This file includes:

Supplementary Text
Figs. S1 to S15
Tables S1 to S5

Supplementary Text

Text S1. Global theoretical hydropower potential from the high-resolution discharge dataset

Our assessment reveals that the baseline global theoretical hydropower potential is 57.9 PWh yr^{-1}. This assessment substantially reduces the uncertainty of the global theoretical hydropower potential assessment (30.67 to 127.58 PWh yr^{-1}). The Himalayas region has the highest theoretical hydropower potential, with the Rockies, Andes, and European Alps also having large hydropower potential (Fig. S3). Mountain areas have the highest theoretical potential owing to high altitudinal gradients that allow for sufficient water fall heights for relatively high volumes of streamflow year-round. Although discharge in the Amazon Basin is high, the low altitudinal gradient in the basin is not ideal for hydropower generation. Asia (24.26 PWh yr^{-1}) has the largest theoretical hydropower potential in the world. In contrast, Oceania and Europe have less than one-eighth of Asia's theoretical hydropower potential (2.13-3.22 PWh yr^{-1}). Africa (8.24 PWh yr^{-1}), North America (8.36 PWh yr^{-1}), and South America (11.63 PWh yr^{-1}) are intermediate.

Text S2. Environmental flows impact on hydropower global profitable potential

The incorporation of environmental flow allowances can affect hydropower generation potential; therefore, to quantify the impact of different environmental flows on global unused profitable potential, we incorporate thirteen hydrological environmental flow scenarios (Table S3) to quantify the interaction between water allocation to the environment and human use. For example, when environmental flows are zero, the global unused profitable potential is 10.48 PWh yr^{-1} but when environmental flows are adjusted to 90% of the multi-year average river discharge, the global profitable potential decreases to 1.94 PWh yr^{-1}. Thus, environmental flows have a significant impact on global profitable potential (Fig. S11) but their incorporation is core to minimizing and preferably preventing further deteriorations in global freshwater ecology and biodiversity. Incorporating the Tennant and Tessmann methods for allocating environmental flows gave a global unused profitable potential of 6.26 PWh yr^{-1} and 5.58 PWh yr^{-1}, respectively, which are higher than the global unused profitable potential when the environmental flow is set to the Q_{30}

environmental flow value.

<u>Text S3. Construction cost sensitivity analysis</u>

In the economic evaluation of hydropower development, most of the parameters are derived from the prediction and estimation, which contain some errors related to the actual expenditure of hydropower development. We conduct a sensitivity analysis on the hydropower development cost to analyze the possible impact on the profitable potential (Table S5). We find that generation efficiency has the most significant positive impact on profitable potential, with the second most influential factor being the interest rate, which reduces the global profitable hydropower potential when raised. Construction costs are also important. This study assumes that construction costs in developed countries, such as the labor and material costs, are relatively high, which raises their actual profitable potential. Other variables considered have relatively little impact on global unused profitable potential (Fig. S15).

Fig. S1. Relative error histogram of global discharge dataset. We calculate the hydropower potential using the multi-year average discharge, and 90% of the feasible and profitable potential hydropower systems are located in the river with the multi-year mean discharge of over 93 $m^3 s^{-1}$. We select the hydrological stations with multi-year mean discharge of 93 $m^3 s^{-1}$ from over 14,000 hydrological stations worldwide for accuracy evaluation.

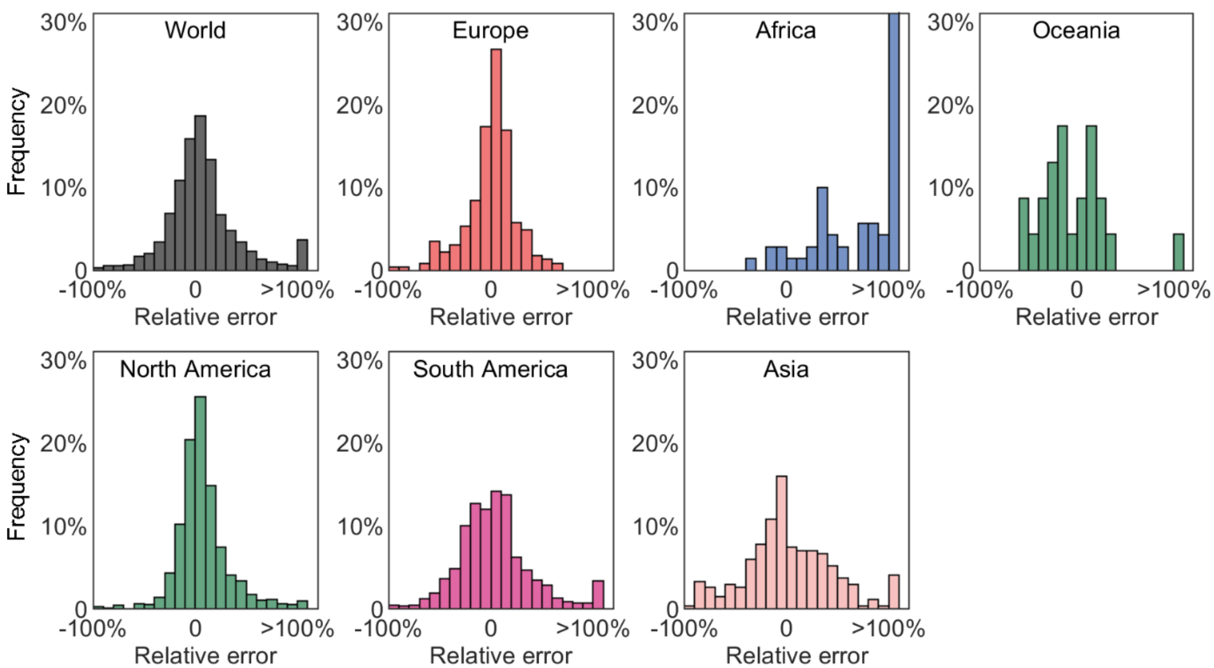

Fig. S2. Flowchart of global hydropower potential assessment.

