

## Supplementary File S1:

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Table S1. Population–economy–society–environment indicators.

First goals	Second goals	Third goals	SDGs	Variable	Data sources
Society	Population		8.1	Total population growth rate	The World Bank—World Development Indicators <a href="https://www.worldbank.org/">https://www.worldbank.org/</a>
				Total population change	
				Total population	
				Gross domestic product (GDP) growth rate	
				GDP change	
	Economy		2.3	GDP	Food and Agriculture Organization of the United Nations <a href="https://www.fao.org/">https://www.fao.org/</a>
				Gross production value of the agriculture industry	
				Production quantity of roundwood	
				Gross production value of the livestock industry	
				Total fisheries production	
	Food security		2.1.1	Gross production value of the aquaculture industry	Sustainable Development Report <a href="https://dashboards.sdindex.org/">https://dashboards.sdindex.org/</a>
				Prevalence of undernourishment	
	Infrastructure		7.1.2	Population with access to clean fuels and technology for cooking	Department of Economic and Social Affairs of the United Nations <a href="https://unstats.un.org/">https://unstats.un.org/</a>
				Air transport, freight	
				Air transport, passengers carried	
			9.1.2		The World Bank—World Development Indicators <a href="https://www.worldbank.org/">https://www.worldbank.org/</a>
			9.2.1	Manufacturing value added as a	Department of Economic and

			proportion of GDP	Social Affairs of the United Nations
				<a href="https://unstats.un.org/">https://unstats.un.org/</a>
		9.c.1	Population using the internet	Sustainable Development Report
				<a href="https://dashboards.sdgindex.org/">https://dashboards.sdgindex.org/</a>
		1.a.2	Government expenditure on education	The World Bank--World Development Indicators
				<a href="https://www.worldbank.org/">https://www.worldbank.org/</a>
	Education	4.1.2	Lower secondary completion rate	Sustainable Development Report
		4.2.2	Participation rate in pre-primary organized learning	<a href="https://dashboards.sdgindex.org/">https://dashboards.sdgindex.org/</a>
		6.4.1	Water use efficiency	Food and Agriculture
	Water efficiency	6.4.2	Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (total)	Organization of the United Nations
				<a href="https://www.fao.org/">https://www.fao.org/</a>
		7.2.1	Share of renewable energy in total primary energy supply	Department of Economic and Social Affairs of the United Nations
	Energy efficiency			<a href="https://unstats.un.org/">https://unstats.un.org/</a>
		7.3.1	Energy intensity	International Energy Agency
	Innovative development			<a href="https://www.iea.org/">https://www.iea.org/</a>
		8.2.1	Annual growth rate of real GDP per employee	International Labour Organization
				<a href="https://ilostat.ilo.org/">https://ilostat.ilo.org/</a>
		9.4.1	Carbon dioxide emissions per unit of GDP purchasing power parity (PPP)	Department of Economic and Social Affairs of the United Nations
	Technical innovation	9.5.1	Research and development expenditure as a proportion of GDP	<a href="https://unstats.un.org/">https://unstats.un.org/</a>
		9.b.1	Proportion of medium- and high-tech industry value added in the total value added	
	Pollution control	13.2.2	Total greenhouse gas emissions per year	Our World in Data
				<a href="https://github.com/owid/co2-data">https://github.com/owid/co2-data</a>
		15.1.2	Average proportion of freshwater key biodiversity areas (KBAs) covered by protected areas (%)	Department of Economic and Social Affairs of the United Nations
	Biodiversity		Average proportion of terrestrial KBAs covered by protected areas (%)	<a href="https://unstats.un.org/">https://unstats.un.org/</a>
		15.4.1	Average proportion of mountain KBAs covered by protected areas (%)	
		15.5.1	Red list index	



Table S2. Formulas for land use types utilized in the SD model.

