Supplementary information for:

The greenhouse gas emissions reduction co-benefit of end-of-life electric vehicle battery treatment strategies

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1. Inventory data of materials related to the battery recovery phase

(1) Metallurgical recycling of LFP battery

Table S1 (A) inventory data for the metallurgical recycling of LFP battery[1]

Types		Parameter	Amount	Unit
Input	Materials	End of Life LFP batteries	1.00E+00	kg
		Limestone	2.43E-01	kg
		Hydrochloric acid	1.80E-01	kg
		Hydrogen peroxide	3.45E-01	kg
		Ammonium hydroxide	2.54E-02	kg
		Sodium hydroxide	4.54E-01	kg
		Sulfuric acid	1.43E+00	kg
		Soda ash	1.70E-02	kg
	Energy	Electricity	2.49E-01	kWh
		Diesel	5.44E-01	MJ
		Natural Gas	8.83E-01	MJ
Output	Product	Lithium carbonate	1.54E-01	kg
		Aluminum	1.52E-01	kg

(2) Metallurgical recycling of NCM battery

Table S1 (B) inventory data for the metallurgical recycling of NCM battery[1]

Types		Parameter	Amount	Unit
Input	Materials	End of Life NCM batteries	1.00E+00	kg
		Limestone	3.00E-01	kg
		Hydrochloric acid	2.10E-01	kg
		Hydrogen peroxide	1.25E-01	kg
		Citric acid	5.05E-02	kg
		Sulfuric acid	1.38E+00	kg
		Soda ash	3.61E-01	kg
	Energy	Electricity	2.49E-01	kWh
		Diesel	5.44E-01	MJ
		Natural Gas	8.84E-01	MJ
Output	Product	Lithium carbonate	1.09E-01	kg
		Aluminum	1.50E-01	kg
		Nickel sulfate	2.03E-01	kg
		Cobalt sulfate	2.04E-01	kg
		Manganese sulfate	1.99E-01	kg

(3) Regeneration of LFP battery

Table S1 (C) inventory data for the regeneration of LFP battery[1]

Types		Parameter	Amount	Unit
Input	Materials	End of Life LFP batteries	1.00E+00	kg
		Lithium carbonate	2.96E-03	kg
		Carbon dioxide	2.20E+00	kg
	Energy	Electricity	1.14E+00	kWh
		Diesel	2.50E-01	MJ
Output	Product	Cathode (95% capacity)	3.42E-01	kg

(4) Regeneration of NCM battery

Table S1 (D) inventory data for the regeneration of NCM battery[1]

Types		Parameter	Amount	Unit
Input	Materials	End of Life NCM batteries	1.00E+00	kg

		Lithium carbonate	3.01E-03	kg
		Carbon dioxide	2.20E+00	kg
	Energy	Electricity	6.88E-01	kWh
		Diesel	1.51E-01	MJ
Output	Product	Cathode (95% capacity)	3.63E-01	kg

(5) Second use of LFP battery

Table S1 (E) inventory data for the regeneration of NCM battery[2]

Types		Parameter	Amount	Unit
Input	Materials	End of Life LFP batteries	1.00E+00	kg
		Cables (Copper)	1.82E-02	kg
		Casing (Steel)	4.85E-02	kg
		Nickel (Metal)	6.07E-03	kg
	Energy	Electricity	1.01E-01	kWh
Output	Product	In-use LFP batteries	1.00E+00	kg

2. Inventory data of materials related to the battery production phase

Table S2 Components of LFP and NCM battery[3,4]

% by weight	LFP	NCM333	NCM532	NCM622	NCM811
Active Cathode Material	36.0%	38.2%	38.6%	36.1%	31.5%
Graphite/Carbon	19.1%	20.2%	20.6%	22.1%	24.4%
Binder	1.1%	1.8%	1.2%	1.2%	2.2%
Copper	8.3%	7.2%	7.2%	7.1%	7.2%
Wrought Aluminum	17.5%	17.3%	17.3%	17.8%	18.4%
Electrolyte: LiPF6	1.8%	1.4%	1.3%	1.4%	1.4%
Electrolyte: Ethylene Carbonate	5.0%	3.9%	3.7%	3.8%	3.9%
Electrolyte: Dimethyl Carbonate	5.0%	3.9%	3.7%	3.8%	3.9%
Plastic: Polypropylene	0.8%	0.7%	0.8%	0.6%	0.8%
Plastic: Polyethylene	0.2%	0.2%	0.2%	0.2%	0.2%
Plastic: Polyethylene	0.2%	0.2%	0.2%	0.2%	0.2%

Terephthalate					
Steel	0.7%	0.6%	0.6%	0.6%	0.6%
Thermal Insulation	0.3%	0.3%	0.3%	0.4%	0.4%
Coolant: Glycol	2.7%	2.6%	2.7%	2.9%	3.0%
Electronic Parts	1.4%	1.7%	1.7%	1.8%	1.9%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

3. Production and retirement forecast data of vehicle power batteries

China's lithium-ion batteries production and retirement are extracted from the Transport Impact Model (TIM) [5-7]. By considering factors such as growth of Gross Domestic Production, elasticity of vehicle sales, EV penetration and technological development, TIM was able to forecast annual production and retirement of various batteries in 2020-2060.