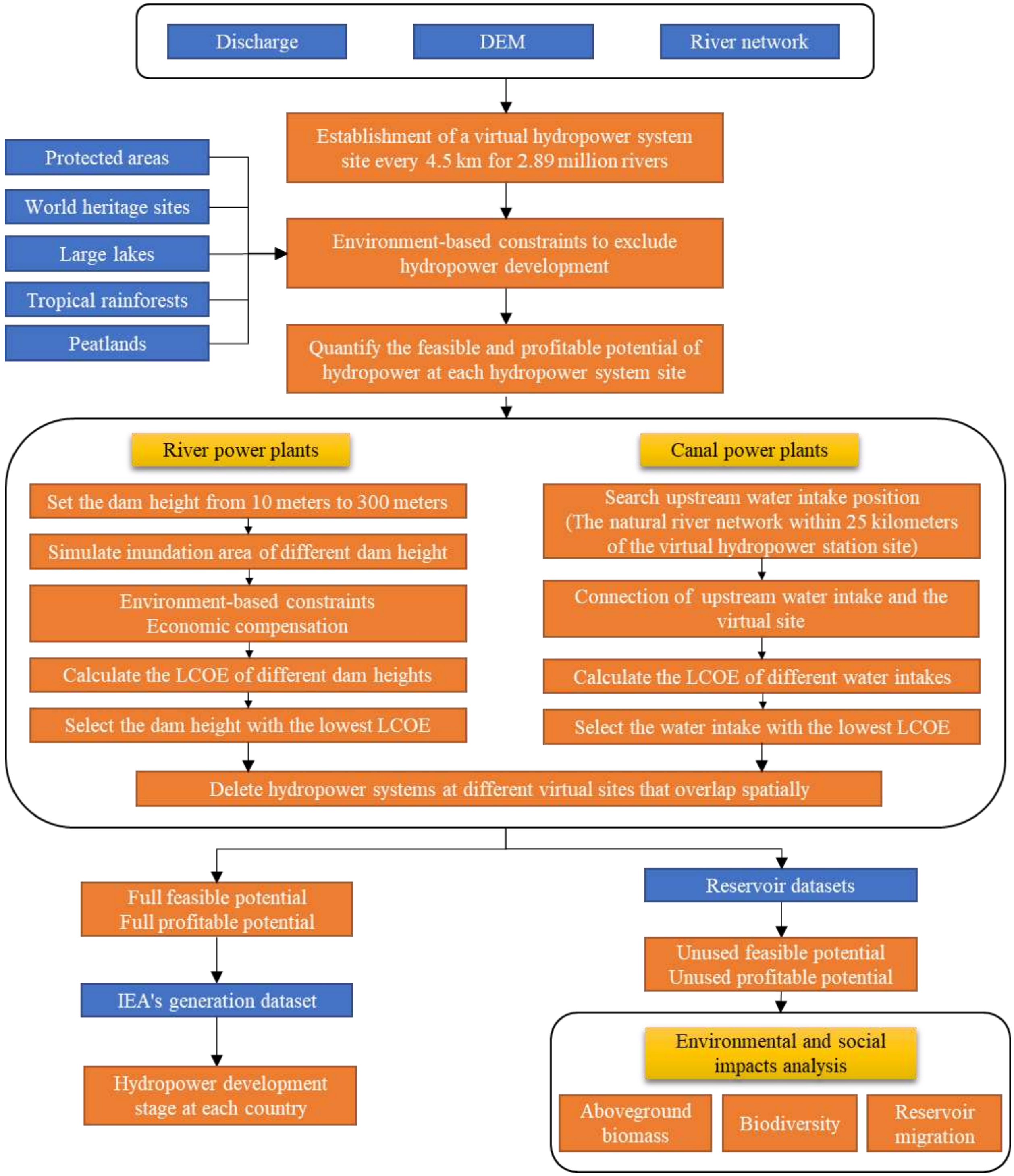

Fig. S3. Spatial distribution of theoretical hydropower potential at the global and continental scales. The theoretical hydropower potential of 2.89 million rivers is allocated to the global raster of 0.1 degree. AS represents Asia, SA represents South America, NA represents North America, AF represents Africa, OA represents Oceania, and EU represents Europe.

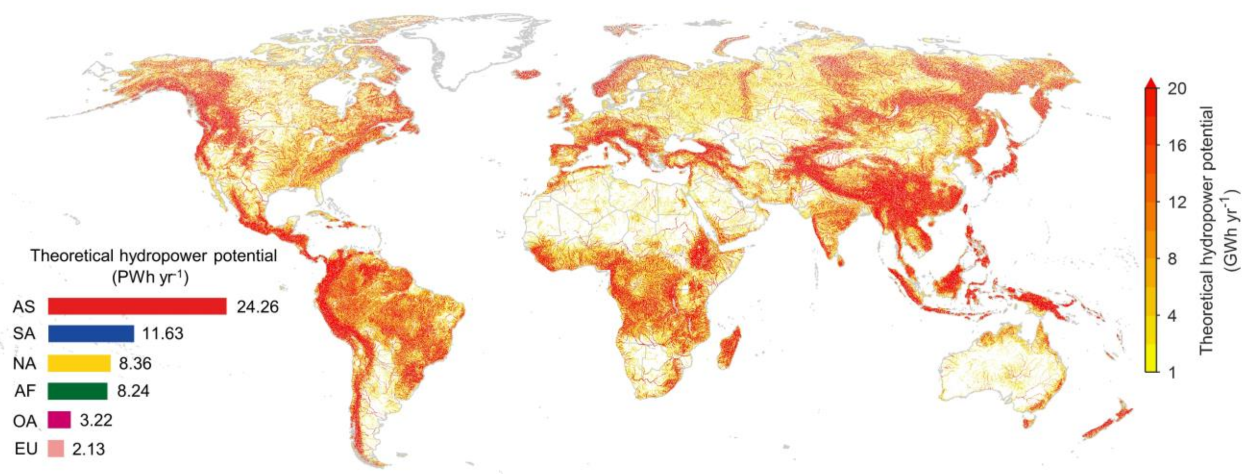

Fig. S4. The multi-year trend in the global unused profitable hydropower potential from 1979 to 2016 based on the global runoff dataset from the Terrestrial Hydrology Research Group at Princeton University[21]

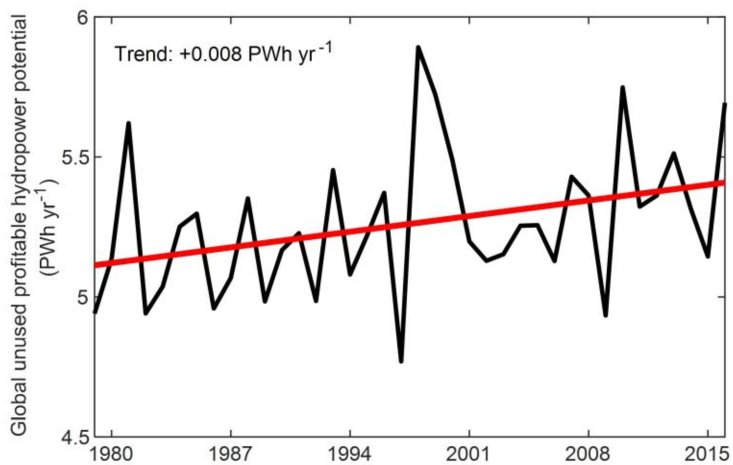

Fig. S5. Spatiotemporal trend in global unused profitable hydropower potential from 1979 to 2016. The profitable potential in Canada, Russia, Andes, southern Africa, Indonesia, and Papua New Guinea has increased over the past 40 years, while profitable potential in the western United States, Europe, and Central Africa has decreased.