Country	Cropland	adj. R <sup>2</sup>	Forestland	adj. R <sup>2</sup>	Grassland	adj. R <sup>2</sup>	Urban	adj. R <sup>2</sup>	Water	adj. R <sup>2</sup>
Kazakhstan	518098-167.784*Pollution control+229.242*Education +0.0127*Food demand+123.232*Food security	0.878	54976.7+18.9967*Biodiversity+11.4499*Technical innovation+44.9248*Energy efficiency+0.32326*Urban	0.96	1.61422e+06+152.79*Food security+193.552*Water efficiency+179.358*Education+0.002*Gross output value of livestock	0.922	IF THEN ELSE(Time<=2005,(2.6e-05*GDP+429.781), (617.564+2.81429*Pollution control+8.86426*Technical innovation+7.84159*Water efficiency+8.43e-05*Total Population+2.5e-06*GDP) )	0.924 0.991	93203.8 -139.122*Water efficiency-297.238 *Biodiversity-74.8949 *Infrastructure	0.919
Kyrgyzstan	0.0003*Gross output value of agricultural-28.3079*Water+1.8982*Education+416994	0.916	9.27762*Energy efficiency-36.1115*Water efficiency+88.368*Pollution control+374.489*Biodiversity-30.1792*Infrastructure-8329.82	0.89	98135.5-0.30181*Urban+0.00022*Total Population+0.00116*Gross output value of livestock	0.933	IF THEN ELSE(Time<=2005, (63442.4-1289.46*Biodiversity) , (2.2e-05*GDP-2.1103*Technical innovation-22.6991*Pollution control-146.66*Biodiversity+9845.28))	0.896 0.915	13079.5-1.02871*Infrastructure-1.18968*Water efficiency	0.861
Tajikistan	189806-19.9317*Biodiversity-12.9022*Water	0.698	2706.11+0.166784*Education-0.041774*Cropland	0.662	630533-17.1582*Water efficiency-46.3034*Water+8.1464*Forestland-0.0001*Total Population-0.0003*SDG2.3 Gross output value of livestock	0.819	ELSE(Time<=2005,(9.8e-05*GDP-146.871),(2468+3.5e-05*Total Population+1.5e-05*GDP-30.6145*Pollution control+5.65259*Infrastructure+1.57399*Energy efficiency+11.7052*Water efficiency))	0.938 0.967	0.00089*SDG2.3 gross output value of aquaculture-0.1826*Energy efficiency+12258.4	0.446

Turkmenistan	70160.3+0.00099*Food demand+26.9091*Food security-141.963*Forestland+1e-05*GDP	0.872	149.107+0.515586*biodiversity-0.0139647*Technical innovation-0.0336554*Energy efficiency+6e-07*Total population	0.817	0.0004*Total population+0.0004*SDG2.3 Gross output value of livestock+14.2747*Food security-53.1207*Water efficiency-9.6638*Energy efficiency-294.576*biodiversity+116210	0.947	IF THEN ELSE(Time<=3, (5028.71-64.788*biodiversity+0.000121*Total population+5e-06*GDP) , (3.2e-06*GDP+0.000123*Total population+1.36589*Technical innovation-3.66056*Pollution control-185.984) )	0.942	26711.9-2.2713*Infrastructure-11.1165*Water efficiency	0.835
	95280.4-65.4277*Water efficiency+9.29584*Education-0.00022*Food demand-5.0212*Food security-0.00769*SDG2.3 gross output value of agriculture	0.947	262.888-1.60066*Infrastructure+20.2224*Biodiversity-0.0020588*production of roundwood	0.836	132348-994.362*Biodiversity+20.0169*Energy efficiency+126.63*Water efficiency-0.0108*SDG2.3 Gross output value of livestock	0.907	ELSE(Time<=2005 , (65132.6-1752.71*Biodiversity+0.0001*Total Population) , (7.45e-05*Total Population+25.3107*Energy efficiency+30.9213*Technical innovation-901.498))	0.993	2535.4*Biodiversity-304.999*Water efficiency-61.4098*Energy efficiency+0.8718*Cropland-159400	0.903

\* To ensure a constant total area of each country, the area of barren land is the total area minus the area of all other land use types.