(1) Production forecast

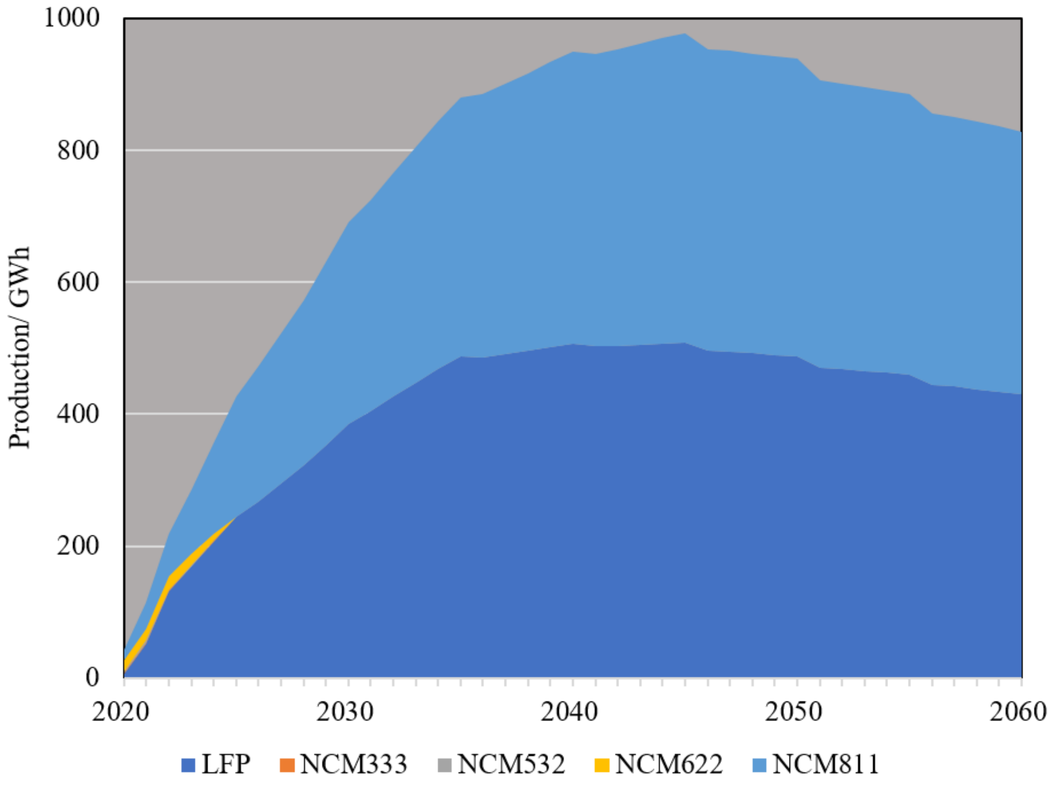

Figure S1 Annual production forecasts for vehicle power batteries in China, where the data for 2022 and earlier are realistic and the data after that are forecasts.

