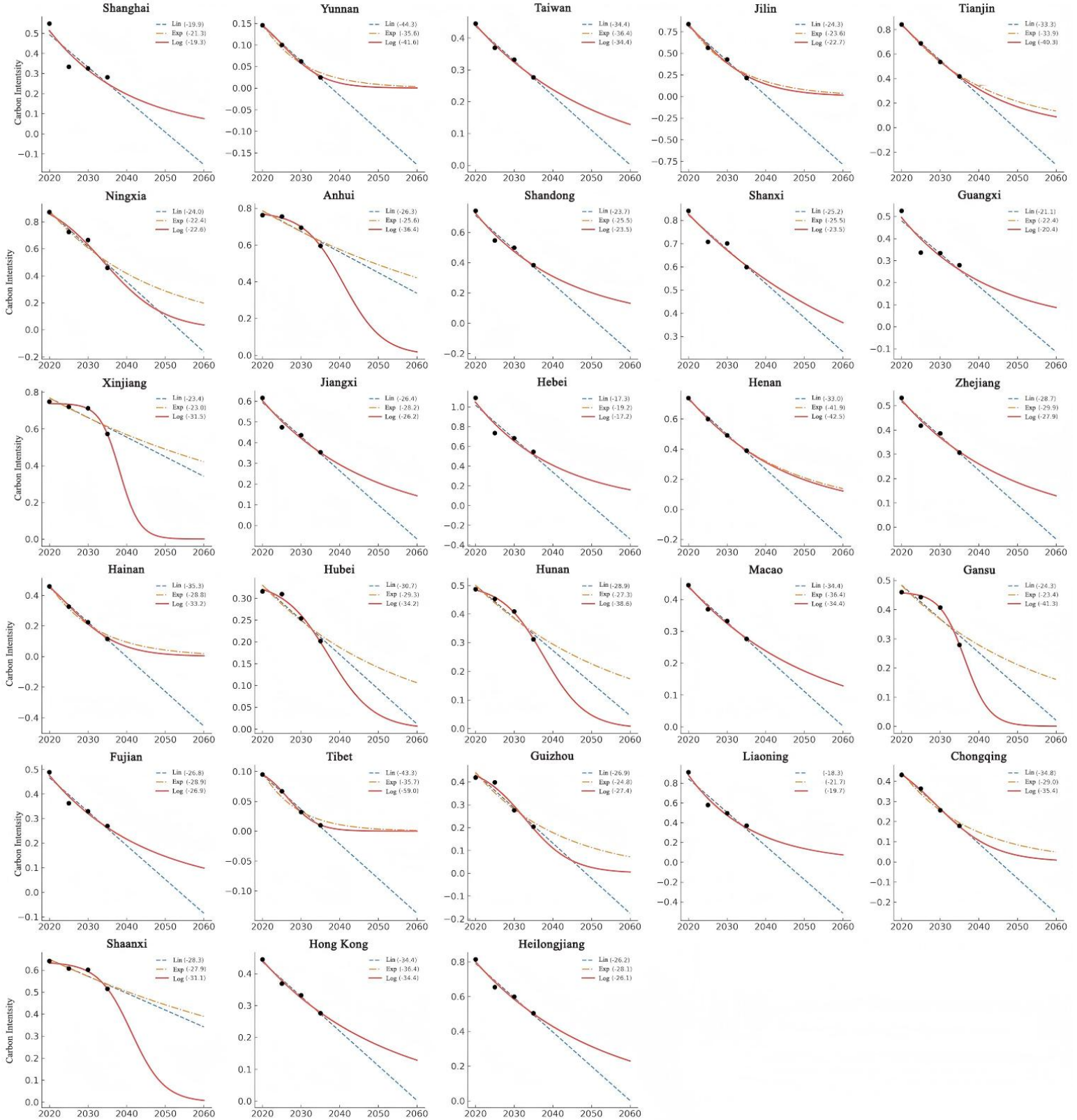


Supplementary Material

Fig S1:



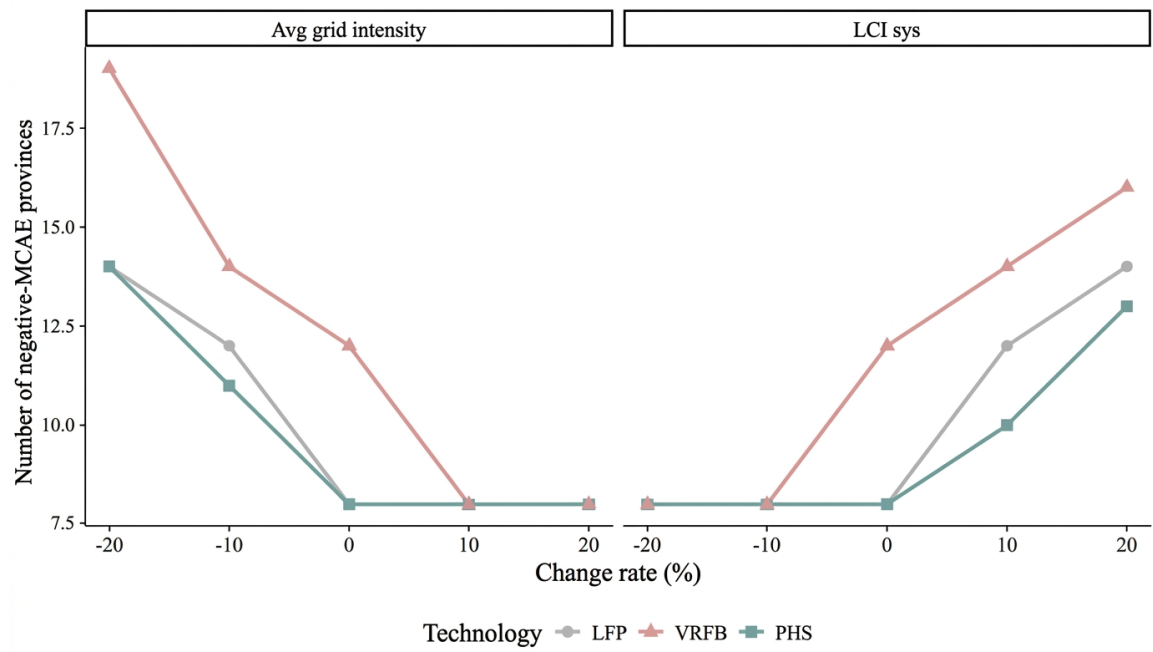


Fig. S2. Robustness of negative-MCAE province identification under one-way sensitivity scenarios

