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Land use land cover change and the resilience of social-ecological systems in a sub-region in South west Cameroon

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Abstract The old paradigm of horizontal expansion of agricultural land and built-up areas over highland and lowland ecosystems remains highly prevalent in Cameroon, causing significant changes in LULC and undermining the resilience and sustainability of social-ecological systems. We analysed satellite imagery of 1986 and 2018 to examine the extent and spatial patterns of LULCC in Fako sub-region of Cameroon. In addition, we explored the likelihood of LULCC and magnitude of impact of the drivers and predictors of LULCC in the sub-region by engaging 25 stakeholders in a focus group survey. Other cultivated areas of cropland, built-up, oil palm, and banana plantation covers increased by 21,360 ha (10.5%), 3152 ha (1.6%), 5721 ha (2.8%), and 1823 ha (0.9%), while dense forest, rubber and tea plantation covers decreased by − 44,945 ha (− 22.1%), − 15,557 ha (− 7.7%), and − 110 ha (− 0.1%), respectively, from 1986 to 2018. Most of the deforestation and LULCC was caused by expansion of other cultivated areas of cropland by smallholders, contrary to the widely publicised narrative of agro-industrial and built-up areas expansion. The spatial pattern of LULCC showed that expansion of other cultivated areas of cropland and agro-industrial plantations were highest in the north and east zones, respectively, while expansion of built-up areas and decrease in agro-industrial plantation covers were highest in the central, south and western coastal zones of Fako division. The variations in the spatial patterns of LULCC between the sub-divisions are attributed to differences in rates of population growth and urbanisation, topography, size of farming population, proportion of cultivable land, socio-economic opportunities, and strength and resilience of

Highlights

- Most of the deforestation and LULCC was caused by expansion of other cultivated areas of cropland by smallholders, contrary to the widely publicised narrative of agro-industrial plantation and built-up area expansion from 1986 to 2018.
- Dense forest and rubber plantation covers decreased, while oil palm and banana plantation covers increased, owing to local economics and increase in local and international palm oil demand.
- Spatial patterns of change in LULC classes were highly variable within the sub-region, but common temporal trends in LULCC were observed on the most part.
- Differences in biophysical and socio-economic factors explained the variability in the spatial patterns of LULCC among sub-divisions.
- Changes in LULC decreased with elevation, but increased with nearness to the sea and national road networks.

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local economy. The presence of the Mount Cameroon (4095 m), with high value forests, endemism, and conservation attractiveness restricted increased LULCC with elevation, while LULCC increased with nearness to the sea and national road networks. The likelihood of change from one LULC to oil palm plantation, banana plantation, and other cultivated areas and from rubber plantation, dense forest, lowland grassland to other land uses was 95% and 90%, respectively. Population growth, agricultural and farmland expansion, and infrastructural development were ranked as the three most important drivers of degradation under the business as usual scenario, while sustainable land management, good governance, and reforestation were ranked as the three most important predictors of LULCC reduction under the green economy scenario. In general, production and living space functions significantly increased at the expense of ecological land cover. Prioritising and increasing the legal protection of the mountain and coastal land-boundary ecosystems while providing for production and living land are invaluable for the sustainability of the social-ecological systems in the western highlands of Cameroon.

Keywords Deforestation and Degradation · LULCC · Mount Cameroon · Focus group survey · Scenario analysis · Scenario development · Sustainability · Vulnerability

Introduction

Holistically, landscape as a geographical area is characterised by its biophysical contents of observable, natural, and human-induced characteristics, including ecosystem type and socio-cultural relations to areas at different spatial scales (Erikstad et al., 2015; Simensen et al., 2018). Landscape characterisation and assessment involves systematic, area-covering identification, classification, and/or character assessment of landscapes with the aim of integrating natural and socio-cultural aspects of landscapes and human perceptions, while forming a spatial framework for planning and development (Simensen et al., 2018; Swanwick, 2002). Global landscapes and natural ecosystems have become increasingly vulnerable to human-induced modifications. In particular, natural landscapes in developing countries are undergoing significant transformation by human actions and facing increasing planning and management challenges that undermine their resilience and sustainability.

Decision-making in land use land cover change (LULCC) can be explained, to a large extent, by the socio-economic, climatic, and soil conditions of a location (Malek & Verburg, 2020). In general, human alteration of landscapes comes in the form of LULCC and observed through appearing or disappearing land uses, growing or shrinking land uses, and diffuse or cluster spatial patterns of land use distribution (Ewane & Lee, 2020; Ewane, 2020). Human alterations of the environment by way of urbanisation, agricultural expansion, logging and migration, and biophysical stressors such as climate change, forest loss, and multiple degradation events have tremendous effects on the resilience and sustainability of social-ecological systems (SES) through degradation of ecosystem services and massive shifts in land use (Lambin & Meyfroidt, 2011).

SES are integrated complex and adaptive systems, in which social and ecological sub-systems are coupled and interdependent, each a function of the other, expressed in a series of mutual feedback relationships (Berkes et al., 2003; Folke, 2006), and emphasising two sub-systems (social system and ecological system) of equal status and importance (Berkes, 2017). Resilience, adaptability, and transformability are three related attributes of SES that determine their dynamics and future trajectories (Folke et al., 2010; Walker et al., 2004). Resilience is the capacity of a system to buffer or absorb disturbances and re-organise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks, by changing the variables and processes that control behaviour (Berkes & Folke, 1998, Walker et al., 2004; Walker, 2020). Resilience and sustainability of SES may be appreciated by their survival over extended periods of time. It emphasises nonlinearity dynamics, thresholds, uncertainty, and unpredictability and encompasses how periods of gradual change interplay with periods of rapid change and how such dynamics interact across temporal and spatial scales (Folke, 2006). Transformability refers to fundamentally altering the nature of a system (Walker et al., 2004). In this study, vulnerability is conceptualised as the inability of a land use land cover (LULC) class or ecological system to cope with multiple biophysical and socio-economic stressors and influenced by factors such as location, local economics, and level of development.

Landscapes and their ecosystems are influenced by the institutions that govern their use and by the indigenous communities dependent on the forest resources (Folke, 2006). For example, the resilience and sustainability of forests as ecological system are impacted by local communities and government forest management institutions as social systems, who use the forest resources to sustain livelihoods and the local and national economy. Greater vulnerability to deforestation and forest degradation by local communities and government forest management institutions due to poor forest governance, for example, reduces the resilience of forests to adapt to increased human and natural stressors and undermines their structural and functional sustainability. Local communities interact with ecosystems on a daily basis and over long periods of time, and thus, possess the most relevant knowledge of resource and ecosystem dynamics, together with associated management practices (Berkes et al., 2000; Fabricius & Koch, 2004). The SES approach incorporates knowledge systems, including local and indigenous knowledge held by resource-based communities and scientific knowledge held by government resource managers (Folke, 2006). In addition, it further incorporates institutional systems of rules and norms, linking social groups and their resource base (Ostrom, 1990), and governance systems from management to policy levels (Kooiman, 2003).

The spatio-temporal patterns, processes, and causes of LULCC are still not well understood in land system science (Rounsevell et al., 2012; Verburg et al., 2013; Sun, 2018). In general, LULCC reduces biodiversity and the ability of ecosystems to provide some services today and in the future, necessitating the urgent need for research to effectively plan and guide future land use changes in order to prevent further losses of ecosystem services and functions (Rocha et al., 2020). Changes in SES can be better understood using LULCC, accompanied by qualitative research about environmental and social perceptions (Kohler et al., 2015). Stakeholders play an important role in scenario analysis, especially for assessing and modelling future LULCC and their possible impacts (Capitani et al., 2016; Hanspach et al., 2014; Lamarque et al., 2013; Rosenberg et al., 2014; Swetnam et al., 2011).

The old paradigm of horizontal expansion of agricultural land and built-up areas over highland and lowland ecosystems remains the norm in Cameroon, causing significant changes in LULC and undermining the resilience and sustainability of SES along its western highland region, where the study area of Fako division is located. The biophysical landscape of the study area is composed of important lowland agricultural estates, mountain forests, and coastal mangrove ecological systems across its five sub-divisions, which are undergoing increasing transformation. In this study, the concept of SES was used to understand human–environment interactions and outcome, while that of LULCC was used to understand the spatio-temporal patterns and processes of change related to biophysical and socio-economic factors in Fako division from 1986 to 2018. Carodenuto et al. (2015) developed and tested a methodological framework for assessing the drivers and underlying causes of deforestation in Fako division of Cameroon. Ewane (2021) reported increasing trend in forest cover loss in four community forests located in the sub-region from 2001 to 2018, due mainly to agricultural expansion and illegal logging activities, incentivise by poor forest governance actions. Oil palm driven deforestation is still very high in Cameroon, where 67% of oil palm expansion from 2000 to 2015 occurred at the expense of forest in the South west region (Ordway et al., 2017, 2019). No study has combined LULCC mapping and stakeholder perceptions of current and future environmental impact scenarios to study SES, particularly in the study area in Cameroon.

The main objective of this study is to explore LULCC and expert stakeholder perceptions of changing SES in Fako division, South west region of Cameroon. Specifically, the study aims (1) to explore the extent of LULCC and evolving spatial patterns and trajectories of the SES from 1986 to 2018, (2) to analyse the vulnerability to changes in LULC classes in the sub-region based on stakeholder perceptions, (3) to explore the most important socio-economic drivers and predictors of increase and reduction in LULCC, and (4) to develop alternative scenarios as guide to future sustainable land use planning and green economy development in the sub-region. The study is guided by the hypotheses that (1) the conversion of natural vegetation cover of forests and grassland generally decreases with elevation and proximity to the sea and (2) horizontal expansion of agricultural land

and built-up areas (urban sprawl) are the dominant modes of agricultural and urban growth, respectively, in developing countries.