Table S3. Accuracy test of land use demand modeling by the SD model.

Country	Land use type	cropland	forestland	Grassland	Urban	Barren	Water
Kazakhstan	2001	1.09%	0.18%	0.16%	3.60%	0.63%	2.03%
	2002	0.29%	0.02%	0.14%	4.11%	0.72%	1.78%
	2003	0.13%	0.12%	0.13%	2.97%	0.86%	2.49%
	2004	0.93%	0.21%	0.01%	1.34%	1.49%	0.30%
	2005	0.63%	0.18%	0.02%	7.29%	1.04%	0.20%
	2006	0.13%	0.04%	0.04%	0.23%	0.50%	2.47%
	2007	0.08%	0.06%	0.05%	0.01%	0.31%	0.18%
	2008	0.67%	0.17%	0.05%	0.26%	0.76%	0.74%
	2009	0.13%	0.05%	0.02%	0.43%	0.81%	3.78%
	2010	0.72%	0.03%	0.06%	0.68%	0.78%	0.98%
	2011	0.67%	0.04%	0.05%	0.25%	1.46%	0.39%
	2012	0.41%	0.04%	0.10%	0.92%	1.16%	0.00%
	2013	0.09%	0.07%	0.01%	0.16%	0.18%	0.00%
	2014	0.56%	0.19%	0.04%	0.20%	0.65%	1.01%
	2015	0.59%	0.00%	0.10%	0.25%	0.59%	0.20%
	Mean error (%)	0.47%	0.09%	0.07%	1.51%	0.80%	1.10%
Kyrgyzstan	2001	0.81%	0.98%	0.08%	10.50%	1.68%	0.03%
	2002	0.58%	0.34%	0.04%	12.50%	2.06%	0.01%
	2003	0.44%	0.68%	0.01%	1.76%	1.93%	0.05%
	2004	0.46%	0.89%	0.03%	4.58%	2.15%	0.02%
	2005	0.51%	0.75%	0.04%	2.43%	2.37%	0.04%
	2006	0.86%	0.34%	0.05%	4.75%	2.98%	0.02%
	2007	1.50%	0.37%	0.06%	1.75%	3.63%	0.02%
	2008	1.69%	0.22%	0.02%	1.42%	4.43%	0.05%
	2009	1.65%	0.32%	0.03%	0.60%	4.26%	0.03%
	2010	1.81%	0.80%	0.03%	0.46%	4.34%	0.02%
	2011	1.61%	0.41%	0.05%	1.31%	4.63%	0.01%
	2012	1.85%	0.42%	0.04%	0.08%	5.21%	0.03%
	2013	1.14%	0.02%	0.20%	2.67%	4.57%	0.00%
	2014	1.43%	0.15%	0.04%	1.22%	4.32%	0.01%
	2015	1.24%	0.58%	0.01%	0.82%	4.26%	0.03%
	Mean error (%)	1.17%	0.49%	0.05%	3.12%	3.52%	0.02%
Tajikistan	2001	0.02%	0.39%	0.01%	1.36%	0.04%	0.00%
	2002	0.04%	0.05%	0.06%	1.27%	0.16%	0.01%
	2003	0.11%	0.26%	0.02%	2.79%	0.05%	0.02%
	2004	0.06%	0.29%	0.31%	2.08%	0.94%	0.00%
	2005	0.03%	0.17%	0.32%	4.06%	0.96%	0.00%
	2006	0.02%	0.03%	0.37%	2.69%	1.13%	0.01%