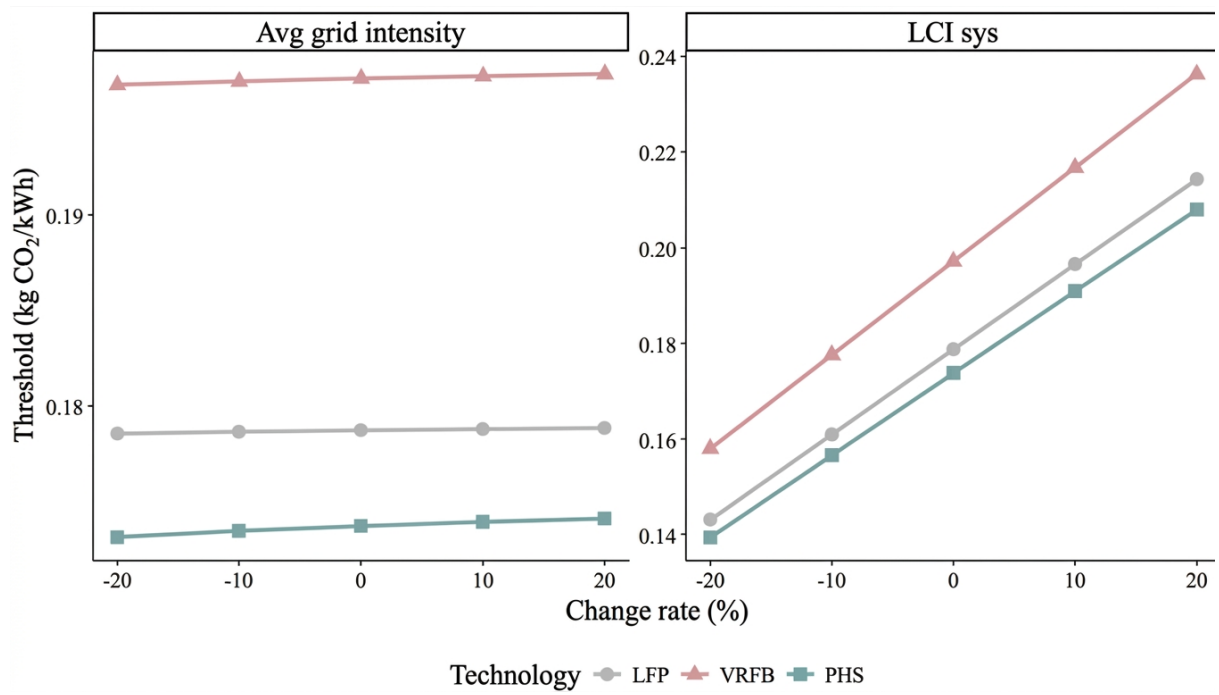


Fig. S3. Sensitivity of the zero-benefit grid-carbon threshold under one-way sensitivity scenarios

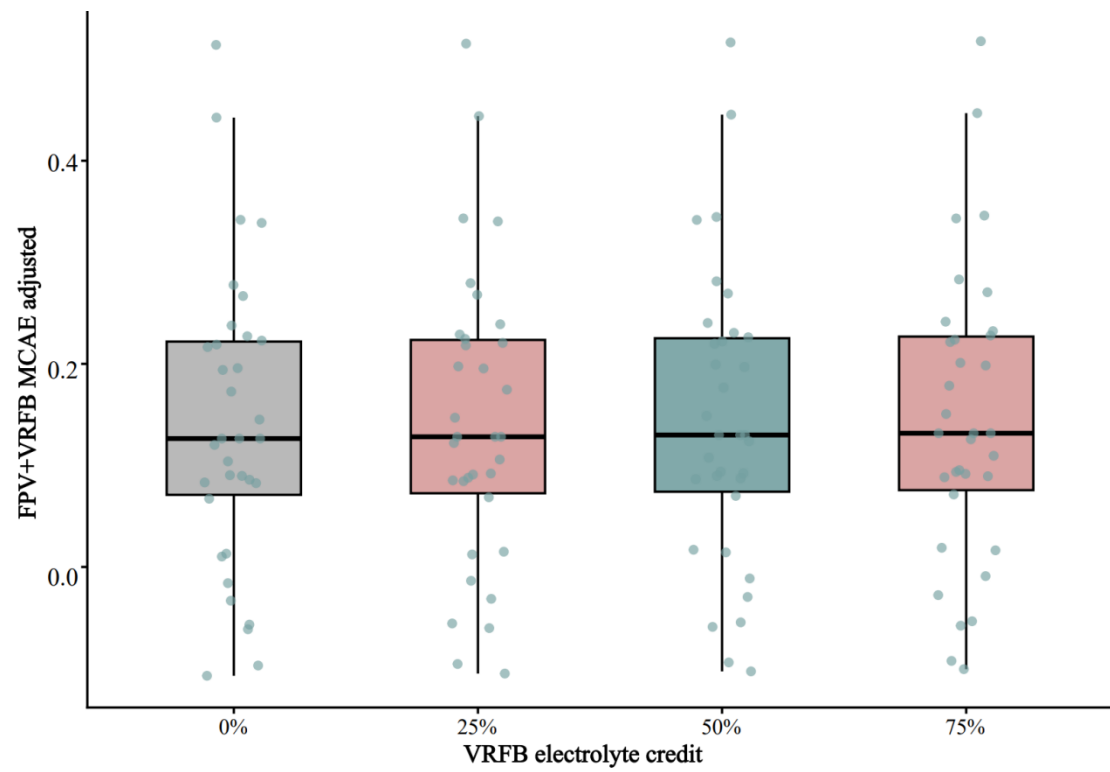


Fig. S4. Distribution of adjusted FPV+VRFB MCAE under electrolyte circularity-credit scenarios

Tab. S1. Share of Thermal Power Generation by Region, 2024

Province	Provincial Electricity Generation (100 million kWh)	Provincial Thermal Power Generation (100 million kWh)	Share of Thermal Power Generation(%)
Anhui	3335.6	3033	90.9282
Macao	Data based on the share of Guangdong Province		73.5734
Beijing	454.9	443.8	97.5599
Fujian	3073.6	1787.6	58.1598
Gansu	1925.4	1038.6	53.9420
Guangdong	6718.6	4943.1	73.5734
Guangxi	2287.3	1405.5	61.4480
Guizhou	2271.4	1668.8	73.4701
Hainan	448	306	68.3036
Hebei	3736.1	2850.5	76.2961
Henan	3171.8	2650.5	83.5645
Heilongjiang	1233.8	935.7	75.8389
Hubei	3012.6	1495.1	49.6282
Hunan	1700.4	1123.6	66.0786
Jilin	1097.8	712.5	64.9025
Jiangsu	6106.3	4950	81.0638
Jiangxi	1669	1407.1	84.3080
Liaoning	2202.5	1346.2	61.1215
Inner Mongolia	7450.5	5935	79.6591
Ningxia	2246.3	1718.5	76.5036
Qinghai	873.8	160.3	18.3452
Shandong	5915.7	5070.2	85.7075
Shanxi	4376.1	3704.1	84.6439
Shaanxi	2945.8	2556.5	86.7846
Shanghai	954.9	926.4	97.0154
Sichuan	4712.6	917	19.4585
Taiwan	Data based on the share of Guangdong Province		73.5734
Tianjin	808.1	762.9	94.4066
Tibet	137.4	3.9	2.8384
Hong Kong	Data based on the share of Guangdong Province		73.5734
Xinjiang	4912.1	3789.6	77.1483
Yunnan	3905.1	640.3	16.3965
Zhejiang	4353.1	3192.3	73.3339
Chongqing	1054.3	843.4	79.9962