(2) Production forecast

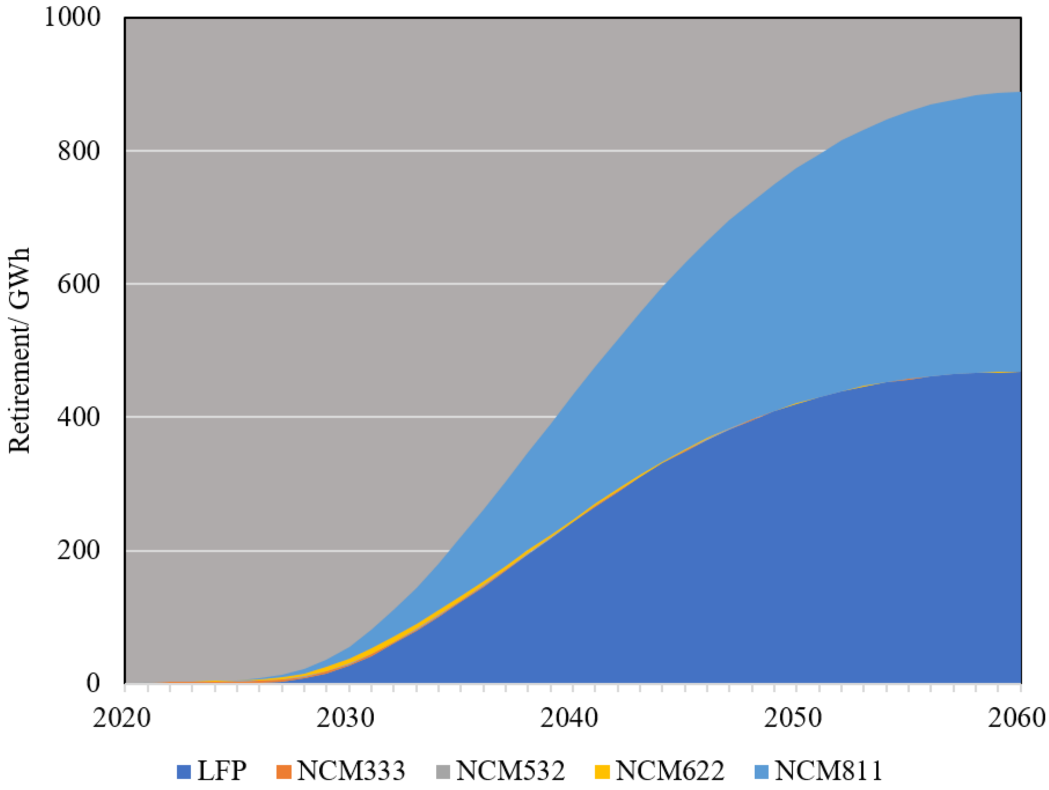

Figure S2 Annual retirement forecasts for vehicle power batteries in China, where the data for 2022 and earlier are realistic and the data after that are forecasts.

4. Energy GHG emissions factors in China

(1) Energy GHG emissions factors in 2022

In the assessment of GHG emissions factors, this study predominantly draws upon data originating from the 2006 report of the United Nations Intergovernmental Panel on Climate Change [8], a recognized authoritative source in the field of climate science. Additionally, the study incorporates emission factors specific to energy usage in EVs. These meticulously selected and rigorously validated factors assume a pivotal role as foundational references, enabling the comprehensive evaluation of the environmental implications pertaining to GHG emissions throughout the analytical processes under investigation, as shown in Table S3.

Table S3 GHG emissions factors of various energy in 2022

Types	Amount	Unit
Coal	1.12E+02	g CO2 eq./MJ

Electricity	1.58E+02	g CO2 eq./MJ
Natural Gas	6.71E+01	g CO2 eq./MJ
Coke	1.07E+02	g CO2 eq./MJ
Residual Oil	1.05E+02	g CO2 eq./MJ
Gasoline	9.12E+01	g CO2 eq./MJ
Diesel	1.04E+02	g CO2 eq./MJ
Blast furnace gas	2.60E+02	g CO2 eq./MJ
Coke oven gas	4.45E+01	g CO2 eq./MJ

(2) Electric GHG emission factors prediction

Notably, the GHG emission factor associated with electricity generation is intricately linked to the composition of power generation sources. Given China's proactive efforts to bolster the development of environmentally sustainable electricity sources, it is postulated within this investigation that a tangible reduction in the GHG emission factor of electricity will transpire. This assumption aligns with data obtained from the Ministry of Ecology and Environment, encompassing the electric GHG emission factors spanning the years 2020 to 2022 [9]. Moreover, to anticipate the realization of a carbon-neutral electricity grid by 2050, this study incorporates annual adjustments in the electric power emission factor, as illustrated in Figure S3.

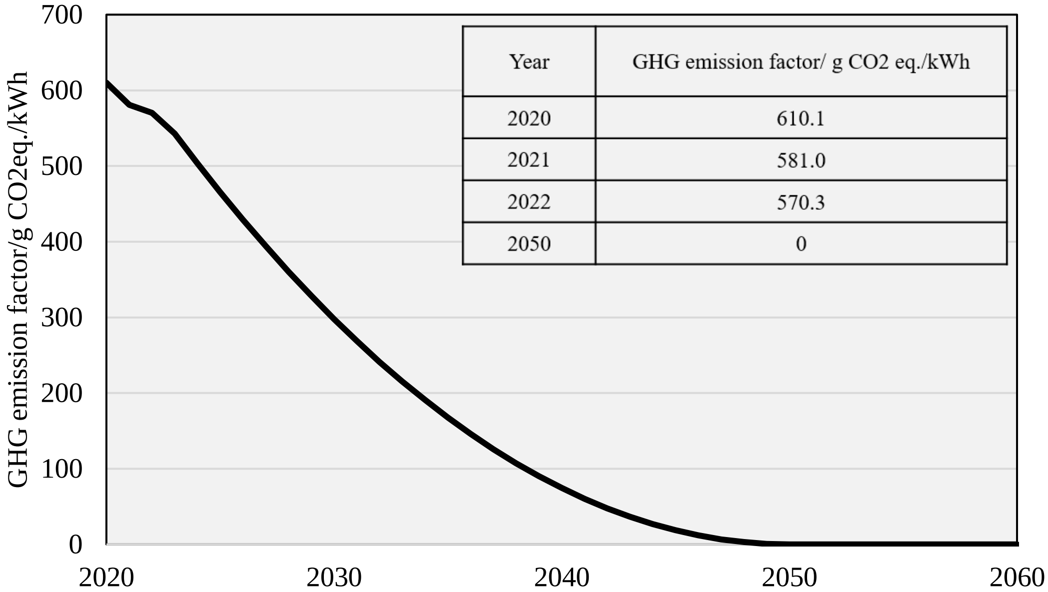

Figure S3 Electric GHG emission factor prediction for China. To estimate the emission factors beyond 2022 and up to the target year of 2050 for achieving zero carbonization of the grid, quadratic interpolation is employed.

Reference

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