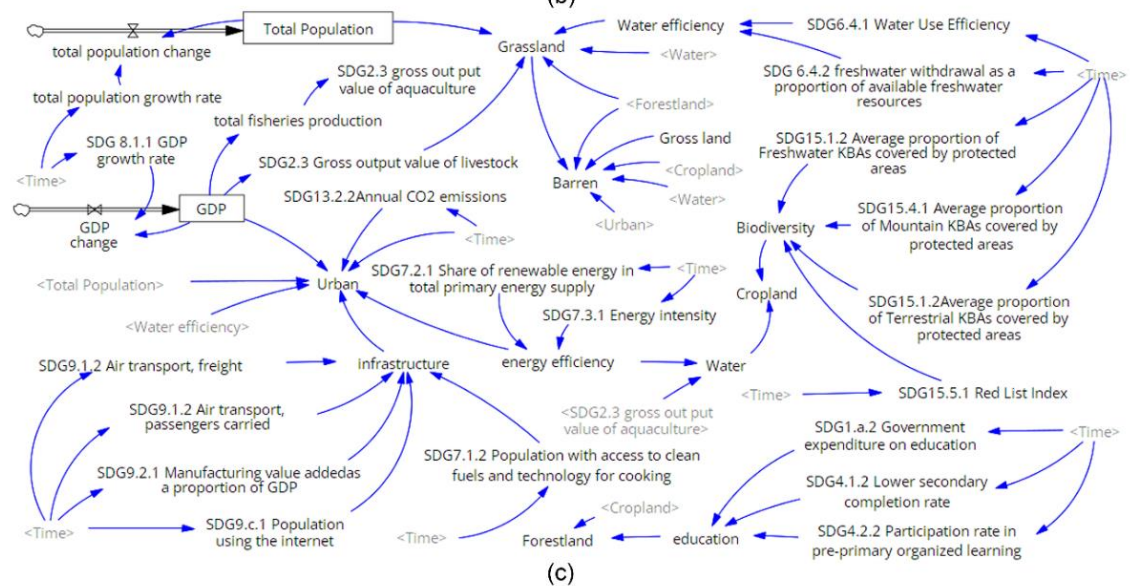
Country	Land use type	cropland	forestland	Grassland	Urban	Barren	Water
Turkmenistan	2007	0.06%	0.27%	0.39%	2.35%	1.29%	0.01%
	2008	0.26%	0.33%	0.31%	1.69%	1.34%	0.02%
	2009	0.12%	0.08%	0.22%	1.83%	0.85%	0.00%
	2010	0.01%	0.02%	0.18%	0.06%	0.58%	0.00%
	2011	0.01%	0.07%	0.10%	0.28%	0.28%	0.00%
	2012	0.01%	0.03%	0.21%	1.27%	0.64%	0.01%
	2013	0.01%	0.17%	0.21%	0.45%	0.65%	0.01%
	2014	0.04%	0.20%	0.12%	0.77%	0.37%	0.01%
	2015	0.09%	0.10%	0.19%	1.57%	0.47%	0.01%
	Mean error (%)	0.06%	0.16%	0.20%	1.63%	0.65%	0.01%
	2001	1.39%	2.81%	0.13%	2.49%	0.15%	0.01%
	2002	1.43%	3.14%	0.22%	8.30%	0.13%	0.02%
	2003	1.47%	3.37%	0.28%	12.48%	0.11%	0.02%
	2004	1.86%	2.99%	0.07%	1.31%	0.23%	0.08%
	2005	1.61%	3.27%	0.06%	3.26%	0.21%	0.02%
	2006	1.60%	3.13%	0.12%	5.35%	0.20%	0.07%
	2007	1.82%	3.03%	0.11%	10.78%	0.24%	0.09%
	2008	2.14%	3.02%	0.20%	6.91%	0.25%	0.01%
	2009	2.17%	3.30%	0.13%	11.14%	0.28%	0.00%
	2010	2.38%	3.92%	0.14%	7.93%	0.30%	0.02%
	2011	2.41%	3.85%	0.08%	0.10%	0.31%	0.01%
	2012	2.48%	3.77%	0.04%	6.26%	0.32%	0.03%
	2013	2.13%	3.69%	0.08%	6.23%	0.27%	0.01%
	2014	1.79%	3.61%	0.16%	4.55%	0.21%	0.03%
	2015	1.42%	3.60%	0.22%	5.80%	0.14%	0.01%
	Mean error (%)	1.87%	3.37%	0.14%	6.19%	0.22%	0.03%
Uzbekistan	2001	0.12%	0.58%	0.34%	11.47%	0.29%	0.00%
	2002	0.04%	1.47%	0.34%	5.47%	0.32%	0.00%
	2003	0.03%	0.00%	0.43%	8.13%	0.77%	0.00%
	2004	0.14%	2.05%	0.37%	2.67%	0.02%	0.00%
	2005	0.09%	1.60%	0.18%	1.59%	0.32%	0.00%
	2006	0.15%	1.68%	0.20%	6.78%	0.28%	0.00%
	2007	0.28%	0.73%	0.17%	2.76%	0.01%	0.00%
	2008	0.13%	1.26%	0.21%	3.74%	0.15%	0.00%
	2009	0.08%	1.24%	0.13%	3.11%	0.83%	0.00%
	2010	0.07%	0.50%	0.12%	0.58%	0.02%	0.00%
	2011	0.00%	0.43%	0.04%	0.74%	0.23%	0.00%
	2012	0.08%	0.67%	0.15%	5.25%	0.21%	0.00%
	2013	0.00%	1.25%	0.17%	0.94%	0.01%	0.00%