Note: This study uses the provincial share of thermal power generation (>69.5%) as a binary benchmark, serving as a physical proxy for “urgent decarbonization needs,” and validates the MCAE index against this benchmark. The classification threshold for the provincial thermal power share is set at 69.5%, which corresponds to the national average share of thermal power generation in the base year.

Tab. S2. Optimal AIC Models by Region and Their Scores

Province	Best Model	AIC Score
Anhui	Logistic	-36.3828641
Macao	Exponential	-36.42137178
Beijing	Logistic	-45.57432027
Fujian	Exponential	-28.91015924
Gansu	Logistic	-41.26570559
Guangdong	Exponential	-36.42137178
Guangxi	Exponential	-22.37865581
Guizhou	Logistic	-27.44953138
Hainan	Linear	-35.30240406
Hebei	Exponential	-19.2486886
Henan	Logistic	-42.50716249
Heilongjiang	Exponential	-28.09033854
Hubei	Logistic	-34.21131429
Hunan	Logistic	-38.64335267
Jilin	Linear	-24.31381854
Jiangsu	Linear	-43.66856541
Jiangxi	Exponential	-28.15808481
Liaoning	Exponential	-21.67593652
Inner Mongolia	Exponential	-22.47053612
Ningxia	Linear	-24.02389875
Qinghai	Logistic	-58.99147685
Shandong	Exponential	-25.54083961
Shanxi	Exponential	-25.48562705
Shaanxi	Logistic	-31.07965427
Shanghai	Exponential	-21.25914346
Sichuan	Logistic	-59.8852538
Taiwan	Exponential	-36.42137178
Tianjin	Logistic	-40.26300062
Tibet	Logistic	-58.99147685
Hong Kong	Exponential	-36.42137178
Xinjiang	Logistic	-31.50877073
Yunnan	Linear	-44.31775998
Zhejiang	Exponential	-29.91354204
Chongqing	Logistic	-35.44951371

Tab. S3. Predicted Grid Carbon Factors for 2040 and the 30-Year Average Based on the Optimal AIC Model

Province	Grid Intensity 2040	Grid Intensity 30years
Anhui	0.426	0.4117
Macao	0.238	0.2472
Beijing	0.079	0.2034
Fujian	0.2165	0.2302
Gansu	0.1119	0.1774
Guangdong	0.238	0.2472
Guangxi	0.2075	0.2236
Guizhou	0.1106	0.1469
Hainan	0.0003	0.0866
Hebei	0.4093	0.4465
Henan	0.3114	0.335
Heilongjiang	0.4284	0.4453
Hubei	0.1287	0.1422
Hunan	0.1992	0.2184
Jilin	0.0115	0.161
Jiangsu	0.3195	0.3195
Jiangxi	0.2939	0.3093
Liaoning	0.2557	0.2966
Inner Mongolia	0.5935	0.6081
Ningxia	0.3555	0.3568
Qinghai	0.0029	0.0134
Shandong	0.3091	0.3321
Shanxi	0.5444	0.5539
Shaanxi	0.3633	0.3418
Shanghai	0.1964	0.2149
Sichuan	0.0157	0.0321
Taiwan	0.238	0.2472
Tianjin	0.3133	0.3461
Tibet	0.0029	0.0134
Hong Kong	0.238	0.2472
Xinjiang	0.2452	0.3267
Yunnan	0.0003	0.0231
Zhejiang	0.2603	0.2732
Chongqing	0.1061	0.1379

Tab. S4. Carbon Abatement Reduction Rate of LFP Battery Replacement and Total Life-Cycle
Carbon Abatement Reduction Rate of FPV+LFP System by Province

Province	Carbon Abatement Reduction Rate in LFP	Total Life-Cycle Carbon Abatement
	Battery Replacement Stage (with Dynamic Factor) (%)	Reduction Rate of FPV+LFP System (%)
Anhui	23.2704	8.4563
Macau	34.7547	13.3424
Beijing	40.2719	15.178
Fujian	35.9882	13.8575
Gansu	40.6735	15.643
Guangdong	34.7547	13.3424
Guangxi	36.4819	14.0607
Guizhou	42.0452	16.3843
Hainan	47.196	18.3799
Hebei	22.1158	7.6997
Henan	29.2333	10.8667
Heilongjiang	21.7374	7.6349
Hubei	41.8435	16.4088
Hunan	36.8981	14.2268
Jilin	43.6619	16.5308
Jiangsu	29.7327	11.2004
Jiangxi	30.7595	11.5718
Liaoning	32.1808	12.0652
Inner Mongolia	10.845	2.9021
Ningxia	27.2783	10.125
Qinghai	50.3523	20.1294
Shandong	29.4129	10.9478
Shanxi	14.3389	4.4489
Shaanxi	27.7624	10.4481
Shanghai	37.1154	14.3248
Sichuan	49.2403	19.6161
Taiwan	34.7546	13.3424
Tianjin	28.7019	10.5899
Tibet	50.3522	20.1294
Hong Kong	34.7547	13.3424
Xinjiang	31.0931	11.3915
Yunnan	49.9908	19.91
Zhejiang	33.1069	12.6065
Chongqing	42.5429	16.6232

Tab. S5. Province-level diagnostic statistics for the linear, exponential, and logistic grid-decarbonization models