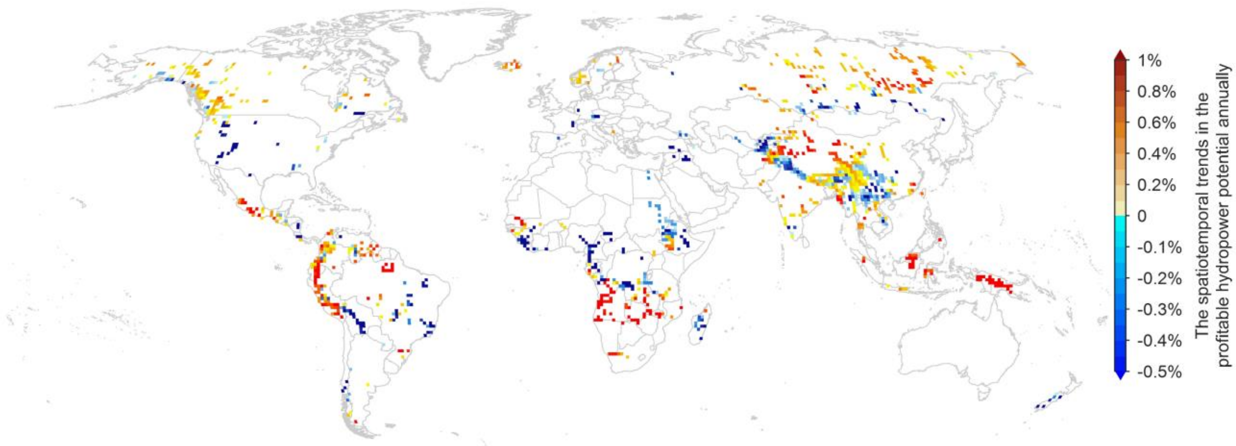

Fig. S6. Discharge histogram of the river where the global unused profitable hydropower system is located. (a) Total profitable hydropower system sites. **(b)** Profitable river power plants. **(c)** Profitable diversion canal power plants.

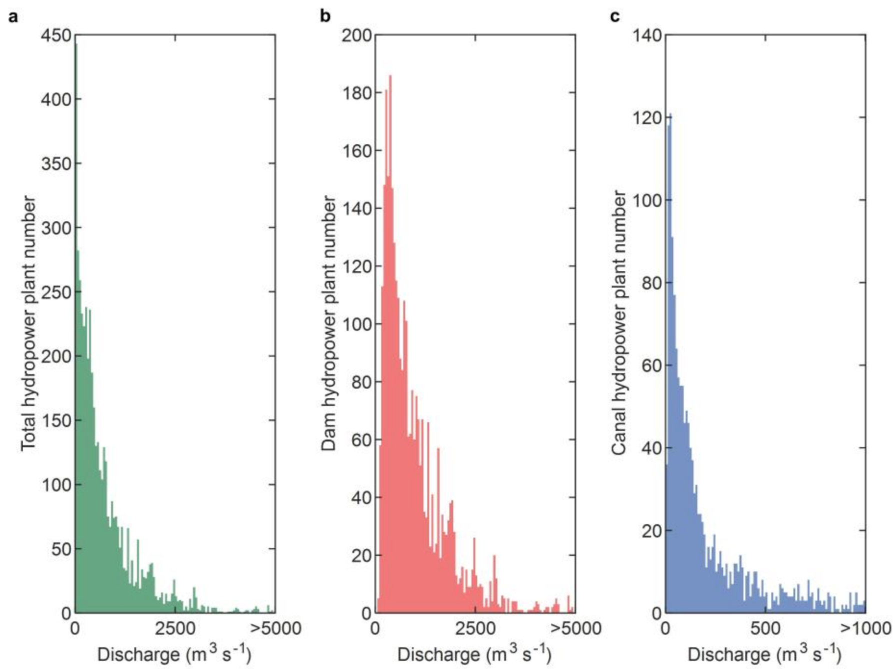

Fig. S7. Installed capacity histogram of the river where the global unused profitable hydropower system is located. (a) Total profitable hydropower system sites. **(b)** Profitable river power plants. **(c)** Profitable canal diversion power plants.

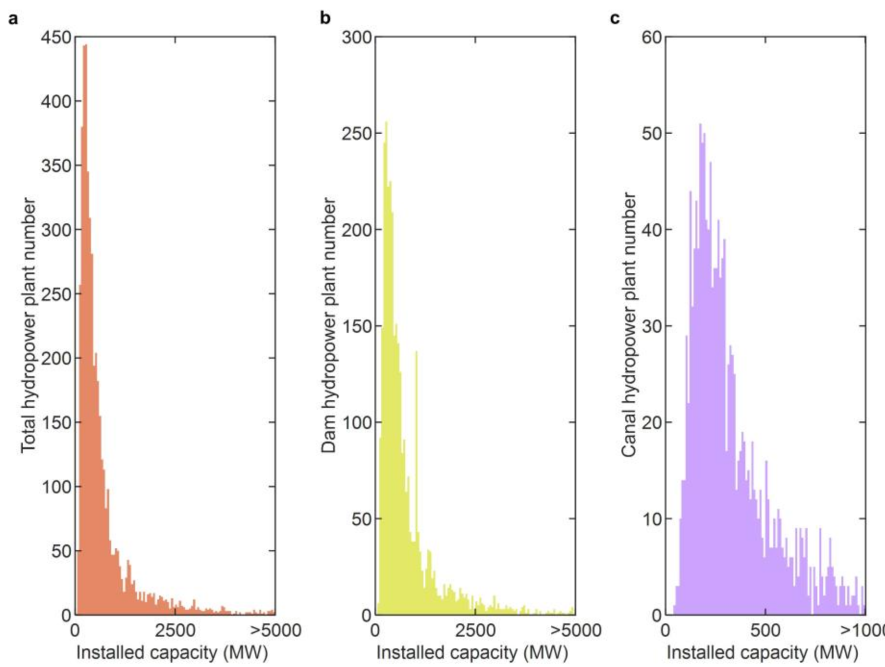

Fig. S8. Cost–supply curves of global non-power dams.

