

Supplementary Materials

Table S1. The percentage of the area occupied by each land-use type and their descriptions [27].

Land Use Type	Description	Areal Percentage (%)	
		Bolgatanga	Bongo
Cereals	Mono- or mixed-cropping of millet and sorghum	13.5	17.5
Legumes	Groundnuts or the intercropping of groundnuts and bambara beans	10.5	13.5
Maize	Mono-cropping of maize	4	5.6
Rice	Mono-cropping of rice	13.4	20.8
Grassland	Grassland including pastures	14.3	26.5
Mixed vegetation	Mixture of shrubs, trees, savanna and herbs	29.4	5.5
Tree/Forest	Tree cover $\geq 70\%$ or single trees on farm plots	9.3	5
Water bodies	Small reservoirs, dams and rivers	0.3	1.3
Bare/Artificial surfaces	Bare areas, laterite and tarred roads, buildings, hamlets, and rocks	5.3	4.3

Table S2. Agricultural land management options and their description [47].

Current Land Use Type	Land Use Management Option		Description
Cereals	Crop intercropping	Cereal-dominant intercropping (CI)	Conversion of cereal mono-cropping into cereal- dominant intercropping with legume
		Cereal intercropping with mango (fruit tree) (CM)	Conversion of cereal mono-cropping into cereal- dominant intercropping with mango
	Agroforestry	Cereal intercropping with leucaena (fodder tree) (CL)	Conversion of cereal mono-cropping into cereal- dominant intercropping with leucaena
		Stone or soil bunds on cereal (CB)	Establishment of bunds to cereal mono-cropping fields
Maize	Soil conservation	Windbreak on cereal (CW)	Establishment of wind break though planting trees in cereal mono-cropping fields
		Crop intercropping	Conversion of maize mono-cropping into maize- dominant intercropping with legume
	Agroforestry	Maize intercropping with mango (fruit tree) (MM)	Conversion of maize mono-cropping into maize- dominant intercropping with mango
		Maize intercropping with leucaena (fodder tree) (ML)	Conversion of maize mono-cropping into maize- dominant intercropping with leucaena
Legumes	Soil conservation	Stone or soil bunds on maize (MB)	Establishment of bunds to maize mono-cropping fields
		Windbreak on maize (MW)	Establishment of wind break though planting trees in maize mono-cropping fields
	Crop intercropping	Legume-dominant intercropping (LI)	Conversion of legume mono-cropping into legume- dominant intercropping with cereal and maize
		Legume intercropping with mango (fruit tree) (LM)	Conversion of legume mono-cropping into legume- dominant intercropping with mango

		Legume intercropping with leucaena (fodder tree) (LL)	Conversion of legume mono-cropping into legume- dominant intercropping with leucaena
Grassland	Afforestation	Grassland afforestation (GA)	Conversion of grassland into grassland dominant afforested land
Mixed vegetation	Afforestation	Mixed vegetation afforestation (MxA)	Conversion of mixed vegetation into mixed vegetation dominant afforested land

Table S3. Ecosystem services assessment matrix to display the capacity of current land-use types and agricultural land management options to provide ecosystem services in Bolgatanga and Bongo [47]. The values are presented within a scale from 0 (lowest level of provision) to 100 (highest level of provision).