Country	Land use type	cropland	forestland	Grassland	Urban	Barren	Water
	2014	0.08%	0.11%	0.38%	3.04%	0.24%	0.01%
	2015	0.39%	0.53%	0.15%	1.60%	0.22%	0.00%
	Mean error (%)	0.11%	0.94%	0.22%	3.86%	0.26%	0.00%

Table S4. Uncertainty analysis statistics for various land use types in five countries.

Country	Land use type (km <sup>2</sup> )	Minimum	5% CI	Median	95% CI	Maximum
Kazakhstan	cropland	607283.5	611851.2	620128.2	628163.6	632838
	forestland	58367.34	58619.04	58955.75	59280.03	59490.98
	grassland	1648152	1651971	1656765	1661281	1664282
	urban	2907.195	3150.968	3396.987	3626.098	3801.944
	water	67182.07	68899.21	72005.33	75078.4	77267.1
Kyrgyzstan	cropland	48212.46	48376.02	48735.38	49086.95	49226.3
	forestland	16989.75	17237.13	17570.79	17865.16	18040.27
	grassland	99539.18	99630.16	99778.59	99928.18	100019
	urban	393.655	436.0374	498.0592	564.4208	601.7376
	water	13008.2	13011.66	13019.69	13028.1	13031.86
Tajikistan	cropland	31245.81	31260.44	31291.05	31324.56	31338.94
	forestland	1394.745	1396.71	1402.407	1407.507	1409.535
	grassland	73502.35	73603.17	73783.93	73955.1	74090.44
	urban	233.7714	305.5114	381.135	459.0911	517.3012
	water	12238.03	12238.75	12240.68	12242.44	12243.11
Turkmenistan	cropland	46820.83	47227	47656.37	48067.44	48348.47
	forestland	193.4014	193.9796	194.9352	195.9487	196.4975
	grassland	93784.4	94069.63	94511.67	94969.11	95389.38
	urban	158.6648	247.2095	344.704	445.145	508.928
	water	26491.38	26502.87	26533.38	26565.28	26577.51
Uzbekistan	cropland	91956.36	92275.34	92816.92	93286.59	93791.73
	forestland	853.9229	868.3693	889.7458	912.4687	926.1317
	grassland	94653.65	95156.67	96157.64	97102.01	97683.78
	urban	1429.07	1891.958	2573.311	3294.032	3682.718
	water	8762.076	10483.39	12988.86	15866.1	17271.79