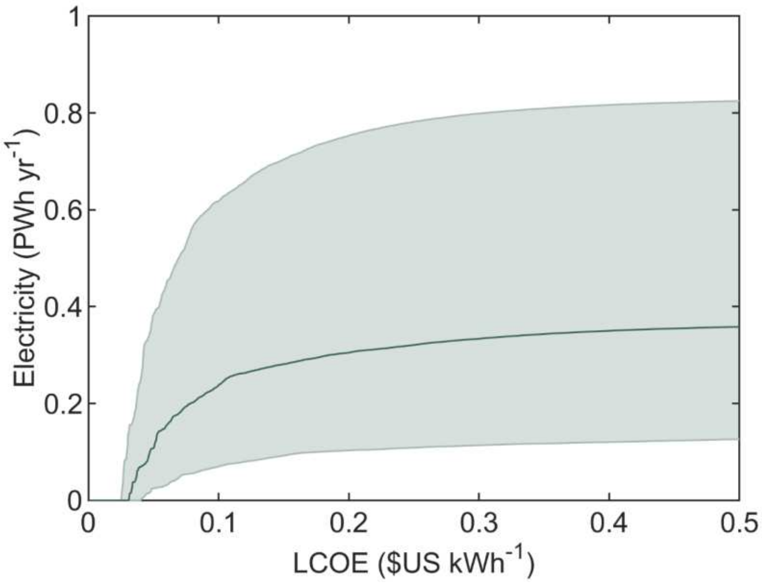

Fig. S9. Global distribution of dams not equipped to generate electricity.

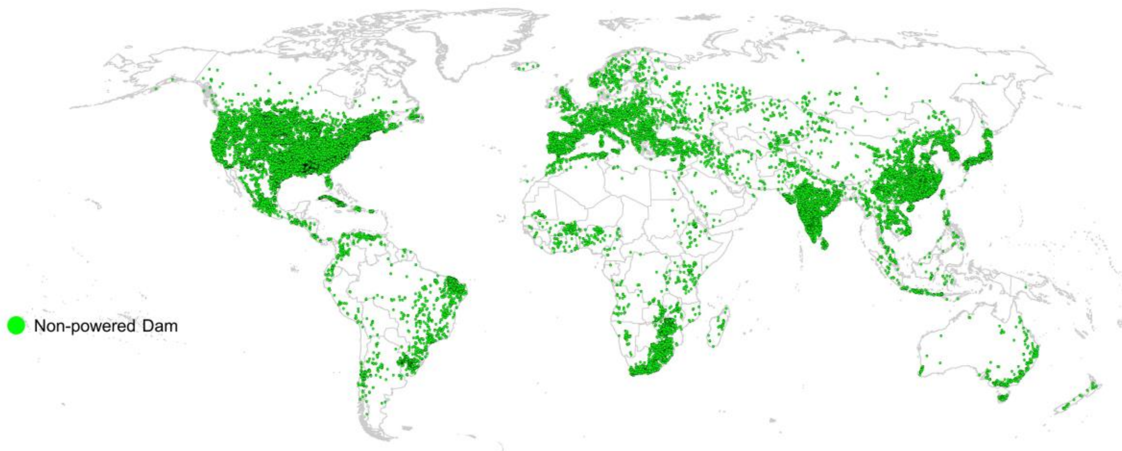

Fig. S10. The global river power plants overlap with pumped hydropower resources. The pumped hydropower resources come from the global atlas of closed-loop pumped hydro energy storage. The atlas has 616,000 potential storage sites that can build pump storage plants[32].

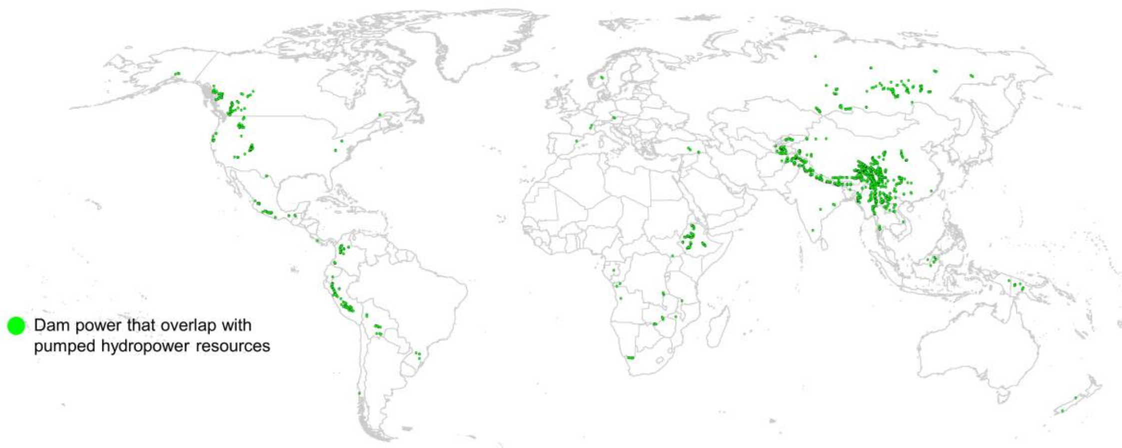

Fig. S11. Global profitable potential of different environment flow scenarios. The detailed environment flow scenarios are shown in Table S3.