Methods

Study area

The study area is Fako division (Fig. 1), one of the six divisions or sub-regions in the South west region of Cameroon. It comprises of five main sub-divisions; namely, Buea, Limbe, Tiko, Muyuka, and West Coast sub-divisions (Fig. 1). The study area is geographically located between latitude 3° 57′ 17″ to 4° 09′ 72″ N and longitude 8° 58′ 49″ to 9° 27′ 86″ E. Fako division has a surface area of 2031.93km^2 and a population density of 229.5/km^2 from 1987 to 2005 compared to a national average of 56.34/km^2. The populations of Buea, Limbe, Muyuka, Tiko, and West Coast sub-divisions, respectively, stood at 131,325, 118,210, 86,268, 117,884, and 12,725 inhabitants in 2005. The surface areas of Buea, Limbe, Muyuka, Tiko,

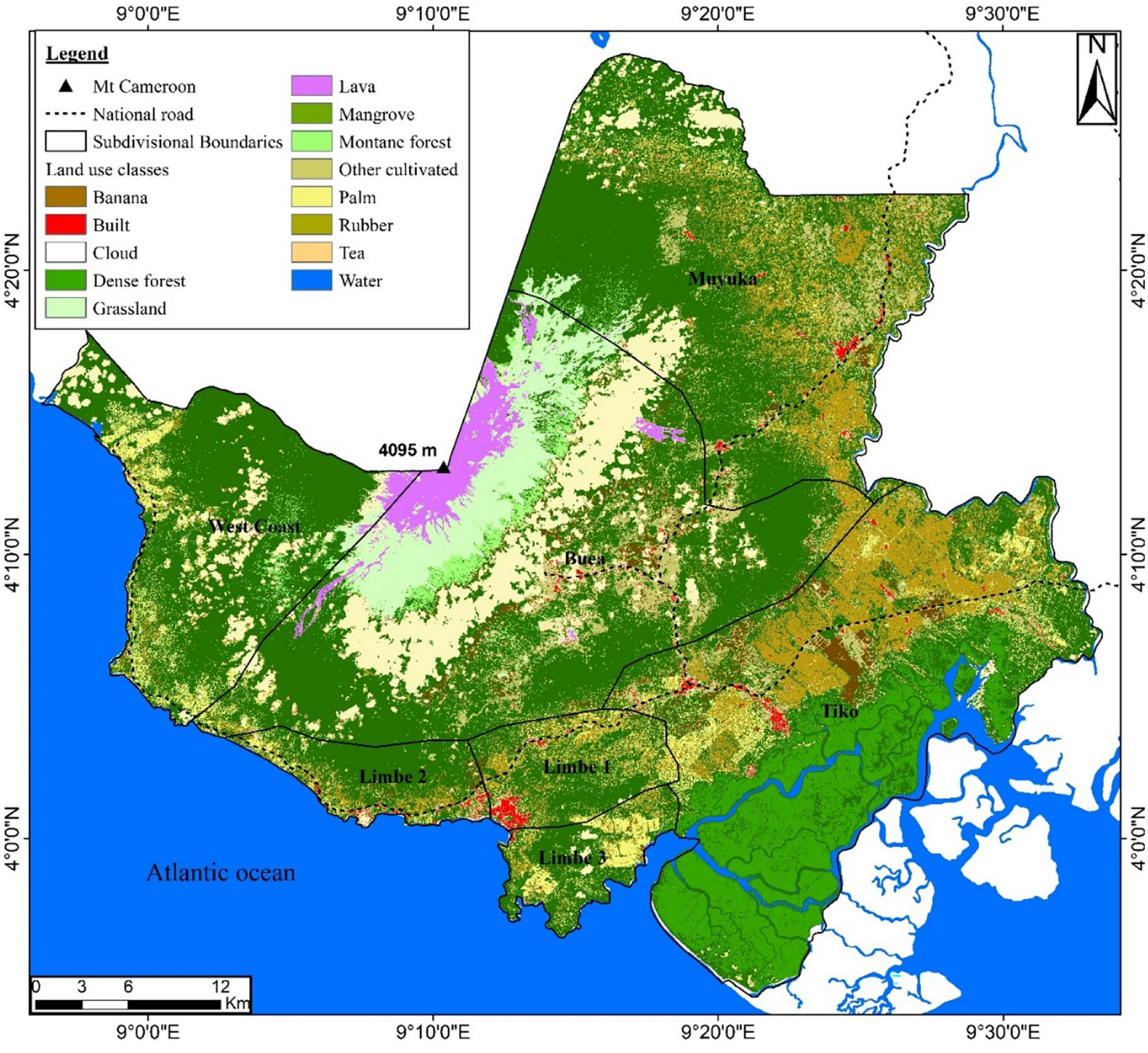

Fig. 1 Land use land cover map of Fako division of the South west region of Cameroon for 1986

and West Coast sub-divisions, respectively, stands at 591.2km^2, 242.8km^2, 479.9km^2, 472.3km^2, and 245.7km^2 with population densities of 222.1/km^2, 486.8/km^2, 179.8/km^2, 249.6km^2, and 51.8/km^2, respectively. The population of Fako division has increased significantly and almost doubled over the last 30 years, that is, from 248,032 inhabitants in 1987 to 466,412 inhabitants in 2005, with a calculated annual population growth rate of 4.89%, compared to a national average of 2.59% (National Institute of Statistics of Cameroon, 2006).

The sub-region falls within the tropical rainforest zone with an equatorial monsoon climate. Annual rainfall ranges from 2000 to 4000 mm, attributed to the effect of the forested Mount Cameroon (4095 m above sea level), which intercepts wet air masses and its proximity to the Atlantic Coast of Cameroon. The highest rainfall comes between July and September with monthly amounts ranging from 400 to 500 mm, particularly in Limbe, Buea, and West Coast sub-divisions, with the latter receiving even higher monthly and annual rainfall. The high annual rainfall and historical volcanic eruption of lava and ash contributes to the very high soil fertility in the sub-region, which is highly exploited for small-, medium-, and large-scale agricultural production activities. The sub-region presents the best example of historically human-induced progressive conversion and changes in lowland dense forest and grassland cover in Cameroon, predominantly for plantation agriculture, a legacy of German colonial administration. Current urban sprawl dominated by housing development and expanding arable cropland and agro-industrial plantations in peri-urban areas are significantly transforming the landscape and producing varied social-ecological systems in Fako Division.

Data sources

Land use land cover data

A combination of Multispectral Scanner 3 (MSS), Landsat Enhanced Thematic Mapper Plus 7 (ETM+), and Landsat Operational Land Imager 8 (OLI) was used to obtain the LULC and LULCC data of Fako division, in the South west region of Cameroon (http://glovis.usgs.gov/), supplemented with Google Earth Imagery data. Details of the methods of LULCC data collection and the general procedure for acquisition of the LULC maps and classification of LULC classes can be found in Ewane and Lee (2020) and Ewane (2020). The LULC classes were identified before their mapping because it is important to identify corresponding LULC classes to be mapped, aiming at creating classes that are clearly distinct (Carodenuto et al., 2015). The information on the classification and specification of the satellite data for the acquisition of the LULC maps is presented in Table 1. The study is based on the biophysical landscape characterisation approach using statistical analyses to obtain LULC data in order to identify gradients of variation in the presence and /or abundance of landscape diversity (Simenssen et al., 2018). The LULC of the study area is dominated by plantations of banana, tea, rubber, oil palm, and natural vegetation cover of montane forest, grassland, dense forest, mangrove, urban areas, water, other (food) crop cultivated areas, and lava/rock areas (Figs. 1 and 2) with highly varied area cover (Table 2). The land cover statistics for oil palm plantations include land covered by formal agro-industrial plantations and informal non-industrial smallholder oil palm plantations in the sub-region.

The study used two LULC maps of Fako division for the period 1986 (Fig. 1) and 2018 (Fig. 2), representing the Mount Cameroon landscape. A LULC

Table 1 Classification and specification of satellite data for the acquisition of the LULC maps

Landsat	Sensor	Date	Spectral bands	Spatial Resolution (m)	Row number	Path number
3	MSS	14/01/1986	6	30	057	187
7	ETM+	18/03//2000	6	30	057	187
8	OLI	12/01/2018	6	30	057	187

MSS Multispectral Scanner, *ETM+* Enhanced Thematic Mapper Plus, *OLI* Operational Land Imager

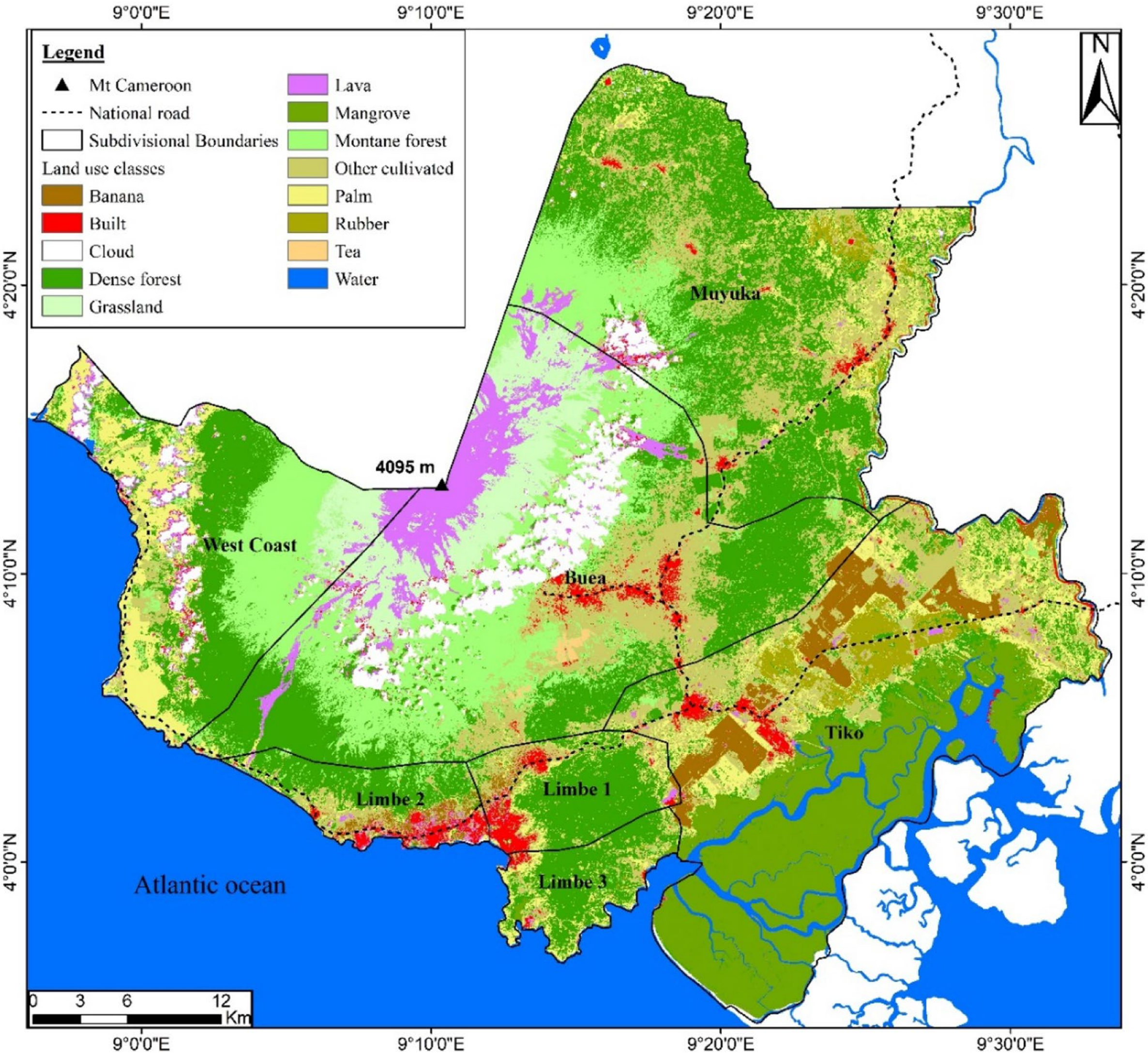

Fig. 2 Land use land cover map of Fako division of the South west region of Cameroon for 2018