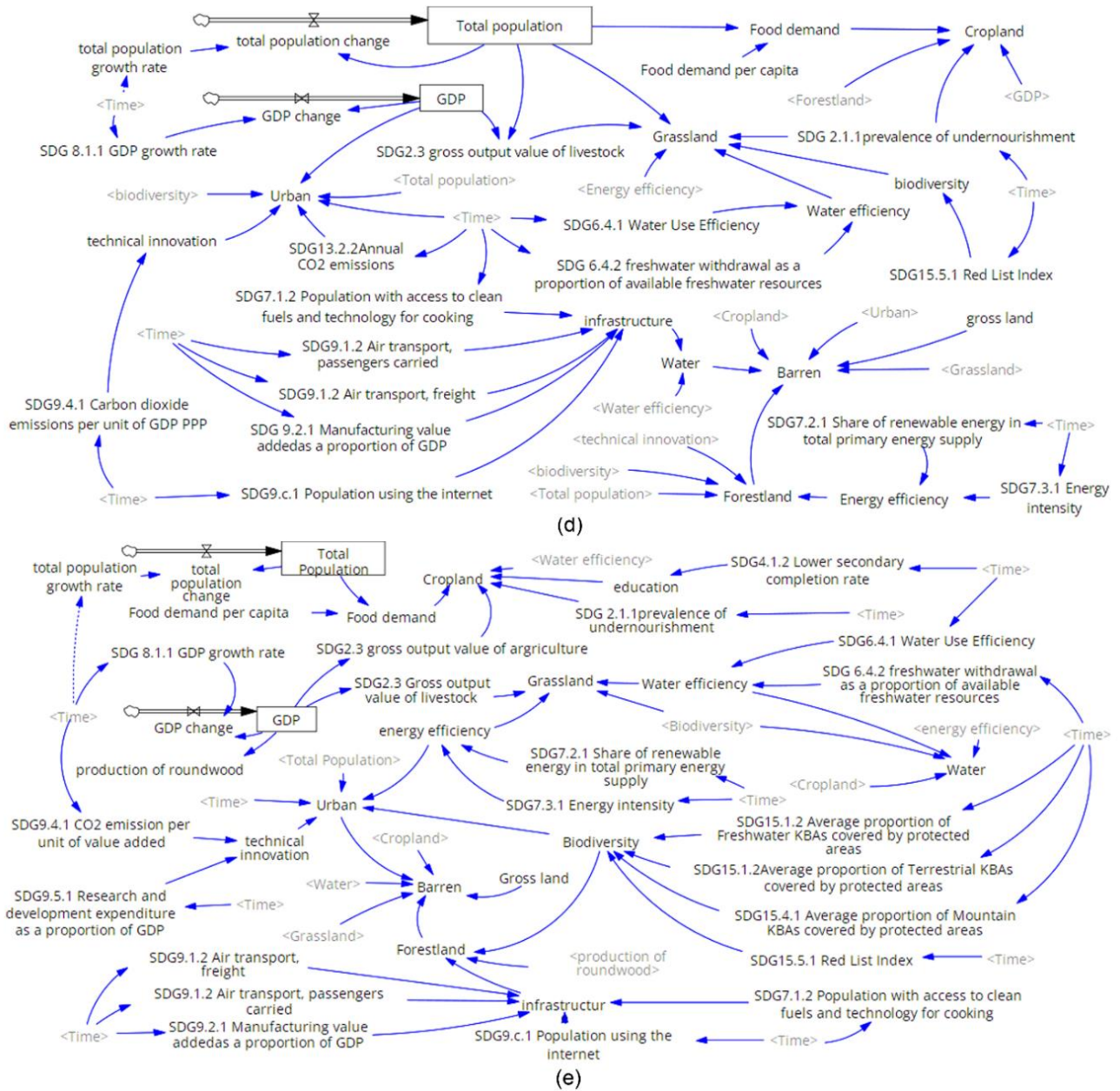


Figure S1. The interactions and feedback among different variables: (a) Kazakhstan, (b) Kyrgyzstan, (c) Tajikistan, (d) Turkmenistan, (e) Uzbekistan.