District		Land use type	Food	Fodder	Energy	Construction materials	Marketable products	Water	Erosion control
Bolgatanga	Current	Cereal monocropping	58	7	29	4	30	97	60
		Maize monocropping	52	12	7	4	43	98	62
		Legume monocropping	60	4	3	4	65	97	95
		Rice monocropping	44	1	3	0	70	83	88
		Grassland	1	100	32	37	11	95	98
		Mixed vegetation	19	47	63	63	12	98	100
		Tree/Forest	28	7	57	31	54	97	100
		Bare/Artificial surfaces	0	0	0	0	0	100	0
		Water body	0	0	0	0	0	100	100
		Cereal-dominant intercropping	96	12	34	4	46	30	90
	Agricultural land management option	Maize-dominant intercropping	89	19	8	4	71	31	86
		Legume-dominant intercropping	100	6	4	4	100	28	97
		Grassland afforestation	2	100	53	60	18	20	99
		Mixed vegetation afforestation	27	49	100	100	17	31	100
		Mango agroforestry on cereals	51	7	32	4	36	0	77
		Mango agroforestry on maize	46	11	8	4	52	1	78
		Mango agroforestry on legumes	86	5	4	4	95	6	97
		Leucaena agroforestry on cereals	71	11	39	4	38	8	83
		Leucaena agroforestry on maize	64	19	10	4	55	9	84
		Leucaena agroforestry on legumes	70	7	4	4	85	20	98
		Soil or stone bunds on cereals	94	11	42	4	52	20	87
		Soil or stone bunds on maize	85	18	11	4	75	7	87
		Windbreak on cereals	89	11	43	4	44	32	84
		Windbreak on maize	80	18	11	4	63	33	85
Bongo	Current	Cereal monocropping	63	6	28	6	42	88	71
		Maize monocropping	56	11	6	6	60	89	63
		Legume monocropping	53	16	0	5	71	88	96
		Rice monocropping	51	15	0	0	69	92	92
		Grassland	11	97	11	65	20	89	99
		Mixed vegetation	21	53	68	68	20	94	100
		Tree/Forest	33	13	62	24	60	94	100
		Bare/Artificial surfaces	0	0	0	0	0	89	0
		Water body	0	0	0	0	0	100	100
		Cereal-dominant intercropping	100	9	32	6	65	94	85
		Maize-dominant intercropping	90	15	6	6	92	100	78

Land management option	Legume-dominant intercropping	75	19	0	5	100	14	97
	Grassland afforestation	15	100	17	99	30	0	100
	Mixed vegetation afforestation	29	70	100	100	27	15	100
	Mango agroforestry on cereals	79	7	32	7	61	0	79
	Mango agroforestry on maize	70	13	7	7	86	0	73
	Mango agroforestry on legumes	76	20	0	6	94	30	97
	Leucaena agroforestry on cereals	75	10	37	7	52	19	83
	Leucaena agroforestry on maize	67	16	8	7	73	20	78
	Leucaena agroforestry on legumes	69	25	0	6	90	3	97
	Soil or stone bunds on cereals	99	10	38	8	63	28	91
	Soil or stone bunds on maize	88	16	8	8	89	28	88
	Windbreak on cereals	88	9	39	9	55	28	84
	Windbreak on maize	78	15	9	9	78	28	80

Table S4. Transition probability-based application conditions for land management options [47].

Current Land Use Type	Land Management Option	Transition Probability (%)	Conditions	
			Neighboring Type	Attribute
Cereals	Cereal-dominant intercropping	90	Cereals, legume	Soil type, run-off
Maize	Maize-dominant intercropping	85	Maize, legume	Soil type, run-off
Legumes	Legume-dominant intercropping	80	Cereals, maize, legume	Soil type
Grassland	Grassland afforestation	75	Tree/forest, grassland	Soil type
Mixed vegetation	Mixed vegetation afforestation	80	Tree/forest, mixed vegetation	Soil type
Cereals	Cereal intercropping with mango	75	Cereals, bare/artificial surfaces	Soil type, run-off
Maize	Maize intercropping with mango	70	Maize, bare/artificial surfaces	Soil type, run-off
Legumes	Legume intercropping with mango	90	Legumes, bare/artificial surfaces	Soil type
Cereals	Cereal intercropping with leucaena	80	Cereals	Soil type, run-off
Maize	Maize intercropping with leucaena	75	Maize	Soil type, run-off
Legumes	Legume intercropping with leucaena	90	Legumes	Soil type
Cereals	Stone or soil bunds on cereals	80	Cereals	Soil type, run-off
Maize	Stone or soil bunds on maize	80	Maize	Soil type, run-off
Cereals	Windbreak on cereals	70	Cereals, legumes	Soil type, run-off
Maize	Windbreak on maize	70	Maize, legumes	Soil type, run-off

Table S5. Applied future land-use strategy.

