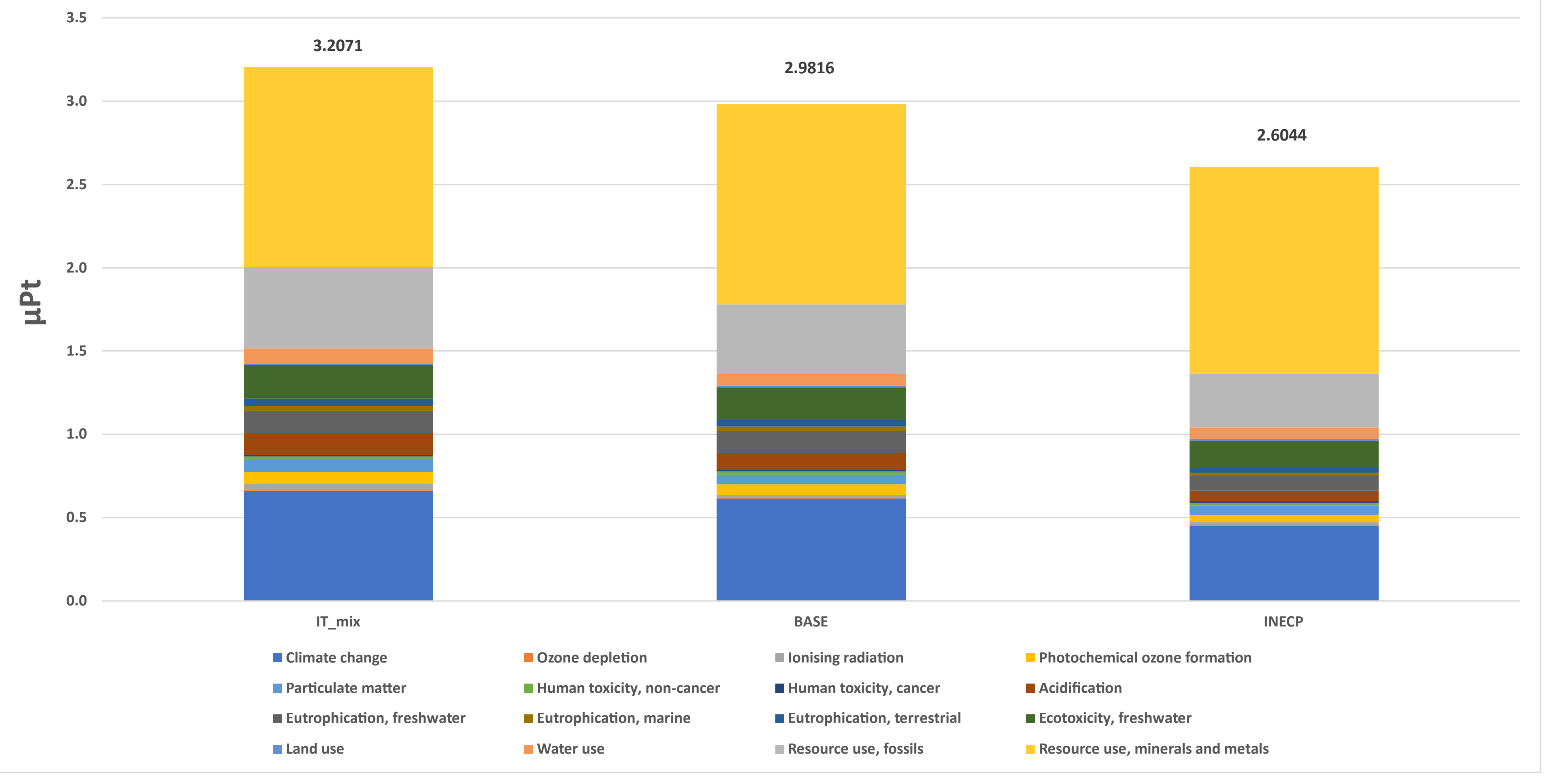


Figure S6: Environmental impact results obtained with EF/3.0 Single Score of comparison between electricity scenarios of Spin Coating + Press