Province	Model	AIC	BIC	R ²	RMSE	MAE	MAPE percent	AIC weight
Anhui	Logistic	-36.3828641	-38.2239810 ₂	0.99438632	0.00500229 ₇	0.00438397 ₆	0.601086111	0.98903304 ₈
Anhui	Linear	-26.3287153 ₈	-27.5561266 ₆	0.88570947 ₈	0.02257099 ₉	0.0225	3.222235425	0.00648604 ₈
Anhui	Exp	-25.5890583 ₃	-26.8164696 ₁	0.86249532 ₇	0.02475736 ₄	0.02462972 ₇	3.547676707	0.00448090 ₄
Beijing	Logistic	-45.5743202 ₇	-47.4154371 ₈	0.99985001 ₆	0.00158560 ₄	0.00133725 ₅	0.237764502	0.99999686 ₃
Beijing	Linear	-19.4050021 ₃	-20.6324134 ₁	0.82841120 ₉	0.05363114 ₈	0.0525	11.72558679	0.00000208
Beijing	Exp	-18.0602374 ₁	-19.2876486 ₉	0.7598432	0.06344831 ₃	0.06166945 ₃	14.36398193	0.00000106
Chongqing	Logistic	-35.4495137 ₁	-37.2906306 ₂	0.99665129 ₆	0.00562131 ₇	0.00513889	1.875461919	0.57136446 ₂
Chongqing	Linear	-34.7664287 ₇	-35.9938400 ₅	0.99345078 ₈	0.00786129 ₈	0.0068	2.149032362	0.40605346
Chongqing	Exp	-28.9877722 ₇	-30.2151835 ₄	0.97222854 ₁	0.01618821 ₉	0.01343093 ₁	4.623037605	0.02258207 ₈
Fujian	Exp	-28.9101592 ₄	-30.1375705 ₂	0.95827393 ₃	0.01634603 ₅	0.01410250 ₆	3.864988042	0.59406974 ₃
Fujian	Linear	-26.8051017 ₃	-28.0325130 ₁	0.92937456 ₁	0.02126617	0.01725	4.612198392	0.20736239 ₇
Fujian	Logistic	-26.7184276	-28.5595445 ₁	0.95622517 ₂	0.01674252 ₄	0.01442849 ₆	3.948470685	0.19856786
Gansu	Logistic	-41.2657055 ₉	-43.1068225 ₁	0.99853152 ₆	0.00271703 ₇	0.00229470 ₅	0.531485987	0.99965941 ₄
Gansu	Linear	-24.3442994 ₂	-25.5717107	0.83356996 ₃	0.02892533 ₅	0.02775	7.448633822	0.000212
Gansu	Exp	-23.355535	-24.5829462 ₇	0.78689902 ₂	0.03273069 ₈	0.03149213 ₄	8.606309897	0.000129
Guangdong	Exp	-36.4213717 ₈	-37.6487830 ₅	0.98915083 ₈	0.00639223 ₄	0.00560072 ₇	1.57811347	0.58256278 ₇
Guangdong	Linear	-34.4402877 ₉	-35.6676990 ₇	0.98219714 ₆	0.00818840 ₆	0.00685	1.840836356	0.21634946 ₁
Guangdong	Logistic	-34.2939806 ₂	-36.1350975 ₄	0.98879975 ₆	0.00649483 ₈	0.00563465 ₃	1.572738664	0.20108775 ₂
Guangxi	Exp	-22.3786558 ₁	-23.6060670 ₉	0.84397727 ₈	0.03698170 ₄	0.03190979 ₉	9.000152714	0.53024156 ₅
Guangxi	Linear	-21.1378160 ₅	-22.3652273 ₃	0.78723003 ₈	0.04318651 ₄	0.03495	9.501784104	0.28512075 ₉
Guangxi	Logistic	-20.2687812 ₃	-22.1098981 ₅	0.83963214	0.03749312 ₇	0.03226162 ₆	9.074340036	0.18463767 ₆
Guizhou	Logistic	-27.4495313 ₈	-29.2906482 ₉	0.97025165 ₇	0.01528029 ₁	0.01407589 ₄	4.499458546	0.49020597 ₃

Guizhou	Linear	-26.9377354 1	-28.1651466 9	0.94425864	0.02091650 1	0.0175	4.907510852	0.37952773 3
Guizhou	Exp	-24.7990416 1	-26.0264528 9	0.90485558 7	0.02732699 6	0.02320381 5	7.066297542	0.13026629 4
Hainan	Linear	-35.3024040 6	-36.5298153 3	0.99664878 9	0.00735187 1	0.006	2.252308979	0.71785163 5
Hainan	Logistic	-33.2235565	-35.0646734 2	0.99658207 5	0.00742468 8	0.00670671 9	3.310117877	0.25387426 7
Hainan	Exp	-28.8337704 3	-30.0611817 1	0.98311408 1	0.01650286 5	0.01536245 6	8.550288932	0.02827409 7
Hebei	Exp	-19.2486886	-20.4760998 8	0.92675077 1	0.05468936 2	0.04752603	6.36581515	0.58112324 1
Hebei	Linear	-17.3278482 2	-18.5552595	0.88159892 2	0.06953110 8	0.0563	7.261337235	0.22241447 8
Hebei	Logistic	-17.0797038 1	-18.9208207 2	0.92358997 3	0.05585685 8	0.04845086 4	6.473979169	0.19646228
Heilongjiang	Exp	-28.0903385 4	-29.3177498 2	0.97408302 3	0.01810997 6	0.01529020 2	2.317287002	0.57969691 2
Heilongjiang	Linear	-26.1941889 2	-27.4216001 9	0.95836523	0.02295375 8	0.019	2.85032168	0.22462460 5
Heilongjiang	Logistic	-25.9182735 7	-27.7593904 9	0.97294384 7	0.01850370 7	0.01567303 3	2.374362194	0.19567848 2
Henan	Logistic	-42.5071624 9	-44.3482794 1	0.99967783 4	0.00232648 8	0.00207334 6	0.406334131	0.56932255 2
Henan	Exp	-41.9261542 9	-43.1535655 7	0.99938580 1	0.00321229 6	0.00255333 6	0.553752995	0.42578863 1
Henan	Linear	-32.9921689 6	-34.2195802 3	0.99426802 8	0.00981325 6	0.0095	1.749474586	0.00488881 7
Hong Kong	Exp	-36.4213717 8	-37.6487830 5	0.98915083 8	0.00639223 4	0.00560072 7	1.57811347	0.58256278 7
Hong Kong	Linear	-34.4402877 9	-35.6676990 7	0.98219714 6	0.00818840 6	0.00685	1.840836356	0.21634946 1
Hong Kong	Logistic	-34.2939806 2	-36.1350975 4	0.98879975 6	0.00649483 8	0.00563465 3	1.572738664	0.20108775 2
Hubei	Logistic	-34.2113142 9	-36.0524312	0.97995868 9	0.00656229 9	0.00591873 2	2.121995061	0.79184255 8
Hubei	Linear	-30.7495542 7	-31.9769655 5	0.92148923 8	0.01298845 6	0.0115	4.127817463	0.14025785 9
Hubei	Exp	-29.2986489 3	-30.5260602 1	0.88716099 7	0.01557121 7	0.01419770 7	5.253423266	0.06789958 4
Hunan	Logistic	-38.6433526 7	-40.4844695 8	0.99670687 6	0.00377098 5	0.00337831 1	0.784674143	0.98925668 5
Hunan	Linear	-28.8509847 6	-30.0783960 3	0.93720166 2	0.01646739 2	0.01575	4.002660071	0.00739474 7
Hunan	Exp	-27.2665106 1	-28.4939218 8	0.90667881 4	0.02007432 1	0.01938239 9	4.984887235	0.00334856