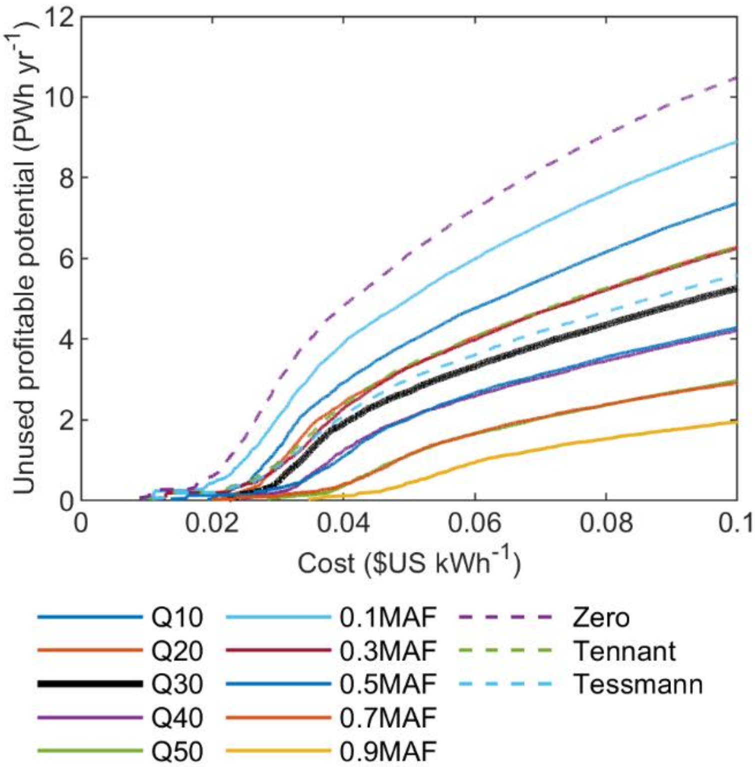

Fig. S12. Spatial distribution of biodiversity influenced by the hydropower systems. (a) Endangered species score. **(b)** Hydropower potential in biodiversity hotpots as a percentage of profitable hydropower potential.

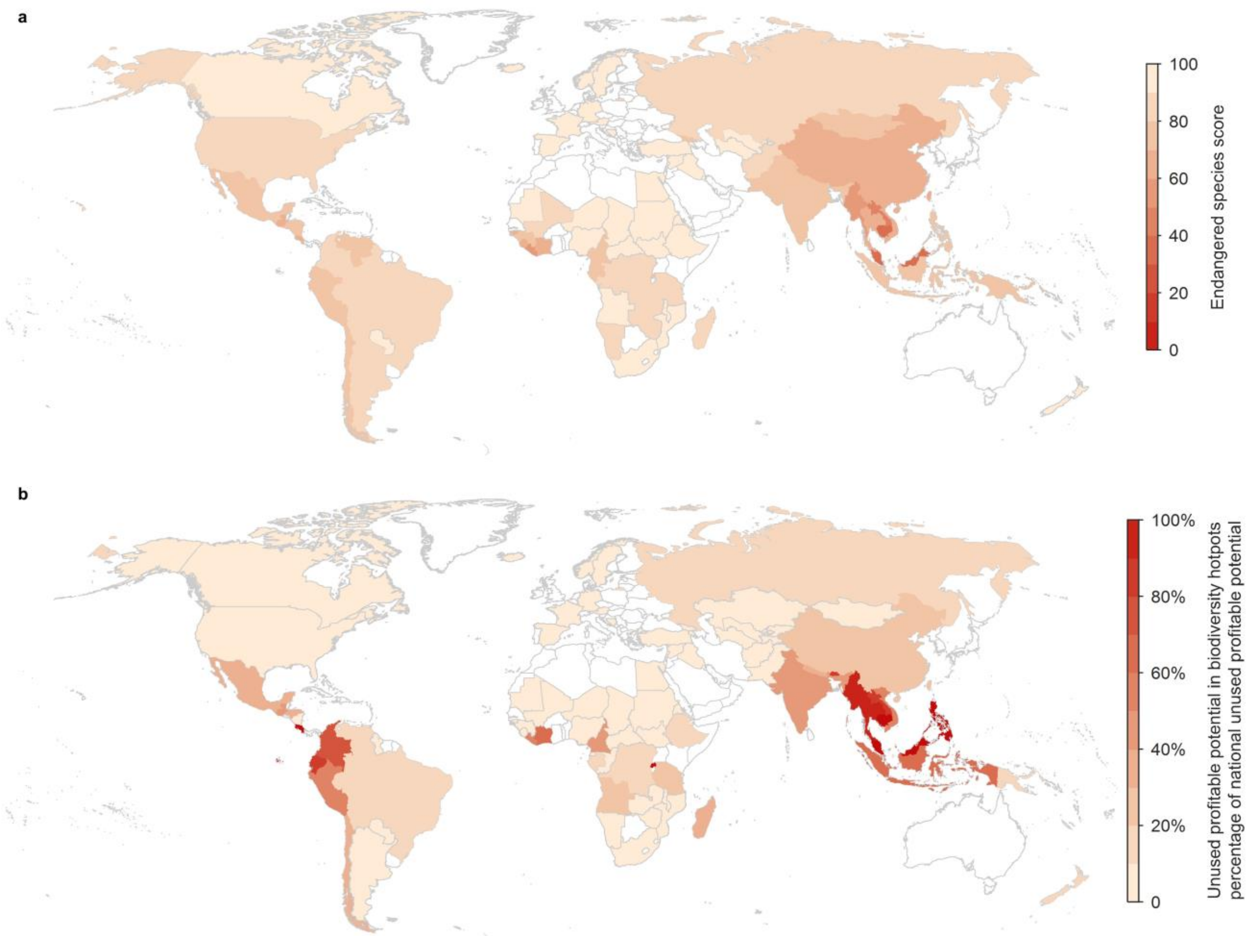

Fig. S13. Spatial distribution of aboveground biomass inundated by the reservoir. (a) Total aboveground biomass. **(b)** Ratio of biomass to hydropower.

