Electronic Supplementary Material (ESI) for Energy & Environmental Science.

Supplementary Information

Table S1: Recoveries of certified element concentrations in BCR 176R fly ash by µXRF quantification

	Spiked ash No. 1			Spiked ash No. 2			Spiked ash No. 3			Mean ± SD
	EC [mg/kg]	DC [mg/kg]	RE [%]	EC [mg/kg]	DC [mg/kg]	RE [%]	EC [mg/kg]	DC [mg/kg]	RE [%]	RE [%]
Antimony	841	955,6	112	832,9	893,8	106,8	832,9	795,6	95,3	104.7 ± 8.5
Barium	4600,8	4079,7	87,2	4556,6	4010,5	86,4	4556,6	4144,8	90,1	87.9 ± 1.9
Bromine	827,1	790	95,3	819,2	786,2	95,8	819,2	784,5	95,6	95.6 ± 0.3
Chromium	801,4	670,5	80,5	793,7	680,2	83,3	793,7	733,3	91,8	85.2 ± 5.9
Copper	1038,9	1081,3	103,9	1028,9	1075,9	104,4	1028,9	1066,7	103,5	103.9 ± 0.4
Iron	12961,3	14021,3	107,6	12836,8	13698,9	106,3	12836,8	14068,5	108,8	107.5 ± 1.2
Lead	4947,1	5028,1	101,6	4899,6	4954,9	101,1	4899,6	4870,9	99,4	100.7 ± 1.2
Manganese	722,3	762,4	105,3	715,3	768,2	106,9	715,3	775,7	107,8	106.6 ± 1.3
Silver	**10732,7**	**12553,6**	**114,5**	**20532,4**	**23633,1**	**113,1**	**20532,4**	**23454,9**	**112,5**	**113.4 ± 1.0**
Sodium	34431,6	41206,1	116,4	34100,9	43110,7	120,9	34100,9	44533,5	123,4	120.3 ± 3.5
Zinc	16622,1	18766,2	111,4	16462,5	18333,9	110,2	16462,5	18306,3	110,1	110.6 ± 0.7

SD from n = 3

EC, expected concentration (acc. BCR 176R certificate and silver spike)

DC, detected concentration by µXRF

RE, recovery

Table S2. Silver extraction efficiencies based on µXRF of original ashes and residues considering mass loss

	original ash % weight	extracted residue % weight	Mass loss [% dry weight]	Exctraction efficiency [%]
800 °C (single encap.)	24,61	0,88	7,5	**96,7**
1000 °C (single encap.)	20,48	4,85	6,2	**77,8**
1000 °C (double encap.)	26,18	3,89	7,7	**86,3**

Table S3. Scenarios of disposal considered for the solar cells.

Scenario	Description	Modelling (incl. Assumptions)
Recycling (RE)	Solar cells are assumed to be collected by a specialised company, which will extract valuable materials (PET + silver) before sending the remaining parts to incineration for energy recovery. This could also be assumed to be the likely scenario in case of handling of solar cells as industrial or hazardous waste.	Recycling pathways with PET recovered from delamination (sent to recycling) and silver recovered from acid treatment and incineration of the mixed plastics and remains (with energy recovery)
Incineration (IN)	Solar cells are assumed to be collected and directly sent to incineration (high caloric value from plastic content)	Incineration modelled as PET incineration (energy recovery); no differentiation due to composition of solar cells (Ag…)
Incineration+Recycling (IN+RE)	Solar cells are assumed to be collected and directly sent to incineration (high caloric value from plastic content). Ultimately the silver content is recovered from the ashes	Recycling path follows Scenario DK-1 described in [Ref. 3]. Incineration path follows Scenario DK-2 described in [Ref. 3]. Landfill is modelled as landfill of PET with amount of Ag corrected to match content of Ag of the solar cells: distinction between short-term and long-term emissions is performed: 1% vs. 99% done.

Table S4. Summarized inventory for the disposal of solar cells

Solar cells disposal
Solar cells disposal
Waste solar cells {CH} treatment of, municipal incineration | Conseq, U
Recycling of silver from the ashes
Recycling of solar cells

Table S5. Recovery of energy facts when the incineration of the solar cells takes place.

Lower Calorific/Heating value (LHV/LCV)		
PET	24	MJ/kg
Incineration of waste -recovered energy DK		
Efficiency in recovering heat	74%	Technology Data for Energy Plants (2012) Energinet.
Efficiency in recovering electricity	24%	Technology Data for Energy Plants (2012) Energinet.

Table S6. Acronyms for the impact categories evaluated in this study coming from ILCD methodology.