								8
Inner Mongolia	Exp	-22.4705361 2	-23.6979474	0.90303457 9	0.03655939 7	0.03008150 2	3.610047492	0.47764397
Inner Mongolia	Linear	-21.8582438 2	-23.0856550 9	0.88699551 6	0.03946739 2	0.03285	3.923029768	0.35167922 6
Inner Mongolia	Logistic	-20.4123483 5	-22.2534652 6	0.90161371 9	0.03682628 1	0.03037209 8	3.643498774	0.17067680 4
Jiangsu	Linear	-43.6685654 1	-44.8959766 9	0.99939730 1	0.00258360 2	0.00215	0.43376376	0.74553900 2
Jiangsu	Logistic	-41.4899814 9	-43.3310984 1	0.99936978 4	0.00264192 4	0.00238090 3	0.443993986	0.25084005 1
Jiangsu	Exp	-33.0138217 2	-34.241233	0.99135182 9	0.00978673 2	0.00954687 1	1.864683199	0.00362094 7
Jiangxi	Exp	-28.1580848 1	-29.3854960 9	0.96411492 2	0.01795726 3	0.01503709 5	3.122124744	0.56859627
Jiangxi	Linear	-26.4132213 8	-27.6406326 5	0.94449143 1	0.02233383 1	0.0186	3.820683426	0.23763572 2
Jiangxi	Logistic	-26.0050667 6	-27.8461836 7	0.96271556 1	0.01830404 2	0.0153996	3.196358877	0.19376800 9
Jilin	Linear	-24.3138185 4	-25.5412298 2	0.98346690 9	0.02903575 4	0.0242	4.455869893	0.46683932 6
Jilin	Exp	-23.6125241 8	-24.8399354 6	0.98029864 4	0.03169597 7	0.02468671	7.983005375	0.32876327 5
Jilin	Logistic	-22.6619805 3	-24.5030974 5	0.98484510 8	0.02779921 3	0.02477258 2	6.581779293	0.2043974
Liaoning	Exp	-21.6759365 2	-22.9033477 9	0.95907204	0.04037711 7	0.03553182 3	6.382630252	0.66305451 9
Liaoning	Logistic	-19.3925794 7	-21.2336963 8	0.95606757 2	0.04183288 9	0.03675189 7	6.583571759	0.21170180 2
Liaoning	Linear	-18.3427446 2	-19.5701559	0.90582908	0.06124683 7	0.05175	8.856594342	0.12524367 9
Macau	Exp	-36.4213717 8	-37.6487830 5	0.98915083 8	0.00639223 4	0.00560072 7	1.57811347	0.58256278 7
Macau	Linear	-34.4402877 9	-35.6676990 7	0.98219714 6	0.00818840 6	0.00685	1.840836356	0.21634946 1
Macau	Logistic	-34.2939806 2	-36.1350975 4	0.98879975 6	0.00649483 8	0.00563465 3	1.572738664	0.20108775 2
Ningxia	Linear	-24.0238987 5	-25.2513100 2	0.95873489 2	0.03010730 8	0.02495	4.107495063	0.51896956 9
Ningxia	Logistic	-22.6109234 7	-24.4520403 9	0.96436739 4	0.02797719 9	0.02548208 3	3.810367922	0.25604612 7
Ningxia	Exp	-22.3522695 3	-23.5796808 1	0.93732738 4	0.03710388 2	0.02978280 1	5.110399301	0.22498430 4
Qinghai	Logistic	-58.9914768 5	-60.8325937 7	0.99991702 5	0.000296	0.000265	1.389037926	0.99959247 6
Qinghai	Linear	-43.3380363 6	-44.5654476 3	0.99315068 5	0.00269258 2	0.00225	10.45690544	0.000399

Qinghai	Exp	-35.7005889 5	-36.9280002 2	0.95377547 5	0.00699490 2	0.00590861 9	27.87727746	0.000009
Shaanxi	Logistic	-31.0796542 7	-32.9207711 8	0.95634075 2	0.00970652 7	0.00832156 6	1.36357421	0.69297715 7
Shaanxi	Linear	-28.2542921 7	-29.4817034 4	0.85412418 9	0.01774260 4	0.0146	2.53605372	0.16873273
Shaanxi	Exp	-27.8563676 8	-29.0837789 6	0.83886592 7	0.01864744 8	0.01502572 3	2.62300261	0.13829011 3
Shandong	Exp	-25.5408396 1	-26.7682508 9	0.96309177 1	0.02490703 6	0.02034735 9	3.644374767	0.57630584 2
Shandong	Linear	-23.6798175 5	-24.9072288 2	0.94122656	0.03143047 9	0.02625	4.670834625	0.22726743 7
Shandong	Logistic	-23.3881415	-25.2292584 2	0.96165557 8	0.02538700 9	0.02092994 7	3.750657437	0.19642672 1
Shanghai	Exp	-21.2591434 6	-22.4865547 4	0.83163619 8	0.04253649 2	0.03617592 5	10.27374076	0.54242986 7
Shanghai	Linear	-19.8621347 1	-21.0895459 9	0.76125899 3	0.05065249 3	0.04275	11.6575433	0.26976586 7
Shanghai	Logistic	-19.1378264 3	-20.9789433 5	0.82645162 5	0.04318645 8	0.03659635 6	10.35555331	0.18780426 7
Shanxi	Exp	-25.4856270 5	-26.7130383 3	0.91558695 2	0.02507952 8	0.02191045 3	3.067489002	0.45086779 3
Shanxi	Linear	-25.1733769 3	-26.4007882 1	0.90873343 4	0.02607776 8	0.0222	3.061342587	0.38569584 6
Shanxi	Logistic	-23.4561261 1	-25.2972430 2	0.91496208 4	0.02517218 2	0.02195460 7	3.069341759	0.16343636 1
Sichuan	Logistic	-59.8852538	-61.7263707 1	0.99991986	0.000265	0.000249	0.318912306	0.99998471 7
Sichuan	Linear	-37.4620920 5	-38.6895033 3	0.96406160 9	0.00561248 6	0.0055	7.423076923	0.0000135
Sichuan	Exp	-33.3924376 7	-34.6198489 5	0.90059328	0.00933434 5	0.00892565 2	13.49341334	0.0000018
Taiwan	Exp	-36.4213717 8	-37.6487830 5	0.98915083 8	0.00639223 4	0.00560072 7	1.57811347	0.58256278 7
Taiwan	Linear	-34.4402877 9	-35.6676990 7	0.98219714 6	0.00818840 6	0.00685	1.840836356	0.21634946 1
Taiwan	Logistic	-34.2939806 2	-36.1350975 4	0.98879975 6	0.00649483 8	0.00563465 3	1.572738664	0.20108775 2
Tianjin	Logistic	-40.2630006 2	-42.1041175 4	0.99962553 5	0.00307984 8	0.00275889	0.487505401	0.93281459 1
Tianjin	Exp	-33.9203072 4	-35.1477185 2	0.99698555 1	0.00873831 1	0.00731256 5	1.196160874	0.03912883 9
Tianjin	Linear	-33.2550333 2	-34.4824446	0.99644008 9	0.00949605 2	0.00875	1.610141766	0.02805656 9
Tibet	Logistic	-58.9914768 5	-60.8325937 7	0.99991702 5	0.000296	0.000265	1.389037926	0.99959247 6
Tibet	Linear	-43.3380363 6	-44.5654476 3	0.99315068 5	0.00269258 2	0.00225	10.45690544	0.000399