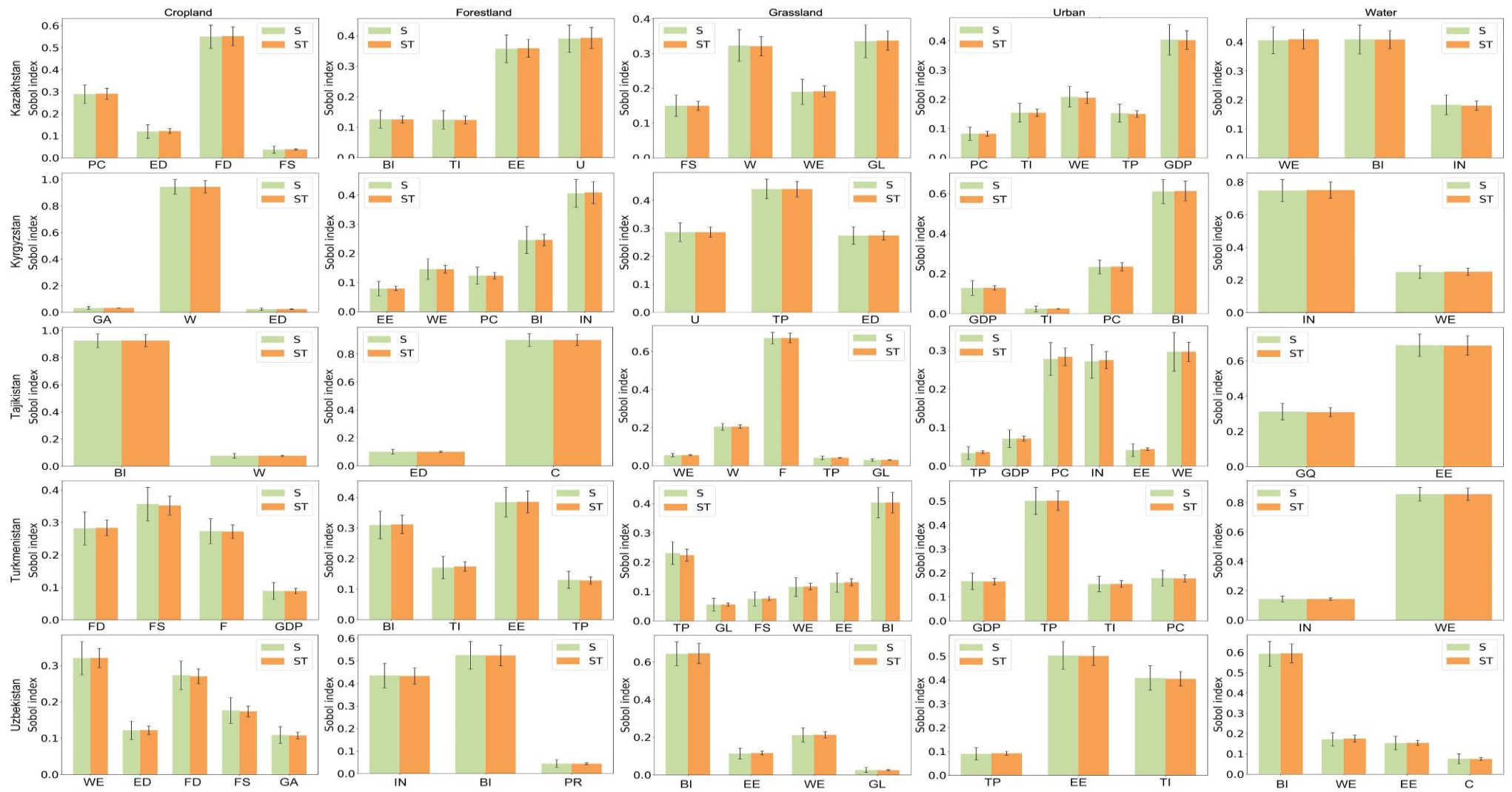




Figure S2. Total sensitivity index ( $ST_i$ ), the first order sensitivity index ( $S_i$ ), and their confidence intervals. FD: food security; IN: infrastructure; ED: education; WE: water efficiency; EE: energy efficiency; TI: technology innovation; PC: pollution control; BI: biodiversity; GA: gross output value of agriculture; GL: gross output value of livestock; GQ: gross output value of aquaculture; PR: production of round wood; C: cropland; F: forestland; U: urban; W: water; TP: total population.