Nº	Future Land Use Strategy	Nº	Future Land Use Strategy	Nº	Future Land Use Strategy
1	CI + MI + LI + GA + MxA	26	CM + MB + LM + GA +MxA	51	CB +MM + LL +GA + MxA
2	CI + MI + LM + GA + MxA	27	CM + MB + LL + GA +MxA	52	CB + ML +LI +GA + MxA

3	CI + MI + LL + GA + MxA	28	CM + MW + LI + GA + MxA	53	CB + ML + LM + GA + MxA
4	CI + MM + LI + GA + MxA	29	CM + MW + LM + GA + MxA	54	CB + ML + LL + GA + MxA
5	CI + MM + LM + GA + MxA	30	CM + MW + LL + GA + MxA	55	CB + MB + LI + GA + MxA
6	CI + MM + LL + GA + MxA	31	CL + MI + LI + GA + MxA	56	CB + MB + LM + GA + MxA
7	CI + ML + LI + GA + MxA	32	CL + MI + LM + GA + MxA	57	CB + MB + LL + GA + MxA
8	CI + ML + LM + GA + MxA	33	CL + MI + LL + GA + MxA	58	CB + MW + LI + GA + MxA
9	CI + ML + LL + GA + MxA	34	CL + MM + LI + GA + MxA	59	CB + MW + LM + GA + MxA
10	CI + MB + LI + GA + MxA	35	CL + MM + LM + GA + MxA	60	CB + MW + LL + GA + MxA
11	CI + MB + LM + GA + MxA	36	CL + MM + LL + GA + MxA	61	CW + MI + LI + GA + MxA
12	CI + MB + LL + GA + MxA	37	CL + ML + LI + GA + MxA	62	CW + MI + LM + GA + MxA
13	CI + MW + LI + GA + MxA	38	CL + ML + LM + GA + MxA	63	CW + MI + LL + GA + MxA
14	CI + MW + LM + GA + MxA	39	CL + ML + LL + GA + MxA	64	CW + MM + LI + GA + MxA
15	CI + MW + LL + GA + MxA	40	CL + MB + LI + GA + MxA	65	CW + MM + LM + GA + MxA
16	CM + MI + LI + GA + MxA	41	CL + MB + LM + GA + MxA	66	CW + MM + LL + GA + MxA
17	CM + MI + LM + GA + MxA	42	CL + MB + LL + GA + MxA	67	CW + ML + LI + GA + MxA
18	CM + MI + LL + GA + MxA	43	CL + MW + LI + GA + MxA	68	CW + ML + LM + GA + MxA
19	CM + MM + LI + GA + MxA	44	CL + MW + LM + GA + MxA	69	CW + ML + LL + GA + MxA
20	CM + MM + LM + GA + MxA	45	CL + MW + LL + GA + MxA	70	CW + MB + LI + GA + MxA
21	CM + MM + LL + GA + MxA	46	CB + MI + LI + GA + MxA	71	CW + MB + LM + GA + MxA
22	CM + ML + LI + GA + MxA	47	CB + MI + LM + GA + MxA	72	CW + MB + LL + GA + MxA
23	CM + ML + LM + GA + MxA	48	CB + MI + LL + GA + MxA	73	CW + MW + LI + GA + MxA
24	CM + ML + LL + GA + MxA	49	CB + MM + LI + GA + MxA	74	CW + MW + LM + GA + MxA
25	CM + MB + LI + GA + MxA	50	CB + MM + LM + GA + MxA	75	CW + MW + LL + GA + MxA

* CI: Cereal-dominant intercropping; MI: Maize-dominant intercropping; LI: Legume-dominant intercropping; GA: Grassland afforestation; MxA: Mixed vegetation afforestation; CM: Cereal intercropping with mango; MM: Maize intercropping with mango; LM: Legume intercropping with mango; CL: Cereal intercropping with leucaena; ML: Maize intercropping with leucaena; LL: Legume intercropping with leucaena; CB: Soil or stone bunds on cereals; MB: Soil or stone bunds on maize; CW: Windbreak on cereals; MW: Windbreak on maize

Table S6. Ecosystem service values provided by land-use strategies in Bolgatanga. Ecosystem service values based on the current land use pattern are used as reference values (R), in blue color. The highest value of each ecosystem service is expressed as green color (the provision of construction materials is excluded as it is equally increased by all land use strategies). Best land-use strategies which have a potential to provide more than three different ES with the highest values are expressed as yellow color.