Tibet	Exp	-35.7005889 5	-36.9280002 2	0.95377547 5	0.00699490 2	0.00590861 9	27.87727746	0.000009
Xinjiang	Logisti c	-31.5087707 3	-33.3498876 5	0.98179237 4	0.00919959	0.00732759 6	1.007514583	0.97006087 5
Xinjiang	Linear	-23.3589849	-24.5863961 8	0.76972206 9	0.03271658 6	0.02775	4.160891156	0.01648524 8
Xinjiang	Exp	-22.9525877	-24.1799989 8	0.74509618 6	0.03442151 5	0.02969473	4.473576093	0.01345387 7
Yunnan	Linear	-44.3177599 8	-45.5451712 6	0.99718458 3	0.00238222 6	0.00225	3.654076447	0.78919978 7
Yunnan	Logisti c	-41.5777768 9	-43.4188938 1	0.99661245 3	0.00261308 9	0.00236039 8	4.922412228	0.20054285 4
Yunnan	Exp	-35.6317117 5	-36.8591230 2	0.97530446 9	0.00705538 6	0.00645044 4	14.95041874	0.01025735 9
Zhejiang	Exp	-29.9135420 4	-31.1409533 2	0.96817326 6	0.01441922 7	0.01244709 6	3.020589978	0.53068326
Zhejiang	Linear	-28.6580548 8	-29.8854661 5	0.95643829 6	0.01686935 1	0.01405	3.268732638	0.28327602 1
Zhejiang	Logisti c	-27.8171424 8	-29.6582593 9	0.96739692 8	0.01459402 9	0.01251668 8	3.017851169	0.18604071 8

Tab. S6. Fitted parameters of the linear, exponential, and logistic grid-decarbonization models for each province

Province	Model	Fitted parameter	Parameter estimate
Anhui	Linear	(Intercept)	0.7863
Anhui	Linear	t	-0.01124
Anhui	Exp	a	0.786211647
Anhui	Exp	b	-0.015597855
Anhui	Logistic	K	0.779729699
Anhui	Logistic	r	0.196465812
Anhui	Logistic	t0	20.95408104
Beijing	Linear	(Intercept)	0.6626
Beijing	Linear	t	-0.02108
Beijing	Exp	a	0.659005757
Beijing	Exp	b	-0.038380894
Beijing	Logistic	K	0.616525128
Beijing	Logistic	r	0.356921785
Beijing	Logistic	t0	14.6534589
Chongqing	Linear	(Intercept)	0.4374
Chongqing	Linear	t	-0.01732
Chongqing	Exp	a	0.444972134
Chongqing	Exp	b	-0.055348046
Chongqing	Logistic	K	0.564896782
Chongqing	Logistic	r	0.133285968
Chongqing	Logistic	t0	9.011811412
Fujian	Linear	(Intercept)	0.4665
Fujian	Linear	t	-0.0138
Fujian	Exp	a	0.475816311
Fujian	Exp	b	-0.039371861
Fujian	Logistic	K	4.89
Fujian	Logistic	r	0.042498862
Fujian	Logistic	t0	-52.45383639
Gansu	Linear	(Intercept)	0.4841
Gansu	Linear	t	-0.01158
Gansu	Exp	a	0.483041221
Gansu	Exp	b	-0.027550073
Gansu	Logistic	K	0.459769751
Gansu	Logistic	r	0.314044474
Gansu	Logistic	t0	16.39164405
Guangdong	Linear	(Intercept)	0.4371
Guangdong	Linear	t	-0.01088
Guangdong	Exp	a	0.441558159
Guangdong	Exp	b	-0.030891547
Guangdong	Logistic	K	4.45
Guangdong	Logistic	r	0.033595404

Guangdong	Logistic	t0	-65.68570235
Guangxi	Linear	(Intercept)	0.4802
Guangxi	Linear	t	-0.01486
Guangxi	Exp	a	0.495365552
Guangxi	Exp	b	-0.043511785
Guangxi	Logistic	K	5.26
Guangxi	Logistic	r	0.046618889
Guangxi	Logistic	t0	-48.6155843
Guizhou	Linear	(Intercept)	0.44
Guizhou	Linear	t	-0.0154
Guizhou	Exp	a	0.44298485
Guizhou	Exp	b	-0.045553688
Guizhou	Logistic	K	0.478256086
Guizhou	Logistic	r	0.167897629
Guizhou	Logistic	t0	12.84376715
Hainan	Linear	(Intercept)	0.4511
Hainan	Linear	t	-0.02268
Hainan	Exp	a	0.467220366
Hainan	Exp	b	-0.080403994
Hainan	Logistic	K	0.693408806
Hainan	Logistic	r	0.147208393
Hainan	Logistic	t0	4.47730722
Hebei	Linear	(Intercept)	1.0183
Hebei	Linear	t	-0.03394
Hebei	Exp	a	1.048808446
Hebei	Exp	b	-0.047047951
Hebei	Logistic	K	10.92
Hebei	Logistic	r	0.050506437
Hebei	Logistic	t0	-44.43738684
Heilongjiang	Linear	(Intercept)	0.7905
Heilongjiang	Linear	t	-0.0197
Heilongjiang	Exp	a	0.800009468
Heilongjiang	Exp	b	-0.031231743
Heilongjiang	Logistic	K	8.14
Heilongjiang	Logistic	r	0.03390288
Heilongjiang	Logistic	t0	-65.40889424
Henan	Linear	(Intercept)	0.7274
Henan	Linear	t	-0.02312
Henan	Exp	a	0.739146853
Henan	Exp	b	-0.042101522
Henan	Logistic	K	3.487707256
Henan	Logistic	r	0.050289426
Henan	Logistic	t0	-26.17844028
Hong Kong	Linear	(Intercept)	0.4371