map of 2000 was produced but not used in the analysis in this study due to overwhelming cloud cover. Cloud is an important cover in the study area due to its nearness to the Atlantic Coast and presence of Mount Cameroon. The presence of these biophysical features produces permanent cloud cover in areas along the Cameroon's Atlantic Coast and mainly contributes to the low-quality satellite images of such locations in Cameroon from 2000 to 2012 (Verheggen et al., 2016).

Focus group survey data

This exploratory study followed a stakeholder-driven scenario development during multi-stakeholder questionnaire administration in focus group discussion sessions held in Buea, headquarter of Fako division. Focus group survey is a form of group interview that capitalises on communication and deliberation between participants to generate data based on a group consensus (Kitzinger, 1995). Danielsen et al. (2014)

Table 2 Land use land cover change for Buea sub-division within Fako division of Cameroon from 1986 to 2018

LULC class for Buea	1986		2018		Change in area from 1986 to 2018		LULCC from 1986 to 2018 (%)	Annual rate of LULCC from 1986 to 2018 (%)
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)		
Mangrove forest	50	0.08	1	0.002	−49	−98	−0.08	−0.003
Oil palm plantation	931	1.57	370	0.626	−561	−60.3	−0.95	−0.03
Banana plantation	1448	2.45	148	0.250	−1300	−89.8	−2.20	−0.07
Rubber plantation	639	1.08	2	0.003	−637	−99.7	−1.08	−0.03
Tea plantation	395	0.67	294	0.497	−101	−25.6	−0.17	−0.01
Clouds	10,968	18.6	5719	9.673	−5249	−47.9	−8.88	−0.28
Water	1	0.00	0	0.000	−1	−100	−0.002	−0.0001
Lava/Rock	4057	6.86	6560	11.01	2503	61.7	4.23	0.13
Grassland	8044	13.6	8388	14.2	344	4.3	0.58	0.02
Dense forest	25,937	43.9	12,736	21.5	−13,201	−50.9	−22.3	−0.70
Montane forest	2150	3.64	14,850	25.1	12,700	590.7	21.5	0.67
Other cultivated areas	4299	7.27	8810	14.9	4511	104.9	7.63	0.24
Built-up areas	202	0.34	1245	2.11	1043	516.3	1.76	0.06

provided recommendations for how to increase the ability of community focus groups to provide natural resource management data that scientists would consider reliable. We selected a total of 25 expert stakeholders, 5 persons per focus group in each sub-division, drawn from available administrative units. The stakeholders comprised of staff of regional governmental agencies that govern and manage land, forests, environment, agriculture, and water, Institute of Agricultural Research for Development (IRAD), University of Buea, civil society organisations, and municipal councils, who are grounded with local socio-economic development knowledge within each sub-division. Stakeholders play an important role in scenario analysis, especially for assessing and modelling future LULCC and their possible impacts (Capitani et al., 2016; Hanspach et al., 2014; Lamarque et al., 2013; Rosenberg et al., 2014; Swetnam et al., 2011).

The identification and selection of participants for the stakeholder focus group interview took into consideration the participant's knowledge of evolving land uses, their drivers, and indicators, and demonstrated interest, willingness, and readiness in local knowledge sharing and collaborative learning. The survey method involved the selection of economic sectors and development of qualitative and semi-quantitative sector trajectories; assessing the likelihood of LULCC, identifying the drivers, indicators, and the spatial patterns. In the stakeholder scenario analysis, we used the business as usual scenario (BUS) and green economy scenario (GES). In the BUS, continuous expansion of human degradation activities such as land use conversion to agricultural uses impacts forests, woodland, and wetlands, with no productivity gain expected. In the GES, decreasing deforestation and degradation with increasing productivity and implementation of payment for ecosystem service schemes is envisaged (Capitani et al., 2016).

In this study, we identified 8 socio-economic drivers of LULCC specific to Cameroon, including population growth, agricultural and cropland expansion, biomass energy (fuelwood and charcoal) exploitation, livestock grazing, commercial logging/timber exploitation (legal and illegal), bushfires (human-set fire), infrastructural development, and mining expansion. All the 25 participants in the focus groups were presented with these socio-economic sectors most relevant to local livelihoods and national economy. It is invaluable to define a representation of the proximate and most important groups of drivers and underlying causes of deforestation and LULCC (Carodenuto et al., 2015). In addition, we identified a total of 23 indicators for the economic sector drivers of BUS and 26 indicators for the economic sector drivers of GES (Appendix 2). The drivers and indicators of LULCC and LULC maps were presented to each focus group participants for deliberation. Thus, in each separate focus group session, the participants discussed the

Table 3 Land use land cover change for Limbe sub-division within Fako division of Cameroon from 1986 to 2018

LULC Class for Limbe	1986		2018		Change in area from 1986 to 2018		LULCC from 1986 to 2018 (%)	Annual rate of LULCC from 1986 to 2018 (%)
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)		
Mangrove forest	4278	17.6	5337	22	1059	24.8	4.36	0.14
Oil palm plantation	2838	11.7	2187	9.01	− 651	− 22.9	− 2.68	− 0.08
Banana plantation	312	1.28	708	2.92	396	126.9	1.63	0.05
Rubber plantation	2220	9.14	49	0.20	− 2171	− 97.8	− 8.94	− 0.28
Tea plantation	5	0.02	0	0.00	− 5	− 100	− 0.02	− 0.0006
Clouds	445	1.83	3	0.01	− 442	− 99.3	− 1.82	− 0.06
Water	229	0.94	474	1.95	245	107	1.01	0.03
Lava/Rock	6	0.02	453	1.87	447	7450	1.84	0.06
Grassland	2	0.01	0	0.00	− 2	− 100	− 0.01	− 0.0003
Dense forest	12,675	52.19	9818	40.4	− 2857	− 22.5	− 11.8	− 0.37
Montane forest	3	0.01	424	1.75	421	14,033	1.73	0.05
Other cultivated areas	819	3.37	3309	13.6	2490	304	10.3	0.32
Built-up areas	455	1.87	1522	6.27	1067	234.5	4.39	0.14

LULCC socio-economic drivers, their indicators, trade-offs, and interrelationships with environmental variables and envisaged alternative futures of degradation of each LULC class under BUS and GES conditions.

In the second task, focus groups were presented structured closed-ended questionnaires containing information on ranking of biophysical and socio-economic variables based on a likelihood scale. For each conversion from one LULC class to another, participants evaluated its likelihood on a scale ranging from 1 (“extremely likely”) to 7 (“extremely unlikely”) and reported where changes would likely occur in the different sub-divisional landscapes. A total of 22 biophysical and socio-economic evaluation indicators of the likelihood assessment of a possible change from one LULC type to another were grouped under

Table 4 Land use land cover change for Tiko sub-division within Fako division of Cameroon from 1986 to 2018

LULC Class for Tiko	1986		2018		Change in area from 1986 to 2018		LULCC from 1986 to 2018 (%)	Annual rate of LULCC from 1986 to 2018 (%)
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)		
Mangrove forest	10,502	22.5	14,613	30.9	4111	39.14	8.5	0.31
Oil palm plantation	3785	8.1	6303	13.3	2518	66.53	5.2	0.18
Banana plantation	1707	3.7	4592	9.7	2885	169.01	6.1	0.20
Rubber plantation	8915	19.1	2757	5.8	− 6158	− 69.07	− 13.2	− 0.37
Tea plantation	0	0.0	0	0.0	0	0.00	0.0	0.00
Clouds	3385	7.2	2	0.0	− 3383	− 99.94	− 7.2	− 0.21
Water	2049	4.4	3304	7.0	1255	61.25	2.6	0.09
Lava/Rock	5	0.0	381	0.8	376	7520	0.8	0.02
Grassland	22	0.0	0	0.0	− 22	− 100	0.0	− 0.001
Dense forest	16,221	34.7	5179	11.0	− 11,042	− 68.07	− 23.8	− 0.67
Montane forest	0	0.0	368	0.8	368	36,800	0.8	0.02
Other cultivated areas	3061	6.6	8723	18.5	5662	184.97	11.9	0.39
Built-up areas	449	1.0	1005	2.1	556	123.83	1.2	0.04

Table 5 Land use land cover change for Muyuka sub-division within Fako division of Cameroon from 1986 to 2018

LULC class for Muyuka	1986		2018		Change in area from 1986 to 2018		LULCC from 1986 to 2018 (%)	Annual rate of LULCC from 1986 to 2018 (%)
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)		
Mangrove forest	137	0.29	188	0.39	51	37.2	0.11	0.003
Oil palm plantation	2258	4.71	4278	8.91	2020	89.5	4.21	0.13
Banana plantation	325	0.68	155	0.32	− 170	− 52.3	− 0.35	− 0.01
Rubber plantation	6832	14.24	778	1.62	− 6054	− 88.6	− 12.62	− 0.39
Tea plantation	3	0.01	0	0.00	− 3	− 100.0	− 0.01	− 0.0002
Clouds	3166	6.60	869	1.81	− 2297	− 72.6	− 4.79	− 0.15
Water	0	0.00	0	0.00	0	0.0	0.00	0.00
Lava/Rock	15	0.03	802	1.67	787	5246.7	1.64	0.05
Grassland	990	2.06	430	0.90	− 560	− 56.6	− 1.17	− 0.04
Dense forest	29,618	61.72	6859	14.29	− 22,759	− 76.8	− 47.43	− 1.48
Montane forest	276	0.58	21,182	44.14	20,906	7574.6	43.57	1.36
Other cultivated areas	4028	8.39	11,786	24.56	7758	192.6	16.17	0.51
Built-up areas	340	0.71	661	1.38	321	94.4	0.67	0.02

three categories: production (5 indicators), living (8 indicators), and ecological (9 indicators) land functions (Appendix 3). The participants ranked (from 1 to n, where 1 is the lowest and n is the highest rank) the specific drivers and their indicators that drive LULCC under the BUS and GES by their relative importance. The participants also ranked the drivers having the highest or lowest impact on current LULCC increase or reduction in the different sub-divisions.