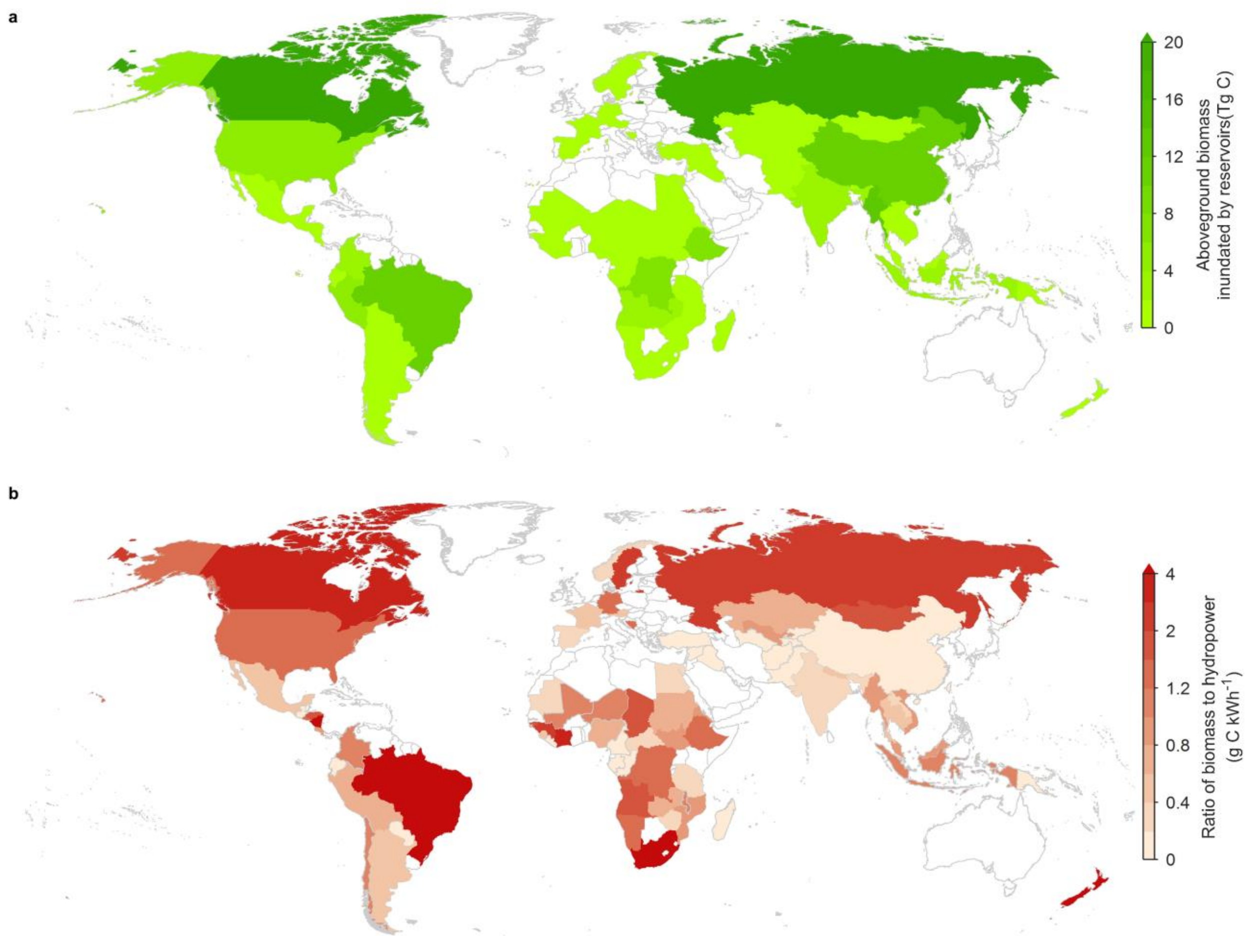

Fig. S14. Sensitivity analysis of reservoir migration threshold. (a) Global profitable potential of different migration thresholds. **(b)** Enlargement of the indicated frame.

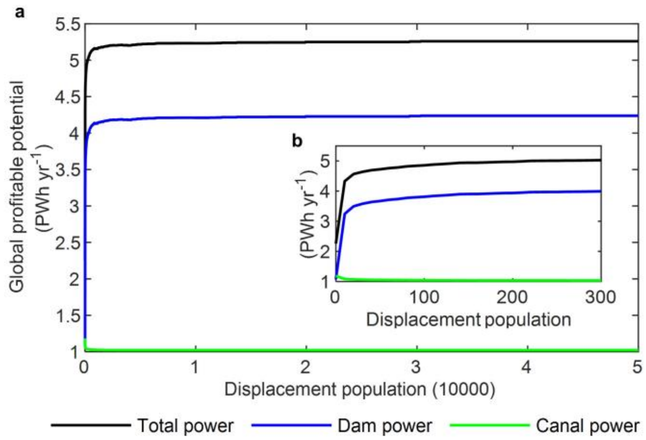

Fig. S15. Sensitivity analysis of key parameters of hydropower system cost. The detailed parameter adjustment scheme is shown in Table S5.

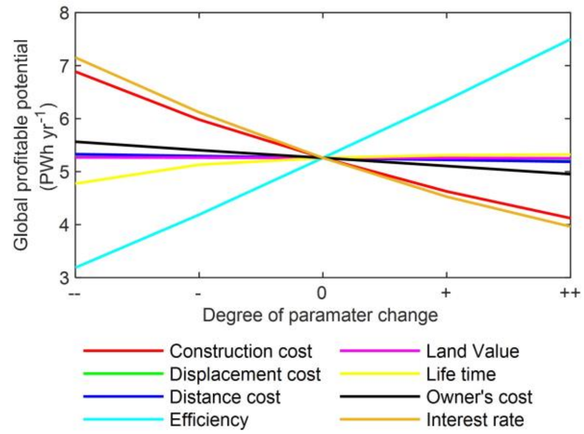

Table S1. Types of the global hydropower potential.

Potential	Description
Theoretical	Theoretical hydropower potential of 2.89 million rivers.
Feasible	Exclusion of prohibited development areas, and incorporating the release of 30% of the multi-year average discharge (Q_{70}). When LCOE is less than 0.5 USD kWh^{-1}, we define the annual average electricity generation of the hydropower plant as the feasible potential.
Profitable[1,2]	Exclusion of prohibited development areas, and incorporating the release of 30% of the multi-year average discharge (Q_{70}). When LCOE is less than 0.1 USD kWh^{-1}, we define the annual average electricity generation of the hydropower plant as the feasible potential.

1. Unused profitable potential: Consider the reservoir dataset, which aims to assess the unused profitable potential.
2. Full profitable potential: Without consider the reservoir dataset, which aims to assess the full profitable potential in a globally unified, quantitative framework.

Table S2. The theoretical, unused feasible, unused profitable potential, and national unused profitable potential percentage of total electricity generation (P/T) in the countries that have unused hydropower potential. The number in the parentheses stands for the percentage of the world's total potential. The unit is TWh yr^{-1}.