Hong Kong	Linear	t	-0.01088
Hong Kong	Exp	a	0.441558159
Hong Kong	Exp	b	-0.030891547
Hong Kong	Logistic	K	4.45
Hong Kong	Logistic	r	0.033595404
Hong Kong	Logistic	t0	-65.68570235
Hubei	Linear	(Intercept)	0.3302
Hubei	Linear	t	-0.00796
Hubei	Exp	a	0.330616219
Hubei	Exp	b	-0.028356525
Hubei	Logistic	K	0.337499336
Hubei	Logistic	r	0.171422659
Hubei	Logistic	t0	17.17562386
Hunan	Linear	(Intercept)	0.5006
Hunan	Linear	t	-0.01138
Hunan	Exp	a	0.501393838
Hunan	Exp	b	-0.026545291
Hunan	Logistic	K	0.5025262
Hunan	Logistic	r	0.184591256
Hunan	Logistic	t0	17.72129968
Inner Mongolia	Linear	(Intercept)	0.9646
Inner Mongolia	Linear	t	-0.01978
Inner Mongolia	Exp	a	0.973040715
Inner Mongolia	Exp	b	-0.024717243
Inner Mongolia	Logistic	K	10
Inner Mongolia	Logistic	r	0.026886598
Inner Mongolia	Logistic	t0	-82.88216086
Jiangsu	Linear	(Intercept)	0.6959
Jiangsu	Linear	t	-0.01882
Jiangsu	Exp	a	0.70204727
Jiangsu	Exp	b	-0.033725829
Jiangsu	Logistic	K	1.020092934
Jiangsu	Logistic	r	0.076169446
Jiangsu	Logistic	t0	9.911469164
Jiangxi	Linear	(Intercept)	0.5936
Jiangxi	Linear	t	-0.01648
Jiangxi	Exp	a	0.602902226
Jiangxi	Exp	b	-0.035918879
Jiangxi	Logistic	K	6.16
Jiangxi	Logistic	r	0.038876699
Jiangxi	Logistic	t0	-57.16619847
Jilin	Linear	(Intercept)	0.8127
Jilin	Linear	t	-0.04006
Jilin	Exp	a	0.84387293

Jilin	Exp	b	-0.078878685
Jilin	Logistic	K	1.702784665
Jilin	Logistic	r	0.117597961
Jilin	Logistic	t0	-0.375792698
Liaoning	Linear	(Intercept)	0.8436
Liaoning	Linear	t	-0.03398
Liaoning	Exp	a	0.880432685
Liaoning	Exp	b	-0.061823294
Liaoning	Logistic	K	9.1
Liaoning	Logistic	r	0.066097073
Liaoning	Logistic	t0	-33.84068723
Macau	Linear	(Intercept)	0.4371
Macau	Linear	t	-0.01088
Macau	Exp	a	0.441558159
Macau	Exp	b	-0.030891547
Macau	Logistic	K	4.45
Macau	Logistic	r	0.033595404
Macau	Logistic	t0	-65.68570235
Ningxia	Linear	(Intercept)	0.8747
Ningxia	Linear	t	-0.02596
Ningxia	Exp	a	0.881553616
Ningxia	Exp	b	-0.037435267
Ningxia	Logistic	K	0.996238097
Ningxia	Logistic	r	0.128287648
Ningxia	Logistic	t0	14.19212527
Qinghai	Linear	(Intercept)	0.0945
Qinghai	Linear	t	-0.0058
Qinghai	Exp	a	0.098751216
Qinghai	Exp	b	-0.109935566
Qinghai	Logistic	K	0.110952562
Qinghai	Logistic	r	0.269871915
Qinghai	Logistic	t0	6.592247401
Shaanxi	Linear	(Intercept)	0.6486
Shaanxi	Linear	t	-0.00768
Shaanxi	Exp	a	0.648769933
Shaanxi	Exp	b	-0.012768018
Shaanxi	Logistic	K	0.63612902
Shaanxi	Logistic	r	0.234869059
Shaanxi	Logistic	t0	21.21954227
Shandong	Linear	(Intercept)	0.711
Shandong	Linear	t	-0.0225
Shandong	Exp	a	0.725645963
Shandong	Exp	b	-0.042671785
Shandong	Logistic	K	7.42

Shandong	Logistic	r	0.046042214
Shandong	Logistic	t0	-48.29529913
Shanghai	Linear	(Intercept)	0.4931
Shanghai	Linear	t	-0.01618
Shanghai	Exp	a	0.512694464
Shanghai	Exp	b	-0.047979678
Shanghai	Logistic	K	5.48
Shanghai	Logistic	r	0.051240656
Shanghai	Logistic	t0	-44.38350578
Shanxi	Linear	(Intercept)	0.8219
Shanxi	Linear	t	-0.01472
Shanxi	Exp	a	0.826395322
Shanxi	Exp	b	-0.020871231
Shanxi	Logistic	K	8.41
Shanxi	Logistic	r	0.022793949
Shanxi	Logistic	t0	-97.27283188
Sichuan	Linear	(Intercept)	0.123
Sichuan	Linear	t	-0.0052
Sichuan	Exp	a	0.123748529
Sichuan	Exp	b	-0.05798031
Sichuan	Logistic	K	0.124390574
Sichuan	Logistic	r	0.235986127
Sichuan	Logistic	t0	11.81365289
Taiwan	Linear	(Intercept)	0.4371
Taiwan	Linear	t	-0.01088
Taiwan	Exp	a	0.441558159
Taiwan	Exp	b	-0.030891547
Taiwan	Logistic	K	4.45
Taiwan	Logistic	r	0.033595404
Taiwan	Logistic	t0	-65.68570235
Tianjin	Linear	(Intercept)	0.8339
Tianjin	Linear	t	-0.02842
Tianjin	Exp	a	0.848419036
Tianjin	Exp	b	-0.045989345
Tianjin	Logistic	K	1.846677906
Tianjin	Logistic	r	0.070564628
Tianjin	Logistic	t0	-2.503916384
Tibet	Linear	(Intercept)	0.0945
Tibet	Linear	t	-0.0058
Tibet	Exp	a	0.098751216
Tibet	Exp	b	-0.109935566
Tibet	Logistic	K	0.110952562
Tibet	Logistic	r	0.269871915
Tibet	Logistic	t0	6.592247401