During the focus groups, participants were encouraged to use information such as specific sites of potential LULCC such as administrative units or gazetted sites, or biophysical factors associated with them such as nearness to mountain, sea and national road network, proportion of cultivable land, endemism, conservation attraction, size of farm labour, and business growth attractions, among others, in the ranking exercises. The stakeholders discussed their different perspectives to generate consensus and harmonise

Table 6 Land use land cover change for West Coast sub-division within Fako division of Cameroon from 1986 to 2018

LULC class for West Coast	1986		2018		Change in area from 1986 to 2018		LULCC from 1986 to 2018 (%)	Annual rate of LULCC from 1986 to 2018 (%)
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)		
Mangrove forest	4	0.02	15	0.06	11	275	0.04	0.001
Oil palm plantation	2985	12.15	5381	21.90	2396	80.3	9.75	0.30
Banana plantation	13	0.05	24	0.10	11	84.6	0.04	0.001
Rubber plantation	570	2.32	33	0.13	− 537	− 94.2	− 2.19	− 0.07
Tea plantation	1	0.00	0	0.00	− 1	− 100	0.00	− 0.0001
Clouds	2613	10.64	1280	5.21	− 1333	− 51.0	− 5.43	− 0.17
Water	12	0.05	13	0.05	1	8.33	0.00	0.0001
Lava/Rock	7	0.03	859	3.50	852	12,171	3.47	0.11
Grassland	4	0.02	869	3.54	865	21,625	3.52	0.11
Dense forest	17,565	71.49	6232	25.36	− 11,333	− 64.5	− 46.13	− 1.44
Montane forest	366	1.49	8156	33.19	7790	2128.4	31.70	0.99
Other cultivated areas	341	1.39	1456	5.93	1115	327.0	4.54	0.14
Built-up areas	88	0.36	253	1.03	165	187.5	0.67	0.02

Table 7 Land use land cover classes combined for the five sub-divisions within Fako division of Cameroon from 1986 to 2018

LULC class name for Fako division	1986		2018		Change in area from 1986 to 2018		LULCC from 1986 to 2018 (%)	Annual rate of LULCC from 1986 to 2018 (%)
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)		
Mangrove forest	14,971	7.37	20,155	9.92	5184	2.55	2.6	0.08
Oil palm plantation	12,797	6.30	18,518	9.11	5721	2.82	2.8	0.09
Banana plantation	3805	1.87	5628	2.77	1823	0.90	0.9	0.03
Rubber plantation	19,175	9.44	3618	1.78	−15,557	−7.66	−7.7	−0.24
Tea plantation	404	0.20	294	0.14	−110	−0.05	−0.1	−0.002
Water	2291	1.13	3790	1.87	1499	0.74	0.7	0.02
Lava/Rock	4090	2.01	9055	4.46	4965	2.44	2.4	0.08
Grassland	9062	4.46	9686	4.77	624	0.31	0.3	0.01
Dense forest	102,016	50.2	57,071	28.09	−44,945	−22.1	−22.1	−0.69
Montane forest	2795	1.38	28,733	14.14	25,938	12.8	12.8	0.40
Clouds	17,704	8.71	8049	3.96	−9655	−4.75	−4.8	−0.15
Other cultivated areas	12,548	6.18	33,908	16.69	21,360	10.5	10.5	0.33
Built-up areas	1534	0.75	4686	2.31	3152	1.55	1.6	0.05

visions within each sub-division and in the sub-region. Each expert focus group discussion session was led by a facilitator, who took notes and ensure a collective understanding of the objectives, without actively participating in the discussion. The structured questions were designed to explore expert stakeholder observations, perceptions, and future scenarios of either continuous resource degradation or improved resource governance, sustainable land use planning and green economy development based on the current activities and practices in the sub-region.

Data analysis

Quantitative analyses for LULCC assessment statistics and understanding of evolving spatial patterns and trajectories in the sub-region from 1986 to 2018 were performed using ArcGIS 10.2. Data on the likelihood for potential changes from one LULC class to another in each of the sub-divisions was analysed using a likelihood probability ratio scale to locate the points of similarity or dissimilarity of variables within the sub-divisions and sub-region. We used the likelihood probability ratio scale of 0.95–1.0 (Extremely likely), 0.9–1.0 (Very likely), 0.66–1.0 (Likely), 0.50-1.0 (Possible), 0.33–1.0 (Unlikely), 0.10–1.0 (Very unlikely), and 0.05–1.0 (Extremely unlikely). This vulnerability or likelihood scale enabled stakeholders to deliberate and negotiate uncertainty and confidence intervals of variables in the LULCC and scenario analysis framework.

Data from stakeholder ranking of the drivers and indicators of LULCC under the BUS and GES were also analysed using radar charts while statistically significant differences in the stakeholder perceptions ranking across the five sub-divisions was detected using Friedman test statistics in XLSTAT version 2020. In a radar chart, the data length of a spoke is proportional to the magnitude of the variable for the data point starting from a center point of 0.0 relative to the maximum magnitude point of 1.0 of the variable across all the data points (Chamber et al., 1983). Results of the mean scores of the likelihood analysis of the LULCC were presented in LULC maps showing degradation vulnerability of each LULC class under BUS and GES, using ArcGIS 10.2.

Results

Spatial distribution of land use land cover change assessment

The spatial distribution of LULCC among the five sub-divisions in the sub-region showed appreciable spatial and temporal variability but with somehow similar trends from 1986 to 2018 (Appendix 1). In Buea sub-division, dense forest cover decreased from 25,937 to 12,736 ha (−50.9%), that is, by 22.3% of the total land surface area, and at an annual rate of 0.7% (Table 2). Other cultivated areas of cropland cover increased from 4299 to 8810 ha (104.9%), and built-up area cover increased from 202 to 1245 ha (516.3%), respectively, that is, by 7.63% and 1.76% of the total land surface area, and at an annual rate of 0.24% and 0.06%. Banana, oil palm, rubber, and tea plantations cover decreased by 2.20%, 0.95%, 1.08%, and 0.17%, respectively, of total land surface area and together with water and mangrove forest areas, were mainly converted to other cultivated areas of cropland and built-up areas in the post 2000s.

In Limbe sub-division, dense forest cover decreased from 12,675 to 9818 ha (−22.5%), that is, by 11.76% of the total land surface area, and at an average annual rate of 0.37% from 1986 to 2018 (Table 3). Other cultivated areas of cropland cover increased from 819 to 3309 ha (304%), and built-up area cover increased from 455 to 1522 ha (234.5%), respectively, that is, by 10.3% and 4.39% of the total land surface area, and at an annual average rate of 0.32% and 0.14%. The area cover of oil palm and rubber plantations decreased by 2.68% and 8.94%, respectively, while banana plantation cover increased by 1.63% of total land surface area, with the former mainly converted to other cultivated area of cropland and built-up areas in the post 2000s.

In Tiko sub-division, dense forest cover decreased from 16,221 to 5179 ha (−68.1%), that is, by 23.8% of the total land surface area, and at an average annual rate of 0.67% from 1986 to 2018 (Table 4). Other cultivated area of cropland cover increased from 3061 to 8723 ha (185%), and built-up area cover increased from 449 to 1005 ha (183.9%), respectively, that is, by 11.9%, and 1.2% of the total land surface area, and at an annual rate of 0.39% and 0.04%. The area cover of oil palm and banana plantations increased by 6.1% and 5.2%, respectively, while that of rubber plantation decreased by 13.2% of the total land surface area, indicative of differences in the export market prices for these commodities.

In Muyuka sub-division, dense forest cover decreased from 29,618 to 6859 ha (−76.8%), that is, by 47.4% of the total land surface area, and at an average annual rate of 1.48% from 1986 to 2018 (Table 5). Other cultivated areas of cropland increased from 4028 to 11,786 ha (192.6%), and built-up area cover increased from 340 to 661 ha (94.4%), respectively, that is, by 16.2% and 0.67% of the total land surface area, at an annual rate of 0.51% and 0.02%. The area cover of oil palm increased by 4.21%, while that of rubber and banana plantations decreased by 12.62% and 0.35%, respectively, of the total land surface area.

In West Coast sub-division, dense forest decreased from 17,565 to 6232 ha (−64.5%), that is, by 46.1% of the total land surface area, at an average annual rate of 1.44% from 1986 to 2018 (Table 6). Other cultivated areas of cropland cover increased from 341 to 1456 ha (327%) and built-up area cover increased from 88 to 253 ha (187.5%), respectively, that is, by 4.54% and 0.67% of the total land surface area, at an annual rate of 0.14% and 0.02%. Oil palm and banana plantation cover increased by 9.75% and 0.04%, respectively, while rubber plantation cover decreased by 2.19% of the total land surface area.