Acronym	Impact category name (Units)
CC	Climate change (kg-CO_2eq/pers)
OD	Ozone depletion (kg CFC-11 eq)
POF	Photochemical ozone formation (kg NMVOC eq)
AC	Acidification (mol H^+ eq)
TE	Terrestrial eutrophication (mol N eq)
FET	Freshwater eutrophication (kg-Peq/pers)
ME	Marine eutrophication (kg-Neq/pers)
FE	Freshwater ecotoxicity (CTUe/pers)
HTC	Human toxicity, cancer effects (CTUh/pers)
HTNC	Human toxicity, non-cancer effects (CTUh/pers)
RI	Respiratory inorganics (kg-PM2.5eq/pers)
LU	Land use (kg C deficit)
WD	Water resource depletion (m^3 water)
RD	Resource depletion (kg-Sbeq/pers)

Table S7. Normalized impact scores for the manufacturing of 1 kWh of OPV (MAN) including their disposal under three different end of lifes: 1) silver recycling (MAN+RE), 2) incineration of solar cells (MAN+IN), 3) incineration of solar cells followed by silver recovery from the ashes (MAN+IN+RE).

	MAN+RE	MAN+IN	MAN+IN+RE	MAN
Climate change	5,22E-05	8,73E-05	3,75E-05	8,66E-05
Ozone depletion	3,59E-07	2,47E-06	8,10E-07	2,58E-06
Photochemical ozone formation	7,68E-05	2,12E-04	6,12E-05	2,15E-04
Acidification	7,29E-05	1,90E-04	5,40E-05	1,93E-04
Terrestrial eutrophication	6,19E-05	1,68E-04	4,44E-05	1,70E-04
Freshwater eutrophication	8,01E-04	2,75E-03	6,85E-04	2,76E-03
Marine eutrophication	5,01E-05	1,47E-04	3,97E-05	1,49E-04
Freshwater ecotoxicity	5,36E-03	1,80E-02	4,63E-03	1,79E-02
Human toxicity, cancer effects	2,08E-03	6,71E-03	1,76E-03	6,74E-03
Human toxicity, non-cancer effects	3,40E-03	1,20E-02	2,90E-03	1,20E-02
Respiratory inorganics	5,94E-05	1,61E-04	3,81E-05	1,71E-04
Land use	4,15E-06	1,38E-05	3,37E-06	1,39E-05
Water resource depletion	1,78E-05	3,26E-05	1,58E-05	3,27E-05
Resource depletion	1,16E-02	4,16E-02	1,00E-02	4,16E-02

Table S8. Characterized impact scores for the manufacturing of 1 kWh of OPV (MAN) including their disposal under three different end of lifes: 1) silver recycling (MAN+RE), 2) incineration of solar cells (MAN+IN), 3) incineration of solar cells followed by silver recovery from the ashes (MAN+IN+RE).

	MAN+RE	MAN+IN	MAN+IN+RE	MAN
Climate change (kg-CO_2eq/pers)	0,47	0,79	0,34	0,79
Ozone depletion (kg CFC-11 eq)	7,74E-09	5,33E-08	1,75E-08	5,57E-08

Photochemical ozone formation (kg NMVOC eq)	2,45E-03	6,76E-03	1,95E-03	6,84E-03
Acidification (mol H^+ eq)	3,44E-03	8,97E-03	2,55E-03	9,12E-03
Terrestrial eutrophication (mol N eq)	1,08E-02	2,93E-02	7,72E-03	2,95E-02
Freshwater eutrophication (kg-Peq/pers)	1,19E-03	4,07E-03	1,01E-03	4,08E-03
Marine eutrophication (kg-Neq/pers)	8,42E-04	2,48E-03	6,67E-04	2,50E-03
Freshwater ecotoxicity (CTUe/pers)	46,58	156,18	40,30	155,66
Human toxicity, cancer effects (CTUh/pers)	7,67E-08	2,47E-07	6,46E-08	2,48E-07
Human toxicity, non-cancer effects (CTUh/pers)	1,81E-06	6,37E-06	1,54E-06	6,39E-06
Respiratory inorganics (kg-PM2.5eq/pers)	2,87E-04	7,80E-04	1,84E-04	8,28E-04
Land use (kg C deficit)	2,61	8,65	2,12	8,72
Water resource depletion (m^3 water)	1,40E-03	2,57E-03	1,25E-03	2,57E-03
Resource depletion (kg-Sbeq/pers)	1,16E-03	4,16E-03	1,00E-03	4,16E-03

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