Xinjiang	Linear	(Intercept)	0.769
Xinjiang	Linear	t	-0.0107
Xinjiang	Exp	a	0.768400077
Xinjiang	Exp	b	-0.015046289
Xinjiang	Logistic	K	0.7386301
Xinjiang	Logistic	r	0.388655291
Xinjiang	Logistic	t0	18.20088145
Yunnan	Linear	(Intercept)	0.1434
Yunnan	Linear	t	-0.00802
Yunnan	Exp	a	0.149513545
Yunnan	Exp	b	-0.095262478
Yunnan	Logistic	K	0.199172837
Yunnan	Logistic	r	0.187726692
Yunnan	Logistic	t0	5.292621786
Zhejiang	Linear	(Intercept)	0.5168
Zhejiang	Linear	t	-0.01414
Zhejiang	Exp	a	0.523758146
Zhejiang	Exp	b	-0.034959357
Zhejiang	Logistic	K	5.32
Zhejiang	Logistic	r	0.037897995
Zhejiang	Logistic	t0	-58.46540428

Tab. S9. Summarized foreground life-cycle inventory data for the FPV generation unit and associated storage technologies

System	Life-cycle stage	Inventory category	Amount	Unit basis
FPV	Manufacturing	PV module	5.2	m ² /kWp
FPV	Manufacturing	Packaging materials	2.991	kg/kWp
FPV	Manufacturing	Grounding and lightning protection	1.868	kg/kWp
FPV	Manufacturing	Combiner, DC protection, and monitoring components	6.907	kg/kWp
FPV	Manufacturing	Cables, cable protection, and connectors	17.087	kg/kWp
FPV	Manufacturing	Sealants and marine sealing materials	0.672	kg/kWp
FPV	Manufacturing	Floating body and walkway structures	59.868	kg/kWp
FPV	Manufacturing	Module fixing system and fasteners	17.559	kg/kWp
FPV	Manufacturing	Inverter and inverter support	4.535	kg/kWp
FPV	Manufacturing	Mooring and anchoring system	87.416	kg/kWp
FPV	Transport and installation	Construction fuel	6.044	L/kWp
FPV	Transport and installation	Installation auxiliary materials	9.630	kg/kWp
FPV	Transport and installation	On-site assembly & commissioning electricity	19.830	kWh/kWp
FPV	Transport and installation	Transport of system components	39.192	tkm/kWp
FPV	Operation and maintenance	Replacement components	9.787	kg/kWp
FPV	Operation and maintenance	Operational electricity use	425.24	kWh/kWp
FPV	Operation and maintenance	Cleaning water	2.49	m ³ /kWp
FPV	Operation and maintenance	Inspection fuel	18.5	L/kWp
FPV	Operation and maintenance	Cleaning agent	0.01	kg/kWp
FPV	End-of-life	End-of-life material flows to treatment	104.145	kg/kWp
FPV	End-of-life	Dismantling diesel	2.145	L/kWp
FPV	End-of-life	Dismantling electricity	46.17	kWh/kWp
FPV	End-of-life	End-of-life transport	6.523	tkm/kWp
System	Life-cycle stage	Inventory category	Amount	Unit basis
LFP	Manufacturing	Battery cells and module assemblies	7.986	kg/kWh
LFP	Manufacturing	Container, cabinet, and structural metal parts	11.19	kg/kWh
LFP	Manufacturing	Foundation and supports	16.33	m ² /kWh
LFP	Manufacturing	Electrical connection materials	1.012	kg/kWh
LFP	Manufacturing	BMS, EMS, and control components	0.364	kg/kWh
LFP	Manufacturing	Electrical protection components	0.609	kg/kWh
LFP	Manufacturing	PCS	0.00325	unit/kWh
LFP	Manufacturing	HVAC / thermal management	0.948	unit/kWh
LFP	Transport and installation	Battery-system transport	20	tkm/kWh
LFP	Transport and installation	Installation diesel	0.627	L/kWh
LFP	Transport and installation	Commissioning electricity	2.26	kWh/kWh

LFP	Operation and maintenance	Auxiliary electricity use	280	kWh/kWh
LFP	Replacement	Replacement material components	8.8392	kg/kWh
LFP	Replacement	Replacement equipment components	0.09805	unit/kWh
LFP	End-of-life	Dismantling diesel	0.593	L/kWh
LFP	End-of-life	End-of-life transport	6.34	tkm/kWh
System	Life-cycle stage	Inventory category	Amount	Unit basis
PHS	Construction&manufacturing	Civil construction materials	21.102	kg/kWh
PHS	Construction&manufacturing	Hydraulic structures and pipework	5.794	kg/kWh
PHS	Construction&manufacturing	Anti-corrosion and protective coating	1.13	kg/kWh
PHS	Construction&manufacturing	Electromechanical equipment	46.13	kg/kWh
PHS	Construction&manufacturing	Control and auxiliary electrical systems	0.9325	kg/kWh
PHS	Transport and installation	Construction fuel	0.362	L/kWh
PHS	Transport and installation	Construction electricity	2.95	kWh/kWh
PHS	Transport and installation	Transport of construction materials and equipment	5.5	tkm/kWh
PHS	Operation and maintenance	Station service electricity	112.5	kWh/kWh;
PHS	Operation and maintenance	Lubricants and hydraulic oil	0.0165	kg/kWh
PHS	Overhaul/replacement	Major overhaul and sealing materials	4.69	kg/kWh
PHS	End-of-life	Dismantling fuel	0.61	L/kWh
PHS	End-of-life	End-of-life transport	2.6	tkm/kWh
System	Life-cycle stage	Inventory category	Amount	Unit basis
VRFB	Manufacturing	Container, rack, and structural supports	17.5	kg/kWh
VRFB	Manufacturing	Electrical connection and protection components	1.669	kg/kWh
VRFB	Manufacturing	Control and monitoring components	0.037	kg/kWh
VRFB	Manufacturing	PCS	1	unit/kWh
VRFB	Manufacturing	Electrolyte and stack components	66.368	kg/kWh
VRFB	Manufacturing	Electrolyte storage and piping system	24.044	kg/kWh
VRFB	Manufacturing	Circulation pump	1	unit/kWh
VRFB	Manufacturing	Ventilation, acid-mist control, and leakage protection	6.39	kg/kWh
VRFB	Transport and installation	Transport of electrolyte and equipment	37.425	tkm/kWh
VRFB	Transport and installation	Installation diesel	1.927	L/kWh
VRFB	Operation and maintenance	Pump electricity use	430	kWh/kWh
VRFB	Replacement/maintenance	PCS and pump replacement	2	unit/kWh
VRFB	Replacement/maintenance	Electrolyte replenishment and water make-up	0.197	kg/kWh
VRFB	End-of-life	Dismantling diesel	0.825	L/kWh
VRFB	End-of-life	End-of-life transport of electrolyte and equipment	34.5	tkm/kWh