For LULCC at the sub-regional scale, mangrove forest, grassland, and montane forest increased from 14,971 to 20,155 ha (2.55%), 9062 to 9686 ha (0.31%), and 2795 to 28,733 ha (12.8%), respectively, from 1986 to 2018 (Table 7). The observed increase in mangrove forest cover may only be due to cloud cover changes instead of an actual increase in the cover (Carodenuto et al., 2015), considering its high exploitation for fuel wood and charcoal by fishers and the local population. Dense forest decreased from 102,016 to 57,071 ha, that is, by 22.12% of the total land surface area. For production land, oil palm and banana plantations and other cropland cultivated areas increased from 12,797 to 18,518 ha, 3805 to 5628 ha, and 12,548 to 33,908 ha, respectively, that is, by 2.82%, 0.92%, and 10.51% of the total land surface area. Tea and rubber plantations decreased from 404 and 19,175 ha and from 294 to 3,618 ha, respectively, that is, by 0.05% and 7.66% of the total land surface area. For living space, built-up areas increased from 1534 to 4686 ha, that is, by 1.6% of the total land surface area. The conversion of lowland dense forest and grassland areas to banana, oil palm, and rubber plantations in the sub-region mostly occurred in the 1980s and 1990s to sustain the weak and dwindling national economy at the time, and remains a legacy of colonial history. From the 2000s, much of the expansion in other cultivated areas of cropland, built-up areas, and oil palm plantations occurred in rubber and banana plantations, in addition to forest and grassland areas.

Drivers and indicators of land use land cover change under the business as usual and green economy scenarios

The identified drivers and indicators of LULCC were ranked following their relative importance to causing LULCC under the BUS and GES conditions by separate mixed group of expert stakeholders in each sub-division of the sub-region. The results of the ranking of the drivers were similar on the most part, with only small variations among the sub-divisions under the BUS (Fig. 3a) and GES (Fig. 3b). Under the BUS, population growth, agricultural and farmland expansion, infrastructural development, and biomass energy exploitation (fuel wood and charcoal) were ranked as the most important drivers of increase in LULCC, while livestock grazing, mining, and human-set bushfires received the lowest ranks for all the sub-divisions (Fig. 3a).

Under the GES analysis, sustainable land management (e.g. adequate master and land use plans), good governance (e.g. law enforcement, capacity building, community awareness), conservation (e.g. creation of protected areas, community forest, council forest), and afforestation and reforestation (ecosystem restoration initiatives) were ranked as the most important measures towards LULCC reduction in all the sub-divisions. On the other hand, sustainable forest management (good practices, access, and equity in benefit sharing), incentives (payment for ecosystem services to smallholders and communities), and technological improvement (improved stoves, alternative energy sources) were ranked as the lowest impact measures towards LULCC reduction under GES in the sub-divisions (Fig. 3b).

Furthermore, the expert stakeholders ranked the indicators of the socio-economic drivers of LULCC under the BUS and GES and the results were similar on the most part, with only small variations in the order of the ranking of the indicators among the sub-divisions (Figs. 4 and 5). In general, under the BUS, investment in agriculture, expansion of commodity markets, and land conflict/land use conflict were generally ranked as the most important indicators of increase in agricultural land expansion (Fig. 4a). Land demand (for administrative units, gazette sites, etc.), land conflict/land use conflict, and high demand for biomass energy were generally ranked as the most important indicators of increase in forest cover loss

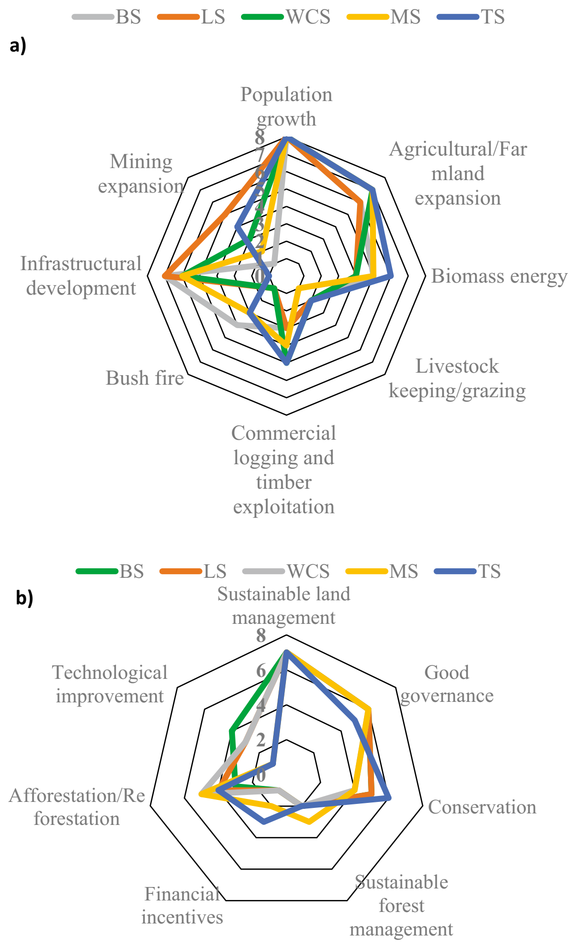

Fig. 3 Ranking of the direct socio-economic drivers having **a**) the highest impact on LULCC increase under the business as usual scenario and **b**) the highest impact on future LULCC reduction under the green economy scenario for the five sub-divisions in Fako division. BS Buea sub-division, TS Tiko sub-division, WCS West Coast sub-division, LS Limbe sub-division, MS Muyuka sub-division

under the BUS (Fig. 4b). High population growth rate (>2.5%), accessibility (nearness to road network, sea, markets, etc.), and investment in housing and road development were mostly ranked as the key indicators of increase in infrastructural development activities under the BUS (Fig. 4c). Land demand and high livestock density were ranked as the key indicators of increase in livestock grazing activities under the BUS (Fig. 4d). Investment in mining activities and high demand for biomass energy (fuel wood and charcoal) were generally ranked as the key indicators of increase mining and biomass energy exploitation, respectively, under the BUS (Fig. 4e and f).

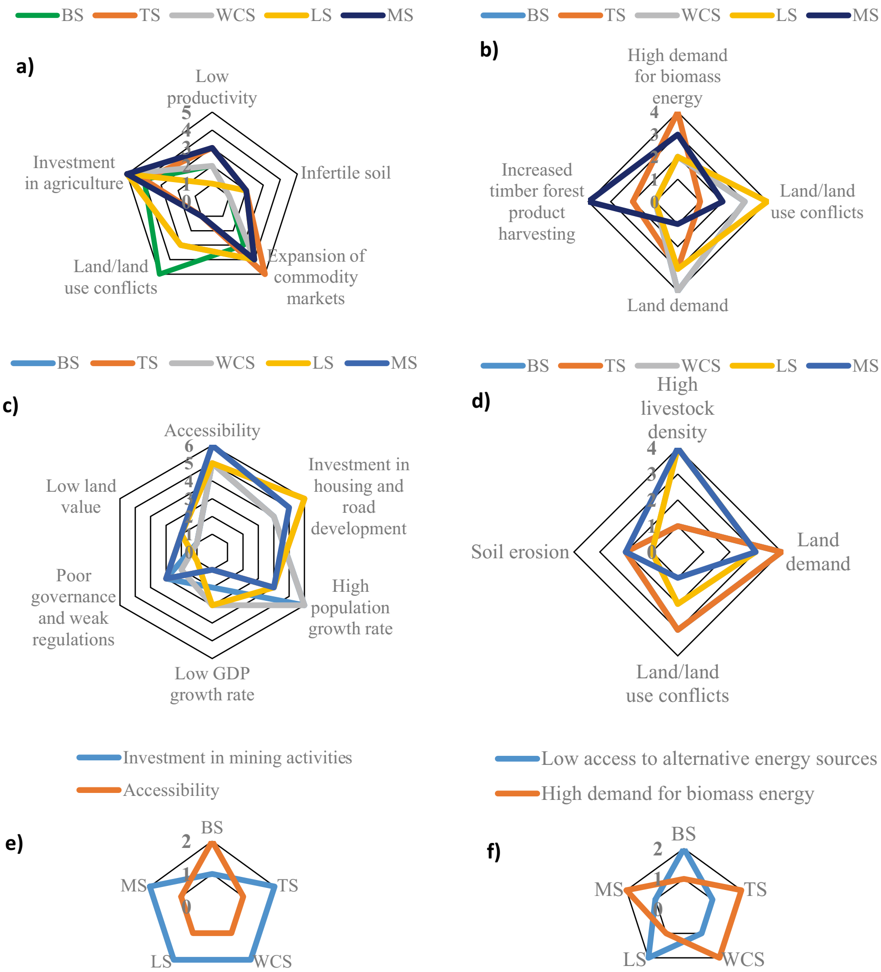

Fig. 4 Ranking of the indicators of **a**) Agriculture, **b**) Forestry, **c**) Infrastructural development, **d**) Livestock rearing, **e**) Mining, and **f**) Biomass energy as the direct socio-economic drivers of increase in LULCC under the business as usual scenario in Fako division. BS Buea sub-division, TS Tiko sub-division, WCS West Coast sub-division, LS Limbe sub-division, MS Muyuka sub-division

For the ranking of the indicators under the GES, the stakeholders mostly ranked community awareness, good practices, and capacity building as the key indicators of reduction of agricultural expansion (Fig. 5a). Afforestation/reforestation, good practices, and improved stoves were mostly ranked as the key indicators of reduction of forest cover loss under the GES (Fig. 5b). Land use planning/land management, low population growth rate, and good governance and strong regulations were mostly ranked as the key indicators of reduction in degradation caused by infrastructural development under the GES (Fig. 5c). Efficiencies in resource consumption and minimising land disturbance were mostly ranked as the key indicators of reduction of degradation caused by mining under the GES (Fig. 5d). Land use planning/land management was ranked as the key indicator of reduction in degradation caused by livestock grazing under the GES (Fig. 5e). High access to alternative energy and improved livelihood conditions were mostly ranked as the key indicators of reduction in degradation caused by increased use of biomass energy under the GES (Fig. 5f). The results on the most part show some appreciable level of similarity in the stakeholder perceptions in the ranking of the socio-economic drivers and indicators under the BUS and GES, indicating that the samples come from the same sub-region. Small variations were particularly observed with respect to the ranking order of the highest and lowest drivers and indicators under both scenarios, and less so with the representation of the highest and lowest drivers and indicators in each sub-division.