	Land use strategy																									
Ecosystem services	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Food	30	42	41	39	41	40	38	41	40	39	42	41	39	42	41	37	35	34	35	34	33	36	35	33	37	37
Fodder	31	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	31	31	31	32	31	32	32	32
Energy	33	47	47	47	47	47	47	47	47	47	47	47	47	47	47	46	46	46	46	46	46	46	46	46	46	46
Construction material	28	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
Marketable product	32	40	40	39	40	39	38	40	39	38	40	40	39	40	40	39	39	38	38	38	37	39	38	37	39	39
Water	95	52	50	51	51	49	50	51	49	51	51	49	50	52	50	48	46	48	48	46	47	48	46	48	48	48
Erosion control	85	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	88	88	88	88	88	88	88	88	88	88
	Land use strategy																									
Ecosystem services	R	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Food	30	35	34	36	35	34	39	38	36	38	36	35	38	37	35	39	38	36	39	37	36	42	40	39	40	39
Fodder	31	31	32	32	31	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32

Energy	33	46	46	46	46	46	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Construction material	28	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
Marketable product	32	39	38	39	38	37	39	39	38	39	38	37	39	38	37	39	39	38	39	39	38	41	40	39	40	40
Water	95	46	47	49	47	48	49	47	49	49	47	48	49	47	48	49	47	48	50	48	49	51	49	50	50	48
Erosion control	85	88	88	88	88	88	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	89	89	89
Land use strategy																										
Ecosystem services	R	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Food	30	38	41	40	38	41	40	39	41	40	39	41	40	38	40	38	37	40	39	37	41	40	38	41	39	38
Fodder	31	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Energy	33	47	48	48	47	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Construction material	28	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
Marketable product	32	39	40	40	39	41	40	40	41	40	39	40	39	39	39	39	38	39	39	38	40	40	39	40	39	38
Water	95	50	50	48	50	50	48	50	51	49	50	52	50	52	52	50	51	52	50	51	52	50	51	52	50	52
Erosion control	85	89	89	89	89	89	89	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89

Table S7. Ecosystem service values provided by land-use strategies in Bongo. Ecosystem service values based on the current land-use pattern are used as reference values (R), in blue color. The highest value of each ecosystem service is expressed as green color (the provision of construction materials is excluded as it is equally increased by all land-use strategies). Best land-use strategies which have a potential to provide more than three different ES with the highest values are expressed as yellow color.

		Land use strategy																									
Ecosystem services	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
Food	38	49	49	48	48	48	47	48	48	47	48	49	48	48	48	48	45	45	45	44	45	44	44	44	44	45	
Fodder	36	39	39	39	39	39	39	39	39	39	38	39	39	39	39	39	38	39	39	38	38	39	38	39	39	38	
Energy	15	18	18	18	19	19	19	19	19	19	18	19	19	19	19	19	18	18	18	18	18	18	19	19	19	19	
Construction material	24	34	34	34	34	34	34	34	34	34	32	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	
Marketable product	44	55	54	54	55	54	54	54	54	53	54	54	54	54	54	53	54	54	53	54	53	53	53	53	53	52	54
Water	90	58	60	57	54	56	53	55	56	54	60	57	54	55	57	54	44	46	43	40	42	39	41	43	40	41	
Erosion control	86	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	88	88	88	88	88	88	88	88	88	88	

		Land use strategy																								
Ecosystem services	R	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Food	38	45	44	45	45	44	45	45	44	44	44	43	44	44	43	45	45	44	44	44	43	48	49	48	48	48
Fodder	36	39	39	38	39	39	39	39	40	39	39	39	39	39	40	39	39	40	39	39	40	39	39	40	39	39
Energy	15	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	
Construction material	24	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Marketable product	44	53	53	54	53	52	53	52	52	53	52	51	52	51	51	53	52	51	52	52	51	55	54	53	54	54
Water	90	43	40	41	43	40	47	49	46	43	45	41	43	45	42	44	46	43	44	46	43	48	50	47	44	46
Erosion control	86	88	88	88	88	88	89	89	89	88	88	88	89	89	89	89	89	89	89	89	89	90	90	90	90	90