Country	Theoretical potential	Unused potential		P/T
		Feasible	Profitable	
China	8452 (14.6%)	3068 (28.2%)	2249 (42.7%)	0.31
Myanmar	1092 (1.9%)	495 (4.5%)	338 (6.4%)	17.98
Russia	4859 (8.4%)	1052 (9.7%)	330 (6.3%)	0.33
India	2171 (3.8%)	552 (5.1%)	294 (5.6%)	0.26
Pakistan	771 (1.3%)	272 (2.5%)	214 (4.1%)	1.71
Canada	3881 (6.7%)	559 (5.1%)	181 (3.4%)	0.32
Peru	2277 (3.9%)	353 (3.2%)	171 (3.2%)	3.49
Nepal	729 (1.3%)	212 (1.9%)	144 (2.7%)	21.98
D.R. Congo	2124 (3.7%)	179 (1.6%)	119 (2.3%)	13.72
Ethiopia	826 (1.4%)	200 (1.8%)	115 (2.2%)	12.66
United States	3056 (5.3%)	441 (4%)	89 (1.7%)	0.02
Laos	412 (0.7%)	137 (1.3%)	74 (1.4%)	14.74
Zambia	284 (0.5%)	86 (0.8%)	70 (1.3%)	5.25
Colombia	2146 (3.7%)	200 (1.8%)	67 (1.3%)	0.94
Indonesia	2700 (4.7%)	258 (2.4%)	66 (1.2%)	0.25
Afghanistan	421 (0.7%)	116 (1.1%)	56 (1.1%)	10.16
P.N. Guinea	1455 (2.5%)	167 (1.5%)	54 (1%)	16.75
Tajikistan	317 (0.5%)	90 (0.8%)	52 (1%)	3.60
Angola	436 (0.8%)	88 (0.8%)	46 (0.9%)	4.39
Mexico	840 (1.5%)	214 (2%)	45 (0.9%)	0.16
Sudan	307(0.5%)	48 (0.4%)	44 (0.8%)	3.75
Brazil	3804(6.6%)	276 (2.5%)	36 (0.7%)	0.07
Bolivia	649(1.1%)	114 (1%)	32 (0.6%)	3.63
Madagascar	398(0.7%)	88 (0.8%)	28 (0.5%)	17.57
Zimbabwe	84(0.1%)	34 (0.3%)	25 (0.5%)	2.83
Bhutan	258(0.4%)	39 (0.4%)	24 (0.5%)	11.02
R. Congo	603(1%)	31 (0.3%)	22 (0.4%)	10.15
Kyrgyzstan	221(0.4%)	52 (0.5%)	20 (0.4%)	1.71
Malawi	101(0.2%)	22 (0.2%)	18 (0.3%)	13.63
Vietnam	311(0.5%)	68 (0.6%)	16 (0.3%)	0.07
Cameroon	380(0.7%)	40 (0.4%)	16 (0.3%)	2.25
Mozambique	311(0.5%)	42 (0.4%)	15 (0.3%)	1.10
Ecuador	515(0.9%)	62 (0.6%)	14 (0.3%)	0.57

Venezuela	1002(1.7%)	52 (0.5%)	12 (0.2%)	0.17
Tanzania	254(0.4%)	34 (0.3%)	9 (0.2%)	1.48
Gabon	218(0.4%)	20 (0.2%)	9 (0.2%)	3.80
South Africa	132(0.2%)	38 (0.4%)	8 (0.2%)	0.04
Egypt	217(0.4%)	8 (0.1%)	8 (0.1%)	0.05
Iceland	169(0.3%)	28 (0.3%)	7 (0.1%)	0.36
Thailand	153(0.3%)	15 (0.1%)	7 (0.1%)	0.04
Malaysia	384(0.7%)	42 (0.4%)	7 (0.1%)	0.04
Chile	485(0.8%)	60 (0.6%)	6 (0.1%)	0.08
South Sudan	135(0.2%)	8 (0.1%)	6 (0.1%)	11.3
Turkey	338(0.6%)	50 (0.5%)	6 (0.1%)	0.02
Guatemala	163(0.3%)	33 (0.3%)	6 (0.1%)	0.52
Norway	324(0.6%)	59 (0.5%)	5 (0.1%)	0.04
Chad	42(0.1%)	7 (0.1%)	5 (0.1%)	25.05
Mali	49(0.1%)	11 (0.1%)	5 (0.1%)	1.63
Kazakhstan	207(0.4%)	24 (0.2%)	5 (0.1%)	0.0500
Sierra Leone	57(0.1%)	11 (0.1%)	4 (0.1%)	15.66
New Zealand	302(0.5%)	39 (0.4%)	4 (0.1%)	0.10
Austria	111(0.2%)	17 (0.2%)	4 (0.1%)	0.06
Guyana	74(0.1%)	11 (0.1%)	4 (0.1%)	5.23
Namibia	43(0.1%)	6 (0.1%)	4 (0.1%)	0.97
Guinea	93(0.2%)	31 (0.3%)	4 (0.1%)	6.96
Niger	21(0%)	4 (0%)	4 (0.1%)	2.32
Liberia	75(0.1%)	12 (0.1%)	4 (0.1%)	12.07
Cote d'Ivoire	53(0.1%)	14 (0.1%)	3 (0.1%)	0.48
C.A Republic	135(0.2%)	16 (0.1%)	3 (0.1%)	19.11
Nicaragua	43(0.1%)	18 (0.2%)	3 (0.1%)	0.71
Uzbekistan	115(0.2%)	10 (0.1%)	3 (0%)	0.04
Nigeria	214(0.4%)	21 (0.2%)	2 (0%)	0.08
Mongolia	148(0.3%)	22 (0.2%)	2 (0%)	0.27
E. Guinea	34(0.1%)	3 (0%)	2 (0%)	1.38
Costa Rica	156(0.3%)	13 (0.1%)	2 (0%)	0.19
Paraguay	65(0.1%)	4 (0%)	2 (0%)	0.14
Argentina	492(0.9%)	46 (0.4%)	2 (0%)	0.01
Sweden	159(0.3%)	20 (0.2%)	2 (0%)	0.01
Eritrea	27(0%)	6 (0.1%)	2 (0%)	3.54
Cambodia	121(0.2%)	5 (0%)	1 (0%)	0.17
Iraq	66(0.1%)	16 (0.2%)	1 (0%)	0.03
Mauritania	4(0%)	2 (0%)	1 (0%)	1.31
Turkmenistan	38(0.1%)	5 (0%)	1 (0%)	0.08
Germany	105(0.2%)	13 (0.1%)	1 (0%)	0

Honduras	95(0.2%)	25 (0.2%)	1 (0%)	0.18
GBS	3(0%)	2 (0%)	1 (0%)	29.88
Georgia	120(0.2%)	18 (0.2%)	1 (0%)	0.08
Spain	138(0.2%)	15 (0.1%)	1 (0%)	0
El Salvador	15(0%)	4 (0%)	1 (0%)	0.15
Armenia	21(0%)	4 (0%)	1 (0%)	0.15
France	219(0.4%)	21 (0.2%)	1 (0%)	0
Rwanda	16(0%)	2 (0%)	1 (0%)	1.58
BiH	44(0.1%)	8 (0.1%)	1 (0%)	0.06
Philippines	292(0.5%)	39 (0.4%)	1 (0%)	0.01
Syria	16(0%)	2 (0%)	1 (0%)	0.03

Table S3. Environmental flow scenarios. MAF (the mean annual flow), MMF (the mean monthly flow).