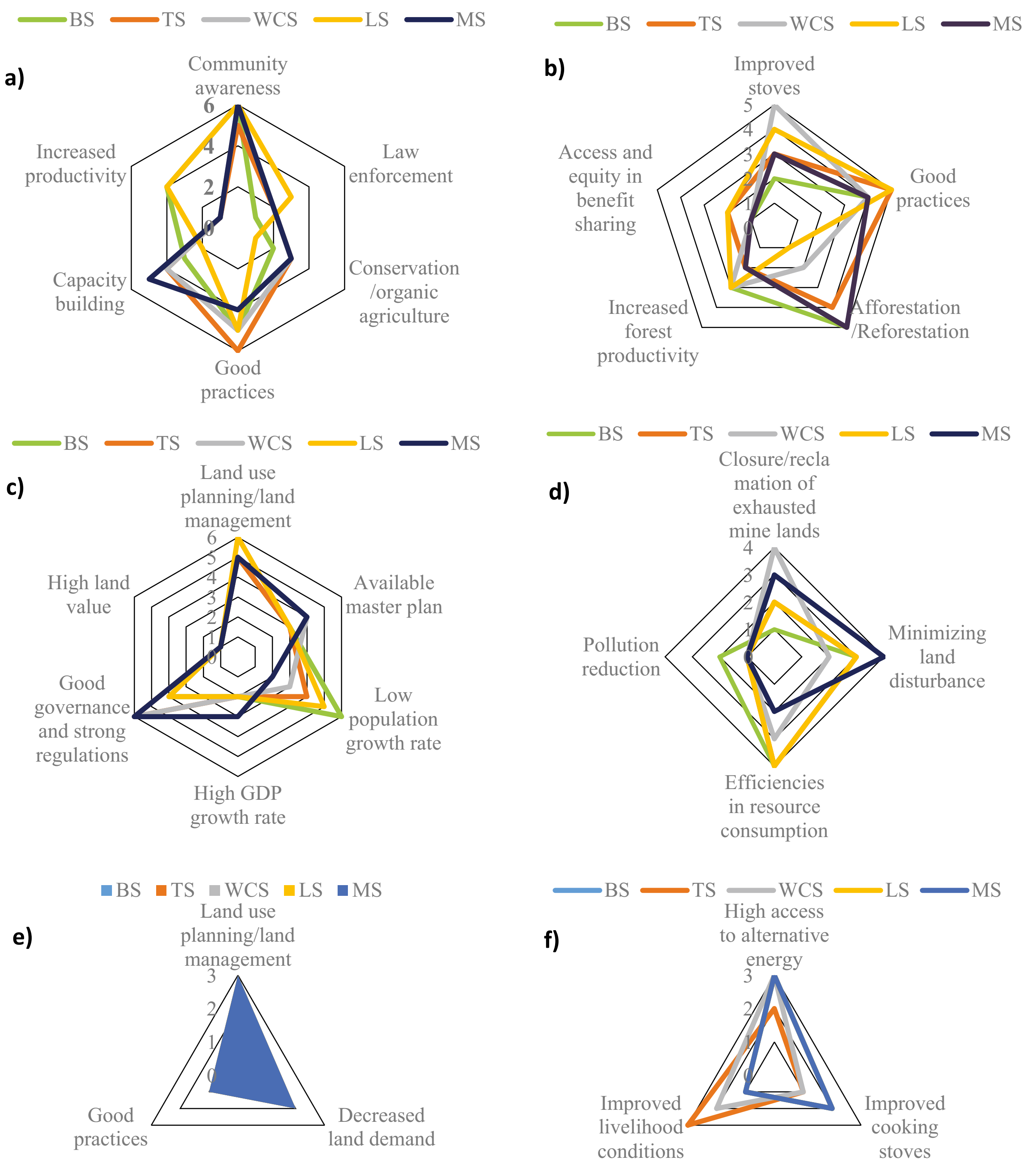

Fig. 5 Ranking of the indicators of **a**) Agriculture, **b**) Forestry, **c**) Infrastructural development, **d**) Mining, **e**) Livestock rearing, and **f**) Biomass energy as the direct socio-economic drivers of reduction in LULCC under the green economy scenario in Fako division. BS Buea sub-division, TS Tiko sub-division, WCS West Coast sub-division, LS Limbe sub-division, MS Muyuka sub-division

Likelihood assessment of potential changes and spatial patterns of degradation in land use land cover under business as usual and green economy scenarios

The likelihood of a potential change from one LULC to another was envisaged to be highest for mangrove forest, oil palm plantation, banana planation, water, dense forest, and other cultivated areas in Buea sub-division (Fig. 6a). For Limbe sub-division, the likelihood of a potential change from one LULC to another was envisaged to be highest for banana plantation and mangrove forest (Fig. 6b). For Tiko sub-division, the likelihood of a potential change from one LULC to another was envisaged to be highest for mangrove forest, oil palm, rubber, and banana plantations, water, grassland, and other cultivated areas (Fig. 6c). The likelihood of a potential change from one LULC to another was envisaged to be highest for dense forest and other cultivated areas in Muyuka sub-division (Fig. 6d) and mangrove forest, dense forest, and water

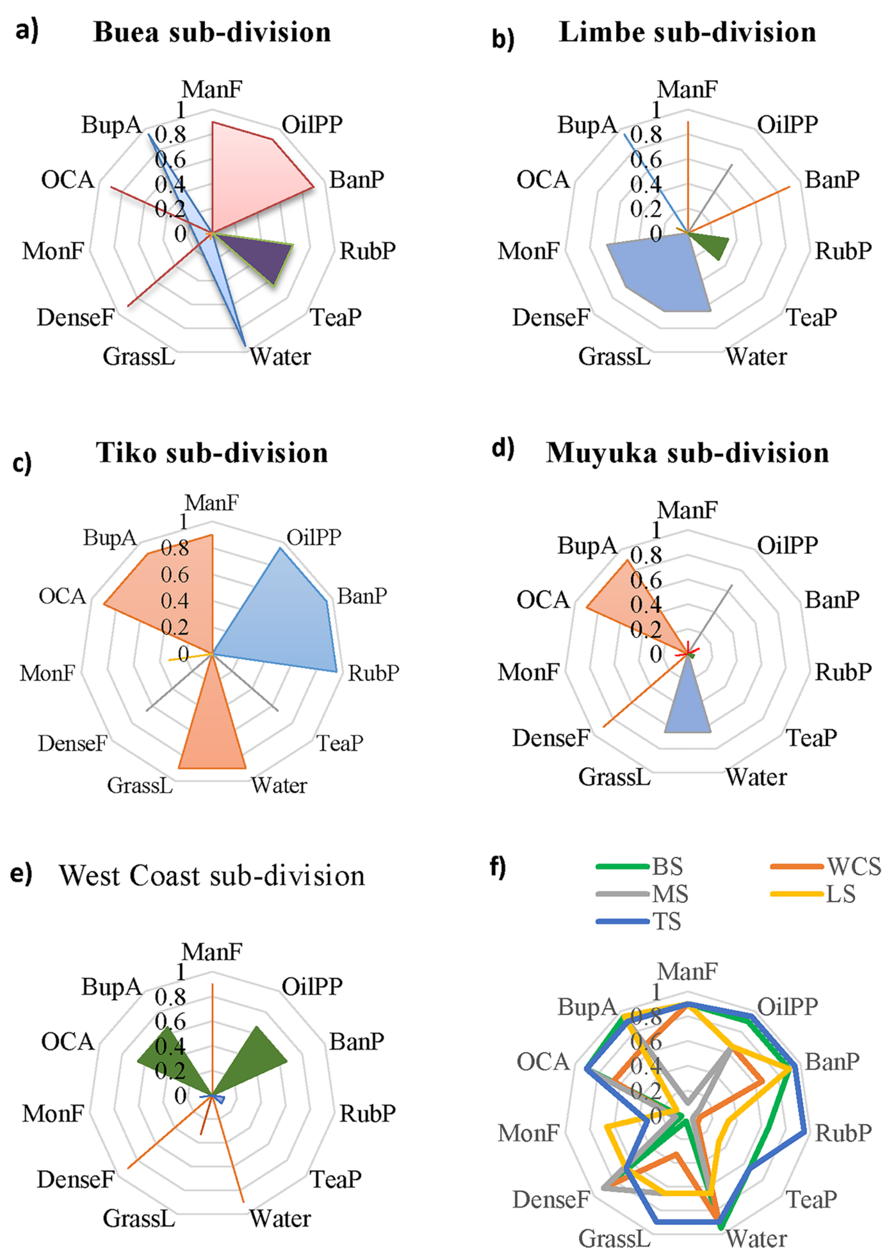

Fig. 6 Likelihood assessment for a potential change from one LULC to another in **a**) Buea sub-division (BS), **b**) Limbe sub-division (LS), **c**) Tiko sub-division (TS), **d**) Muyuka sub-division, **e**) West Coast sub-division (WCS), and **f**) Fako Division of Cameroon. The likelihood of change from one LULC to another was analysed for Mangrove (ManF), Oil palm plantation (OilPP), Banana plantation (BanP), Rubber plantation (RubP), Tea plantation (TeaP), Water, Grassland (GrassL), Dense forest (DenseF), Montane forest (MonF), Other cultivated areas (OCA), and Built-up area (BupA)