		Land use strategy																								
Ecosystem services	R	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Food	38	47	47	47	47	48	48	47	48	48	47	47	47	46	46	46	45	46	46	45	47	47	46	46	46	45
Fodder	36	39	39	39	40	39	39	40	39	39	40	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39
Energy	15	19	19	19	19	19	19	19	19	19	19	19	19	19	20	20	20	20	20	20	20	20	20	20	20	
Construction material	24	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Marketable product	44	53	54	53	52	54	54	53	54	53	53	53	53	52	53	52	52	53	52	51	53	52	52	53	52	51
Water	90	43	45	47	44	45	47	44	45	47	44	48	50	47	44	46	43	45	47	44	45	47	44	45	47	44
Erosion control	86	90	90	90	90	90	90	90	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89

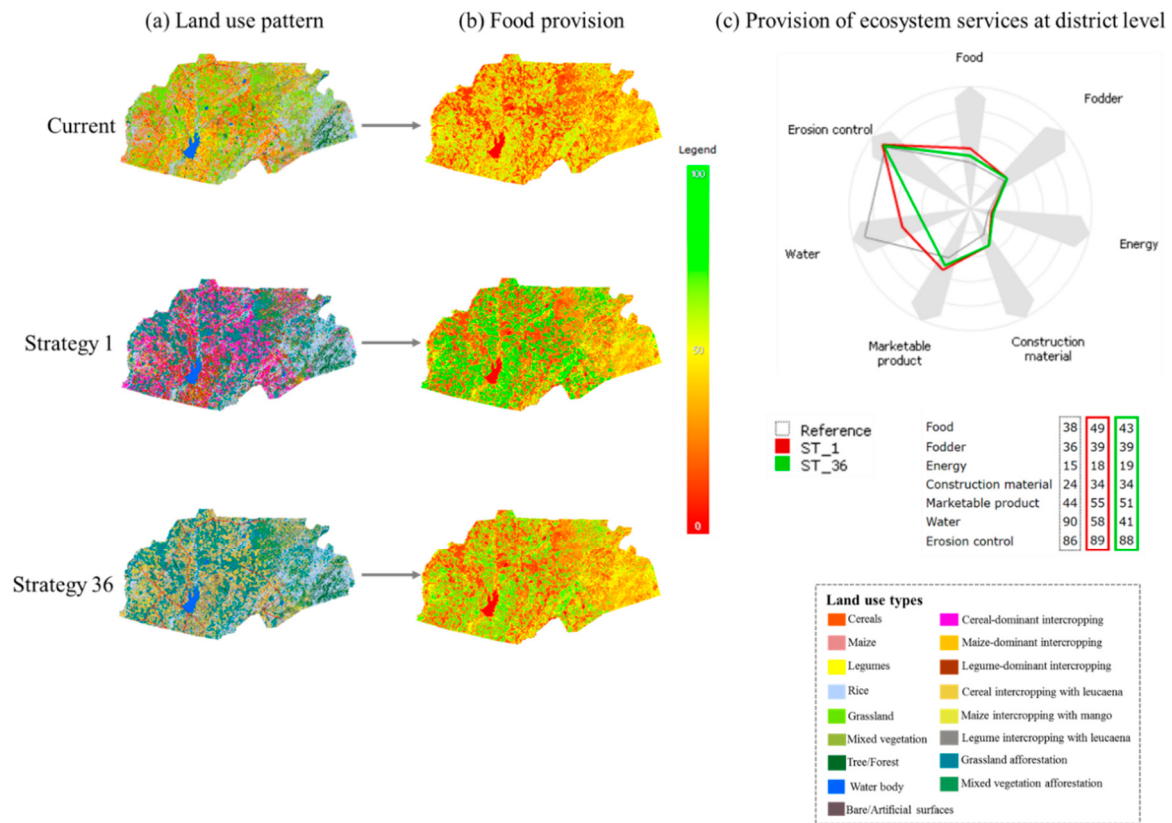


Figure S1. Potential impacts of land-use strategies on the land-use patterns and the provision of ecosystem services in Bongo. Strategy 1 (ST_1) and strategy 36 (ST_36) lead to rearranged land-use patterns (a). The spatial distribution of ecosystem services (e.g., food provision) is changed according to the strategies (b). Impacts on the provision of ecosystem services at district level compared to the current status as reference are expressed in the spider chart and the ecosystem services balance table (c). When these two strategies are compared, strategy 1 is more effective to enhance ecosystem services. The images were captured from GISCAMÉ.