Scenario	Description
Q10	The flow exceeded 10% of the river discharge
Q20	The flow exceeded 20% of the river discharge
Q30	The flow exceeded 30% of the river discharge,
Q40	The flow exceeded 40% of the river discharge
Q50	The flow exceeded 50% of the river discharge
0.1MAF	0.1 times of the multi-year average discharge of the river (MAF)
0.3MAF	0.3 times of the multi-year average discharge of the river (MAF)
0.5MAF	0.5 times of the multi-year average discharge of the river (MAF)
0.7MAF	0.7 times of the multi-year average discharge of the river (MAF)
0.9MAF	0.9 times of the multi-year average discharge of the river (MAF)
Zero	No environment flow
Tennant	$(MMF \leq MAF)$ 0.2 times of MAF $(MMF > MAF)$ 0.4 times of MAF
Tessmann	$(MMF \leq 0.4MAF)$ MMF $(MMF > MAF)$ 0.4 times of MMF $(0.4MAF < MMF \leq MAF)$ 0.4 times of MAF

Table S4. Cost calculation formula of two types of the hydropower system.

Cost component	Equation	Notes	Ref.
Cost components for both hydropower systems			
Turbine (USD2005)	$p_1 = 1.943P_T^{0.7643}10^6$ $P_T = Q_D h\rho g\eta 10^{-6}$	P_T: turbine capacity (MW) Q_D:design discharge (m^3 s^{-1})	12,61
Power station (NOK2010)	$p_2 = (0.4948Q_D + 1.7)10^6$ ($Q_D \leq 50m^3s^{-1}$) $p_2 = (-0.0006Q_D^2 + 0.67Q_D - 6.95)10^6$ ($50m^3s^{-1} < Q_D \leq 500m^3s^{-1}$) $p_2 = 178.05 \times 10^6$ ($Q_D \geq 500m^3s^{-1}$)		12,59
Electro-technical equipment (NOK2010)	$p_3 = 3.9142P_T^{0.6622}10^6$		12,59
Fish passage (USD2002)	$p_4 = 1.3e^6(10^3P_T)^{0.56}$		12,59
Miscellaneous (NOK2010)	$p_5 = (-38.795\log Q_D + 309.89)P_T 10^3$		12,59
Power line connection (NOK2010)	$p_6 = Lp_p$	L: shortest distance to powerline (km) p_p: powerline price (NOK km^{-1})	12,59
Additional cost components for river power systems			
Dam (NOK2010)	$p_7 = 0.72D_H^{1.8}D_L 10^3$	D_H: dam height (m) D_L:dam length (m)	12,59
Land loss cost	$p_8 = A * land\ value.$	Land value of the area inundated, 192 dollars/acre (2010)/ha, 4100 dollars (2020)/acre, 1400 dollars (2020)/acre for the forest, cropland and grassland, respectively	64
Population displacement	$p_9 = 5 * GDP/capita.$	Number of displaced people multiplied by 5 times the GDP per capita caused by the reservoir inundation	62
Additional cost components for diversion canal power systems			
Piping–headrace tunnel (NOK2010)	$p_{10} = 219.99A_t + 13658(L_p - h)m_t$ $m_t = 0.0054(L_p 10^{-3})^2 - 0.0039(L_p 10^{-3}) + 0.9671$	A_t: cross-section area of tunnels (m^2) L_p: length of the pipes (m) h: hydraulic head (m)	12,59
Piping–penstock	$p_{11} = (6D_t + 9.4h)\eta_p 10^3$	D_t: tunnel diameter (m)	12,59

(NOK2010)			
	Composite cost and LCOE		
Seismic hazard cost (USD2020)	$p_{12} = 0.05(\sum_{i=1}^{6} p_i + \sum_{i=7}^{9} p_i)$ (river power) $p_{12} = 0.05(\sum_{i=1}^{6} p_i + \sum_{i=10}^{11} p_i)$ (canal power)		
Soft rock cost (USD2020)	$p_{13} = 0.05(\sum_{i=1}^{6} p_i + \sum_{i=7}^{9} p_i)$ (river power) $p_{13} = 0.05(\sum_{i=1}^{6} p_i + \sum_{i=10}^{11} p_i)$ (canal power)		
Owner cost (USD2020)	$p_{14} = 0.2(\sum_{i=1}^{6} p_i + \sum_{i=7}^{9} p_i + \sum_{i=12}^{13} p_i)$ (river power) $p_{14} = 0.2(\sum_{i=1}^{6} p_i + \sum_{i=10}^{11} p_i + \sum_{i=12}^{13} p_i)$ (canal power)		
Operation and maintenance (USD2020)	$p_{15} = 0.02(\sum_{i=1}^{6} p_i + \sum_{i=7}^{9} p_i + \sum_{i=12}^{14} p_i)$ (river power) $p_{15} = 0.02(\sum_{i=1}^{6} p_i + \sum_{i=10}^{11} p_i + \sum_{i=12}^{14} p_i)$ (canal power)		
LCOE	$LCOE = \frac{I + \sum_{t=0}^{n}(M_t(1+r)^{-t})}{\sum_{t=0}^{n}(E_t(1+r)^{-t})}$	I: initial investment M_t: operation and maintenance E_t: energy production in year t r = 0.1: discount rate n = 40: system lifetime(years)	12,59

Table S5. Sensitivity analysis parameter adjustment scheme.

		--	-	**Default**	+	++
Interest rate		5%	7.5%	10%	12.5%	15%
Owners rate		10%	15%	20%	25%	30%
Construction cost		0.50x	0.75x	1x	1.25x	1.5x
Distance cost		0.50x	0.75x	1x	1.25x	1.5x
Displacement cost		1xGDP	3xGDP	5xGDP	7xGDP	9xGDP
Lifetime		20yr	30yr	40yr	50yr	60yr
Efficiency	Dam	50%	60%	70%	80%	90%
	Canal	80%	85%	90%	95%	100%
Land Value		0.50x	0.75x	1x	1.25x	1.5x