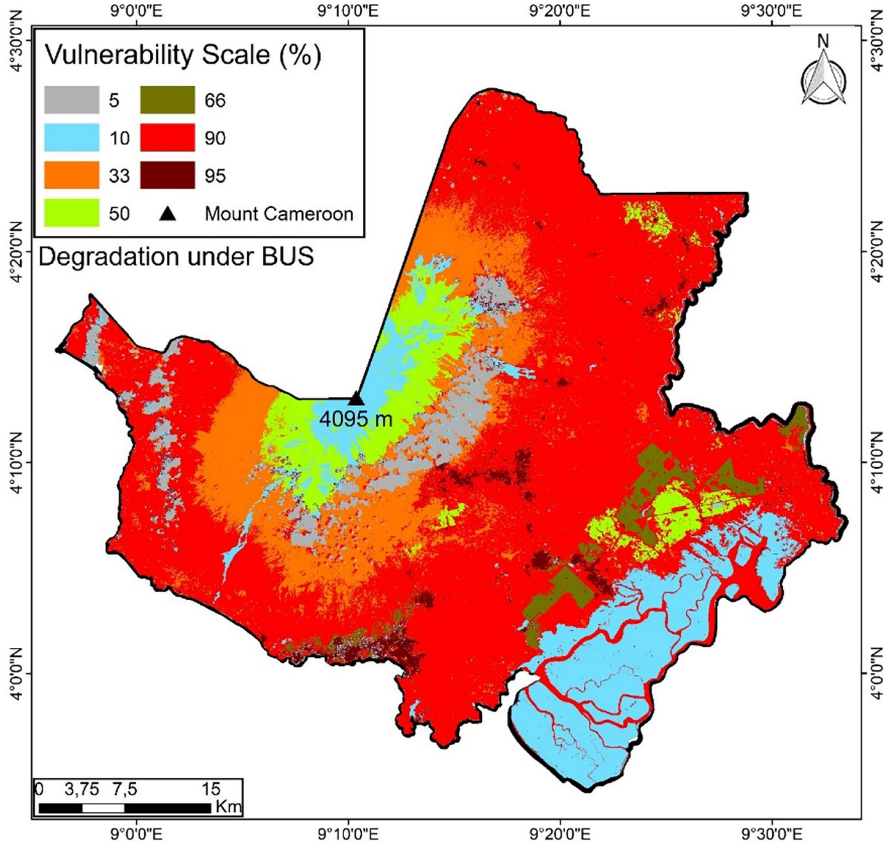

Fig. 7 Land use land cover change likelihood composite indicators for expansion of other cultivated areas of cropland, built-up areas, and agro-industrial plantations (red-brown) following current and envisaged future degradation in all LULC classes, under the business as usual scenario. Areas where such LULCC were not expected are shown in light blue and orange

in West Coast sub-division (Fig. 6e). At the sub-regional scale, the likelihood assessment for a potential change from one LULC to another was highest for all the LULC classes, except for montane forest and tea plantation (Fig. 6f).

The spatial pattern of degradation of LULC under the BUS in the future is presented in Fig. 7 based on the expert stakeholder perceptions. The vulnerability assessment for a potential expansion of other cultivated areas of cropland, built-up areas, and oil palm plantation is very likely (90%) to extremely likely (95%) following continuous expansion of degradation activities in dense forest, lowland grassland, banana, tea, and rubber plantations, based on the ranked indicators under the BUS (See section on ranked BUS indicators). The expansion of other cultivated areas of cropland and agro-industrial plantations was highest in the northern and eastern zones, located in Muyuka and Tiko sub-divisions, while expansion of built-up areas was highest in the centre and south western development corridors located in Limbe and Buea sub-divisions of the sub-region, under the BUS. In general, the expert stakeholders reported a high likelihood for potential increase in forest degradation in the future following the observed trend in the expansion of cultivated areas of cropland and built-up areas in the sub-region.

The spatial pattern of degradation of LULC under the GES in the future is presented in Fig. 8 based on the expert stakeholder perceptions. The vulnerability assessment for a potential increase in dense forest, grassland, mangrove forest, montane forest, water, and agro-industrial plantation covers was envisaged under the GES in the sub-region based on the adoption of the ranked LULCC reduction impact measures (See section on ranked GES indicators). Under the GES, the expansion of other cultivated areas of cropland, agro-industrial plantations, and built-up areas remain unchanged in the northern, eastern, and centre zones, respectively. However, expansion and protection of tree cover was envisaged in the dense forest, montane forest, montane grassland, and

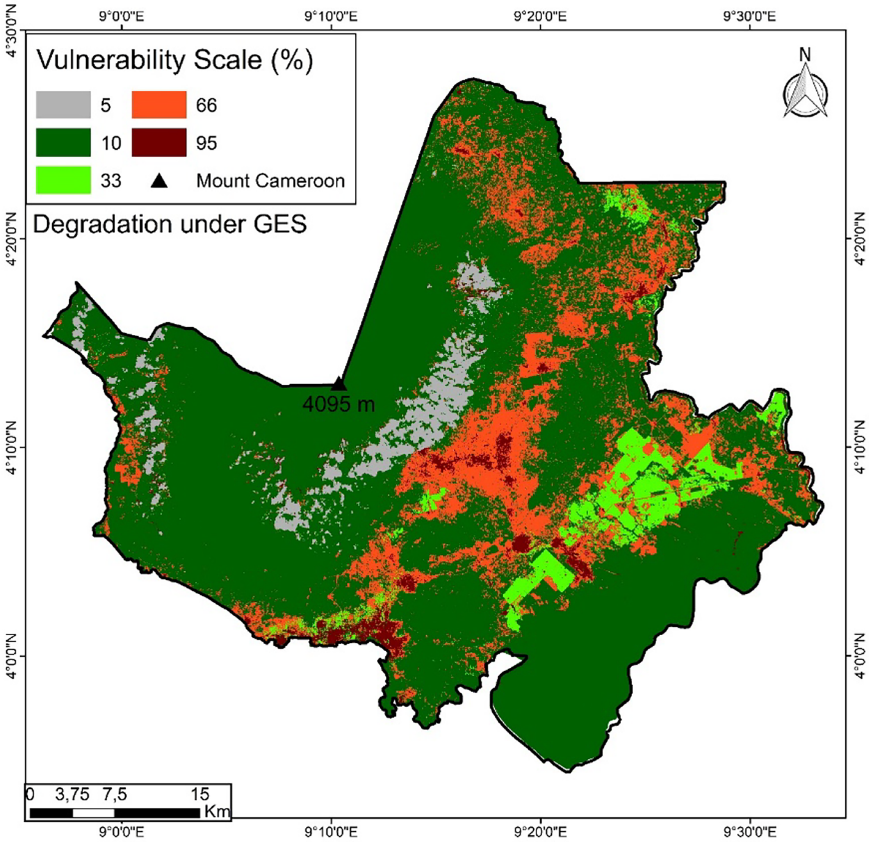

Fig. 8 Distribution of possible future LULCC under the green economy scenario (GES). Potential future expansion in tree cover in other cultivated areas, grassland, and dense forest areas is represented in green and light green colours following envisaged significant reduction in degradation activities. Areas where LULC are not envisaged to change under the GES are represented in brown and orange colours

southern mangrove forest zones under the GES in the sub-region (Fig. 8). The northwest zone is an established conservation corridor with high value forest and endemism, where the Mount Cameroon National Park and four community forests (Etinde, Bakingili, Woteva, and Bimbia-Bonadikombo) are located, and whose protection and sustainability should be prioritised in the sub-region.

Discussion

In the 1980s, landscape transformation in the study area was mainly dominated by conversion of lowland dense forest and grassland to agro-industrial plantations in a time of low population growth and low land and food demand, thus producing more resilient and adaptable SES. In the 2000s, the historical hot zones for agro-industrial plantations that were initial sites of rapid dense forest cover conversion became attractive sites for conversion to built-up areas and other cultivated areas of cropland in the sub-region, following increased population growth and high land and food demand, thus producing less resilient and adaptable SES. The spatial pattern of LULCC show some appreciable common decreasing trends in dense forest cover in all the five sub-divisions, with the decrease ranging from 11.76 to 47.4% from 1986 to 2018. The increased LULCC from the year 2000 are associated with the dwindling resilience and adaptability of SES in areas closer to the sea and national road networks in the sub-region, where social systems such as student villages, residential suburbs, migrant settlements, and farming and fishing village communities have developed and expanded at the detriment of ecological systems such as lowland forests, grassland and mangroves. Consistent with this result, forest cover loss showed increasing trends in four community forests in Fako division from 2001 to 2018, due to mainly to agricultural expansion, illegal exploitation of wood and non-wood products, and weak governance (Ewane, 2021). Dense forest cover was initially mostly converted to agro-industrial plantations of oil palm, banana, and rubber in the lowland zones of the sub-region in the 1980s and 1990s, which epitomises a legacy of colonisation. The dynamics of landscape deforestation and urban sprawl are frequently based on local history (Kohler et al., 2015).

The decrease in rubber plantation cover, ranging from 1.08 to 13.2% across all the sub-divisions, is indicative of changing global commodity consumption patterns and falling commodity product prices in the export market, consistent with the observations of Carodenuto et al. (2015). Rubber plantations were mostly converted to banana plantations, other cultivated areas of cropland and built-up areas across the sub-divisions. Felled rubber tree is of high demand as fuel wood and charcoal energy used for cooking and heating, and its conversion to oil palm plantations and other land uses remains increasingly high in the sub-region. The increase in oil palm and banana plantation covers retained positive figures at the sub-regional scale, indicating their importance to the local and national economy and contribution to deforestation and land use change. Ordway et al., (2017) reported that 73% of 546 oil palm producers are clearing forest to expand cultivation in Cameroon. In addition, oil palm-driven deforestation and land use change stood at 67% from 2000 to 2015 in the South west region of Cameroon, mostly dominated by non-industrial producers operating low-efficiency informal mills than by large-scale agro-industrial producers (Ordway et al., 2019). This trend applies to Africa, with the second largest areas of vulnerable forest to oil palm-driven deforestation and where 7% of oil palm plantations came from areas that were forest in 1989 (Vijay et al., 2016). Inconsistent with this result, oil palm-driven deforestation is reducing in Southeast Asia with a decrease of 36% in the proportion of oil palm plantations replacing forests in Sumatra, Kalimantan, and Papua of Indonesia from 1995 to 2015, following the government's pledge to zero-oil palm driven deforestation (Austin et al., 2017). The results suggest that the government of Cameroon has not effectively complied with reducing oil palm-driven deforestation with the area cover of industrial plantations and smallholder non-industrial estates of oil palm production still increasing in the country.

The population of Fako division has almost doubled over the last 30 years, that is, from 248,032 inhabitants in 1987 to 466,412 inhabitants in 2005 with a growth rate of 4.89, compared to a national average of 2.59%. Urban sprawl remains the dominant and widely prevailing form of urban growth in the sub-region. The observed significant differences in the increase of built-up areas between the sub-divisions are attributable to differences in population growth, socio-economic attractions, and strength and resilience of the local economy. Buea and Limbe sub-divisions have higher population growth rates (> 4.5% compared to 2.59% national average), urbanisation rate, socio-economic attractions, business growth rate, and traffic density than Tiko, Muyuka, and West Coast sub-divisions with significantly more agrarian local economy. Beyond 2000, much of the expansion in built-up areas and other cultivated areas of cropland occurred more in non-forest than forest areas in Buea and Limbe sub-divisions, leading to a decrease in the area cover of agro-industrial plantations. Built-up land expansion due to urban growth usually occurs at the expense of ecological land cover classes in many developing countries (Asabere et al., 2020; Hersperger et al., 2020).