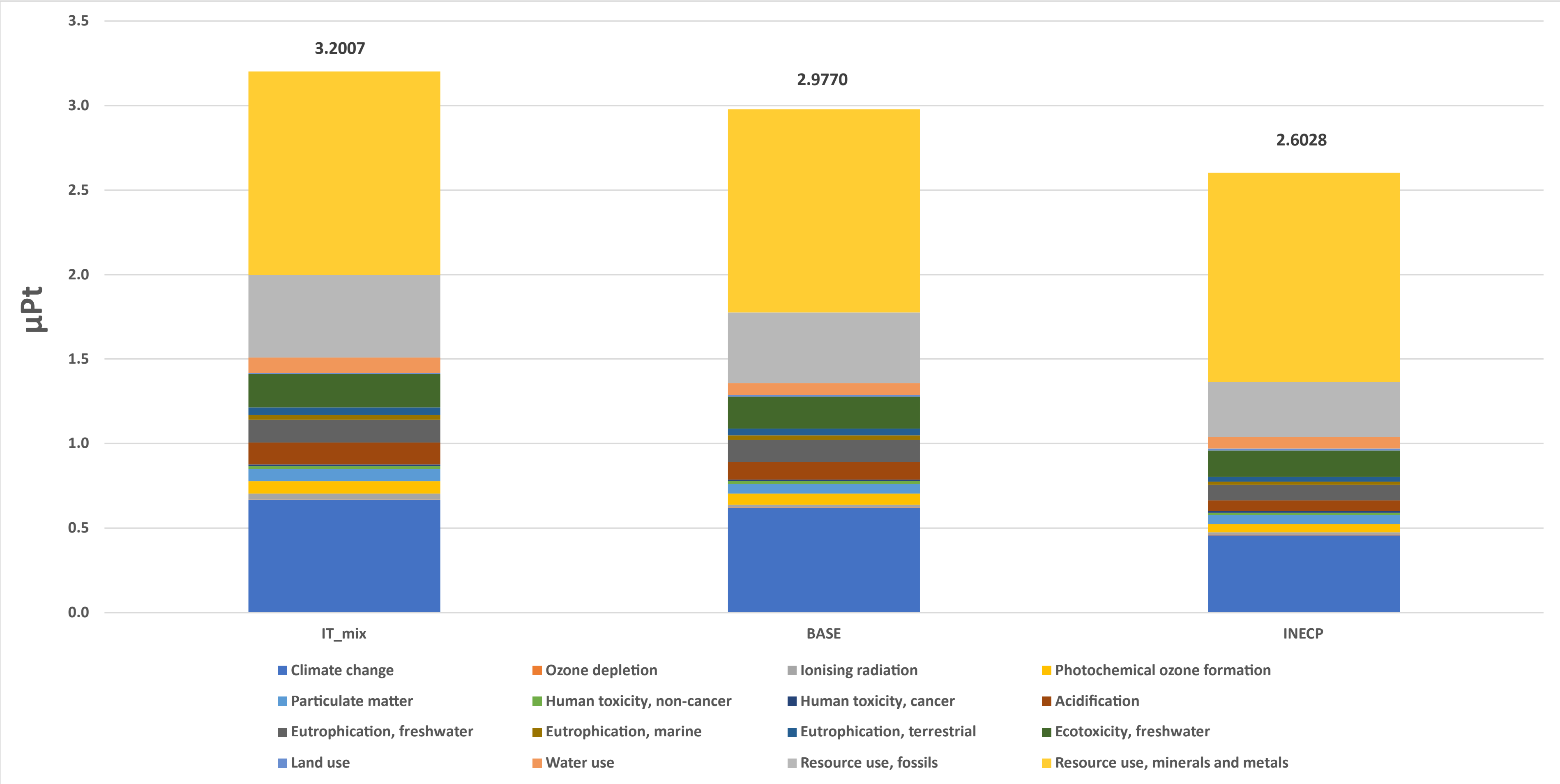
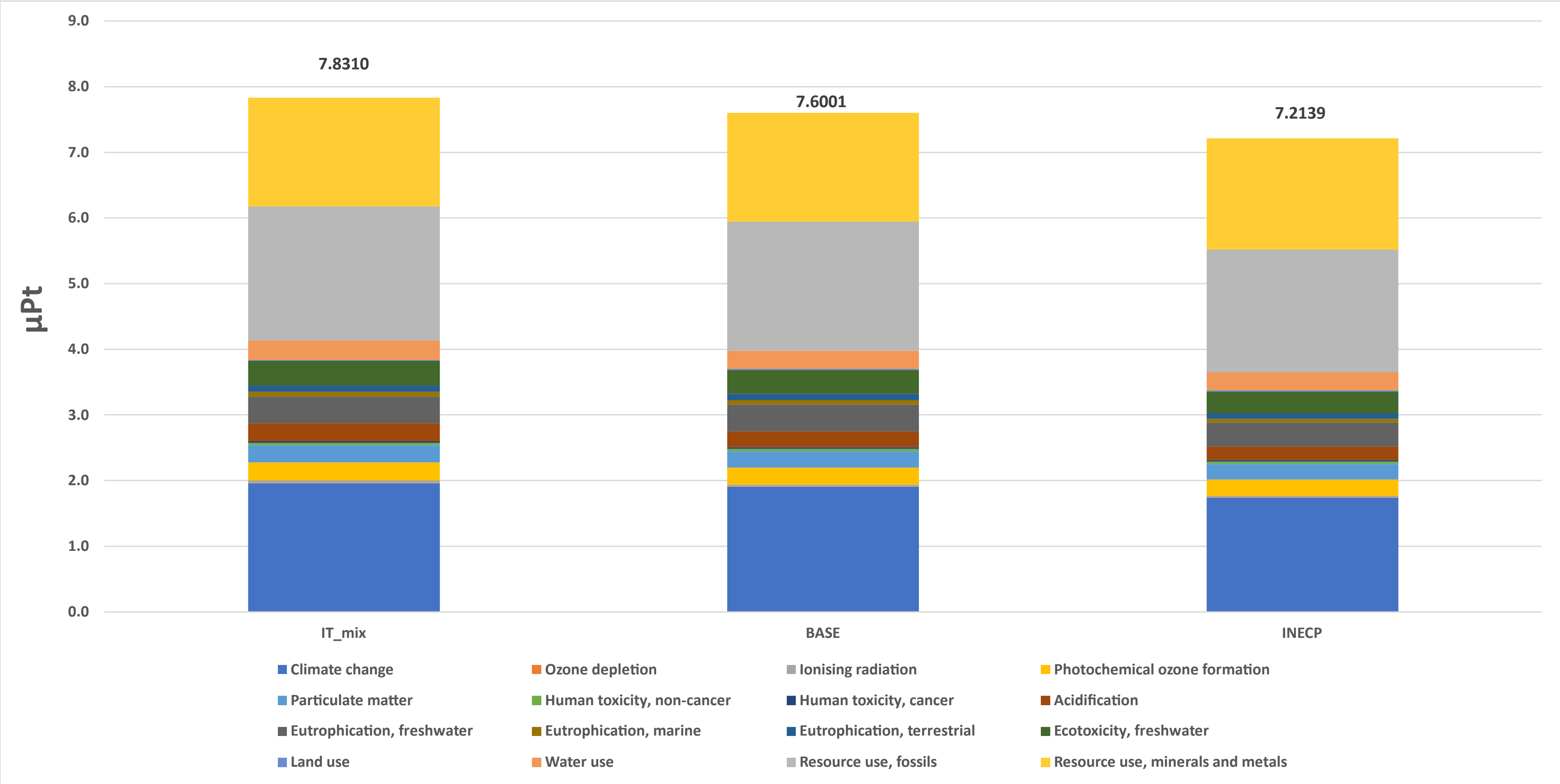