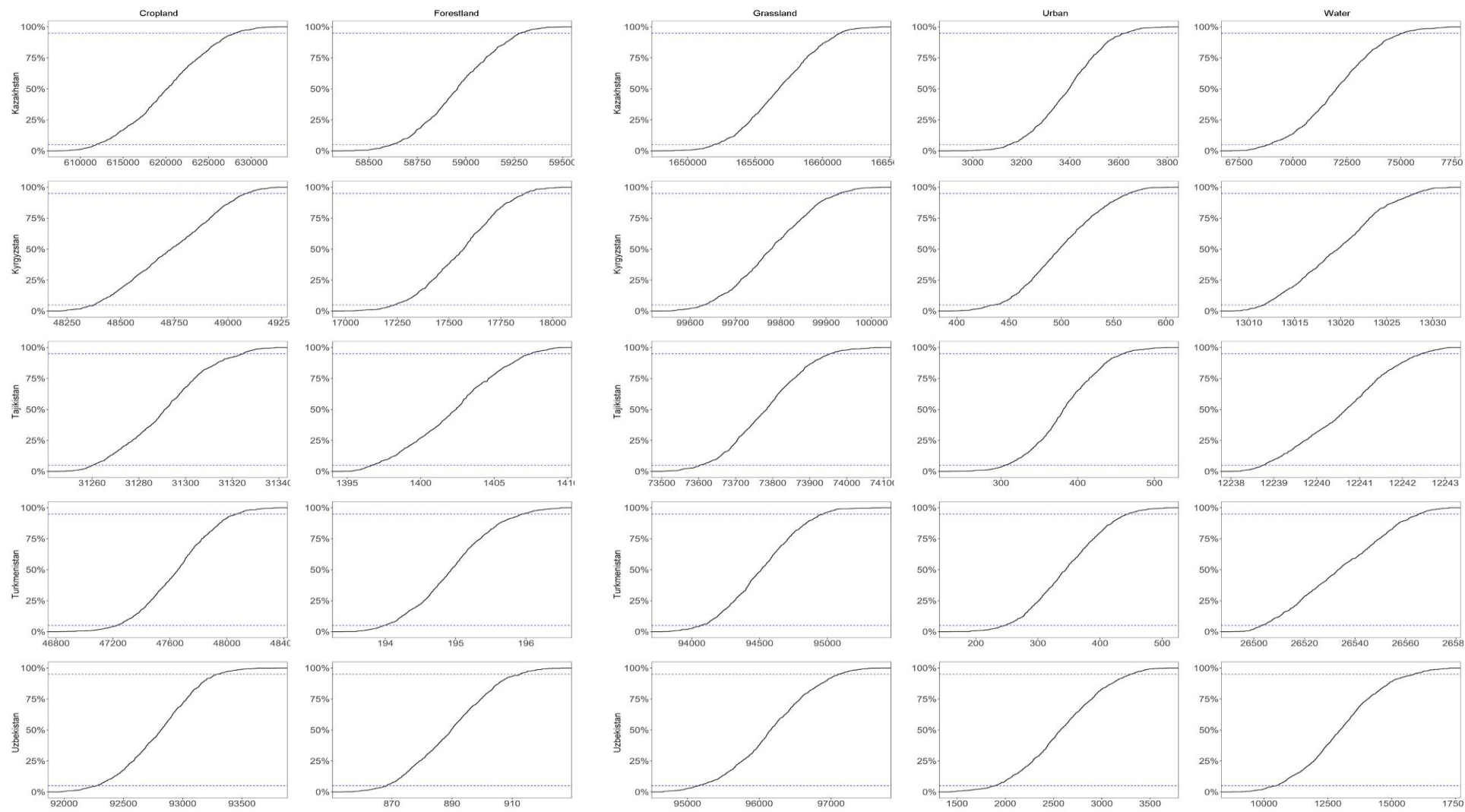


Figure S3. Uncertainty analysis cumulative distribution functions.