In addition, the rapid population growth is causing high land value and increasing competition for farmland, leading to increased food prices, and threatening food security in Buea and Limbe sub-divisions. In particular, the rapid population growth rate due mainly to migration is triggering unprecedented progressive land tenure change from public land tenure to customary tenure and private land ownership since the 2000s to meet up with the increasing land demand for housing and farmland development. The well-intended government development strategy of land redistribution (land reform) has increased land and land use conflict, systematic land grabbing by local elites, wealthy business owners and decentralised government administrators, and exacerbated forest clearing and land use conversion for personal gains, consistent with the results of Ordway et al. (2017). The rapid population growth in the sub-region is fuelled by the presence of the national oil refinery in Limbe and the increase in educational institutions in Buea, bringing high economic and employment opportunities in the formal and informal goods and services industries. These have pushed housing and farmland development to other land uses with the aim of securing private and community land. The processes of LULCC and urban sprawl directly impact natural land cover, particularly agricultural land (Beckers et al., 2020), with population growth as the most significant driving force of LULCC (Salem et al., 2020).

The old paradigm of horizontal expansion of smallholder cultivated areas of cropland and agro-industrial (including non-industrial oil palm) plantations remains the main form of agricultural growth in the sub-region. It occurs in both non-forest and dense forest areas, mostly in West Coast, Muyuka, and Tiko sub-divisions of the sub-region, with higher farming population and poorer socio-economic development. Smallholder land use decision-making in terms of survivalist, subsistence-oriented, and market-oriented types are more likely found in areas with higher poverty levels and overall lower levels of socio-economic development (Malek & Verburg, 2020). Carodenuto et al. (2015) reported net forest loss of 8564 ha, equalling an annual deforestation rate of 0.51% from 1986 to 2010 mainly due to expansion of farmland and agro-industrial plantations of rubber, palm oil, tea, and banana and urban development in Fako division of Cameroon. In eastern Brazilian Amazon, 47.7% of primary forest was converted to other uses, mainly to oil palm plantations (30% out of the 47.7%) from 1991 and 2013 (de Almeida et al., 2020).

Results on the spatial distribution of LULCC in the sub-region indicated dense forest cover and other cultivated areas of cropland, respectively, decreased and increased the highest in the Northern and Eastern zones, located in Muyuka (-47.4% and 16.2%) and Tiko (-23.8% and 11.9%) sub-divisions from 1986 to 2018. In both sub-divisions, the topography is relatively low-lying, high farming population, and large proportion of cultivable land favoured the conversion of dense forest to cocoa, arable cropland, and agro-industrial plantations. In the northern zone, the on-going armed conflict in Anglophone Cameroon is causing more and more people to seek semi-permanent refuge in the forests, clearing more forest land to expand farmland and semi-permanent settlements. In general, the lowland ecological systems in the sub-region experienced tremendous transformation due to greater vulnerability to overwhelming human pressure, undermining their resilience and sustainability. The lowland dense forest and grassland covers were converted to other land uses, mainly other cultivated areas (10.51%), oil palm (2.82%), banana (0.92%) plantations, and built-up areas (1.6%). In the lowland ecological systems, LULCC mostly increased with nearness to the Atlantic Coastline and settlements, and along national road networks and major markets linking main cities, towns, and villages in the sub-region, emphasising the vulnerability of lowland and coastal-land boundary ecosystems. Consistent with this study results, Cassidy et al. (2010) reported decreasing trends in LULC diversity with proximity to roads and markets in two provinces in South East Asia.

On the other hand, the conversion of dense forest to other land uses was lower (−13,201 ha and −22.3%) in the mountain ecological systems in Buea sub-division, indicating their greater resilience to human-induced change relating to deforestation and forest degradation, and lesser vulnerability to agricultural expansion activities compared to lowland areas of Muyuka and Tiko sub-divisions. The results confirm the hypothesis that LULCC decreased with increase in elevation of Mount Cameroon (4095 m), a biophysical barrier in the northwest zone, emphasising the resilience of the mountain ecosystem in the sub-region. Cassidy et al. (2010) reported decreasing trends in LULC diversity with increasing elevation, with SES in two provinces in South East Asia, consistent with this study results.

The stakeholder groups successfully ranked the drivers and indicators of LULCC under the BUS and GES despite the technical complexity of the questionnaire, thanks to the higher education level, academic and professional background, and technical experience. Under the BUS, the expert stakeholders emphasised that population growth, agricultural land expansion, infrastructural development, and biomass energy exploitation (fuelwood and charcoal), respectively, are the key drivers of increased LULCC in the sub-region. This is consistent with the findings of Carodenuto et al. (2015) in the sub-region and Capitani et al. (2016) in Tanzania under the BUS scenario, though some within-country variability. These drivers of LULCC under the BUS would be most predicted by increased investment in housing development, agro-industrial plantations, subsistence farming, accessibility and road development (nearness to road network, markets, railway, and sea), and high demand for fuelwood and charcoal, respectively, in the sub-region.

The expansion of agricultural and croplands is consistent with government policy encouraging more youths to engage in agriculture as a means of employment, with the aim of increasing national GDP from export earnings, food security, nutrition diversity, household income, and local economic resilience. This is consistent with reports that arable production in Cameroon is declining or stagnating, and the situation is pushing more people to facing the problems of food insecurity (Epulle & Bryant, 2015). The fertile volcanic soils, well-distributed annual rainfall, and access to surface water in peri-urban areas are major attractions for expansion of both agro-industrial plantations and arable croplands in the sub-region.

The expert stakeholders ranked sustainable land management, good governance, conservation, and reforestation, respectively, as the highest impact drivers and predictors of green economy development, with only small variations in stakeholder perceptions between the sub-divisions. Consistent with this result, Capitani et al. (2016) reported technical improvements, law enforcement, land use planning, and good practices as key opportunities towards reductions in LULCC and improvements in livelihood under the GES in Tanzania. The variability in the perception of stakeholders about current degradation and future green economy development in the sub-region is consistent with the results of the study conducted by Capitani et al. (2016). Stakeholders' ranking of sustainable forest management, incentives, and technological improvement as the least impact drivers and predictors of green economy development was influenced by their knowledge and experience of the local realities of forest governance in Cameroon. Excessive and uncoordinated government intervention in community forest management, lack of bottom-up approaches, decentralised governance structures and community focal points in access and equity benefit sharing schemes, lack of decentralised jurisdictional and community-led implementation of projects on payment for ecosystem services, and lack of government investment in alternative cooking energy sources undermines the predictive power of the above drivers of green economy in the sub-region.

The stakeholders emphasised that population growth and sustainable land management, respectively, are the main drivers of increased and decreased degradation under the BUS and GES in the sub-region. Population growth drives expansion in oil palm plantations at small scale, while national agricultural development plan triggers expansion of agro-industrial plantations at large spatial scales in the sub-region (Carodenuto et al. 2015). The results clearly confirm the hypothesis that horizontal expansion of agricultural land and urban sprawl are the dominant modes of agricultural and urban growths, respectively, in the sub-region and in Cameroon in general, under the current BUS in the sub-region, like in other countries in Sub-Saharan Africa. In contrast, sustainable land management through effective land use planning and good practices such as afforestation and reforestation and community awareness will reduce the degradation of dense, montane, and mangrove forests covers under the GES, consistent with the results of Capitani et al. (2016). It will also increase the protection of watersheds and riparian zones and increase forest and agricultural productivity per hectare and square meter in the sub-region.

Conclusion

Natural vegetation landscapes are undergoing significant human transformations, causing significant alterations of ecosystem services and functions, and undermining the resilience and sustainability of SES. We analysed satellite imagery of 1986 and 2018 to examine the extent and spatial patterns of LULCC and validated current and future LULCC scenarios with expert multi-stakeholder perceptions in five sub-divisions of Fako division of Cameroon. The increase in other cultivated areas of cropland, oil palm plantations and built-up areas, and decrease in dense forest and rubber plantation covers dominated the LULCC in the sub-region from 1986 to 2018. However, most of the deforestation and LULCC was caused by expansion of other cultivated areas of cropland by smallholders, contrary to the widely publicised narrative of agro-industrial and built-up areas expansion. Expansion of other cultivated areas of cropland, oil palm, and banana plantations were highest in the northern and eastern zones located in Muyuka and Tiko sub-divisions, respectively. The low-lying topography, higher proportion of cultivable land, farm labour, and predominantly agrarian local economy favoured horizontal agricultural land expansion more in the northern and eastern zones of the sub-region. The increase in built-up areas was highest in the central, south, and western coastal zones due to rapid population growth, unregulated urbanisation, and better socio-economic opportunities in Buea and Limbe sub-divisions. Due to the rapid unregulated urbanisation, urban sprawl was the dominant mode of urban growth in the sub-region. Rubber plantations and lowland dense forest are extremely vulnerable to degradation based on the economics of changing commodity market prices. Oil palm and banana plantations, mangrove, and montane forests showed appreciable resilience to human transformation activities in the sub-region. Population growth, agricultural and farmland expansion, and infrastructural development were ranked as the three most important drivers of degradation under the BUS, while sustainable land management, good governance, and afforestation/reforestation were ranked as the three most important predictors of LULCC reduction under the GES. LULCC decreased with increase in elevation of Mount Cameroon (4095 m) in the northwest zone, but increased with nearness to the Atlantic Coast in the western zone and national road networks, emphasising the resilience of the mountain ecosystem and the vulnerability of lowland and coastal-land boundary ecosystems. The west and south facing slopes of Mount Cameroon harbours high value forests with high endemism and conservation attractiveness, and remains a key biodiversity hot spot, watershed providing clean water, healthy soil and regulating the climate in the central Africa sub-region and beyond. In general, production and living land covers significantly increased at the expense of ecological land covers. Therefore, increasing the legal protection of the mountain and coastal land-boundary ecological systems while providing for production and living land is invaluable for the sustainability of ecosystem functions and services in the western highland region of Cameroon and in the rainforest-rich Congo Basin.

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Data availability The data on land use land cover change and focus group survey generated and analysed during this current study are included in this published article (and the questionnaire supplementary information files).

Declarations

Conflict of interest The authors declare no competing interests.

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