Figure S7: Environmental impact results obtained with EF/3.0 Single Score of comparison between electricity scenarios of Blade Coating in Glovebox



3. Compatibility Issues

A comparison between the results obtained in this study with those that have been calculated by previous scientists is generally part of the interpretation step of a LCA analysis. Nevertheless, as explained in this section, this kind of confrontation presents some inconsistencies in this case. As already outlined by Goetz et al. [6], LCA results can be compared only in case they are grounded on the same methodological assumptions such as background databases and life cycle impact assessment methods, system boundaries, functional units, and assumptions in the inventory definition. According to such criteria, none of the 4 papers mentioned in the introduction of the manuscript is directly comparable with this study. In particular, the papers from Okoroafor et al. [7] and Krebs-Moberg et al. [8] are not comparable with our study because the authors did not quantify the environmental impact values for any LCA indicator, but rather they focused on a percentage contribution analysis of the product system. On the other hand, Zhang et al. [9] and Borras et al. [10] provided results that are not comparable to the ones produced in this paper for the following reasons:

- The authors used different background databases and database versions from the one adopted in this study (i.e.. Ecoinvent 3.7.1 [11]).
- The LCIA method used in this study is Environmental Footprint 3.0 [12], whereas Zhang et al. [9] use the International Life Cycle Data System method [13] and Borras et al. [10] use USEtox [14] and CML 2002 [15].
- In this study, LCIs are largely based on direct measurements to estimate both materials and electricity consumption. Differently, Zhang et al. [37] rely on direct measurements only for material consumption and Borras et al. [10] make an extensive use of literature data.

In addition to such considerations, it must be noticed that none of the above-mentioned authors explicitly declare all the datasets used to develop their LCA model. Therefore, replicating the study to carry out a consistent comparison of the results is not possible.

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