# Supplementary Information

### Study region description

***Gran Chaco in Argentina***

The Gran Chaco ecoregion is the largest remaining continuous extent of native tropical dry woodland vegetation in South America, covering over 1.1 million km2 of Argentina, Bolivia, and Paraguay and being inhabited by approximately 9 million people (TNC, 2024). It is characterized by a semi-arid climate and a mosaic of xerophytic forests, open woodlands, scrubs, and grasslands (Bucher, E. H., 1982; Verga & López Lauenstein, 2021). Historically, rural land in the Chaco was mainly used by different Indigenous populations, practicing extensive livestock and hunting-gathering in the forests (Leake, 2010), and small-scale producers, such as European colonizers or forest smallholders from other regions of the American continent who used small patches of land for subsistence cropping and to sell on local markets, and the surrounding woodlands to gather firewood and material for construction, as well as for roaming livestock (Fatecha, 1989; Vallejos et al., 2020). However, in recent decades, the emergence and rapid expansion of large-scale agribusinesses focused on beef and cash crop production has profoundly impacted biodiversity and the livelihoods of forest-dependent smallholders (Fehlenberg et al., 2017; le Polain de Waroux et al., 2018; Levers et al., 2021). Factors such as the introduction of genetically modified soybean variants, highly productive pasture grasses, and the devaluation of the Argentine peso have accelerated deforestation, turning the Gran Chaco into a global hotspot for deforestation (Baumann et al., 2022; Leguizamón, 2014; Neiman & Blanco, 2020; Vazquez, 2013).

***Chiquitano dry forest in Bolivia***

The Chiquitano forest in Bolivia, characterized by semi-deciduous forests, serves as a crucial corridor connecting the Gran Chaco in the South to the Amazonian rainforests in the North (Maillard et al., 2023). Spanning nearly 240,000 km2, it is home to an estimated 3 million people (Maillard et al., 2024; Pacheco, 2006). Traditionally, Indigenous peoples inhabited the forests, practicing nomadic land uses with minimal impact on vegetation, but since the 1960s, Bolivian development strategies have spurred agricultural expansion into these areas (Maillard et al., 2024; Müller et al., 2012)(Pacheco, 2006). Often eased by the state, Indigenous peoples from the Andean highlands, foreign (Mennonite and Japanese) settlers, and medium- and large-scale industrial farmers have steadily increased the conversion of forest to cropland and pasture (de la Vega-Leinert & Huber, 2019; Müller et al., 2014). Driven by policies promoting export-oriented agriculture and the sale of fiscal land at low prices, and compounded by weak enforcement of land-use regulations, the Chiquitano forest is currently experiencing one of the most rapid expansions worldwide of commodity agriculture and livestock frontiers (Romero-Muñoz, Fernández-Llamazares, et al., 2019; Romero-Muñoz, Jansen, et al., 2019).

***Deccan dry forests in India***

The Deccan dry forests are spread across the Deccan plateau of peninsular India, which covers an area of more than 500,000 km2 (Thamminidi, 2020). With a large gradient of rainfall (500-1500mm MAP) shaped by monsoon and orography, this region includes a diverse range of natural ecosystems ranging from open, arid, and semi-arid grasslands and savannas, to closed mesic deciduous woodlands and forests, along a gradient of increasing rainfall (Ratnam et al., 2016; Roy, Behera, et al., 2015). Many of the forests are presently degraded through over-use, with thorn forests and shrub thickets prevalent. The region is densely populated, with an estimated population of over 200 million people (https://www.clearias.com/deccan-plateau/). With a long history of human presence, this area has undergone dramatic land transformations since the 1700s with large-scale conversion to agriculture, horticulture, agroforestry, and human settlements with varying degrees of urbanization and industrialization (Ellis et al., 2021; Ellis & Ramankutty, 2008). Today the region consists ofa mosaic of smallholder agriculture, larger-scale commercial agriculture, rangelands used for livestock grazing, small and large urban settlements, and vast tracts of commercial tree plantations, silviculture, community forests, and state-managed reserved forests and protected areas (Roy, Behera, et al., 2015; Roy, Roy, et al., 2015).

***Miombo-Mopane Woodlands in Mozambique***

The Miombo and Mopane woodlands of southern Africa cover an estimated 1.9 million km2 in seven countries (Angola, Democratic Republic of Congo, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe) and support the livelihoods of 150 million rural people and urban dwellers (N. S. Ribeiro, Katerere, et al., 2020; Ryan et al., 2016). Miombo woodlands, characterized by tree species of the *Brachystegia* and *Julbernardia* genera, occupy areas of higher precipitation and altitude while mopane woodlands, dominated by trees of *Colophospermum* mopane, occupy lower elevations (Sedano et al., 2016). Traditional management practices have historically shaped the woodlands and created mosaics of farmland, shrubland and, degraded as well as conserved woodlands (Matteo & Schoneveld, 2016; Woollen et al., 2016). Following a land use history that was largely shaped by colonial rule, civil conflict and resolution, and more recent policies promoting a liberalized market economy, the post-2000 era in the Mozambican Miombo-Mopane woodlands is characterized by rapid change dynamics (Bey et al., 2020; Kronenburg García et al., 2022; Smith et al., 2019). Population growth, government policies, and increased access to markets have triggered smallholder expansion as well as a transition of agricultural practices from extensive, long-fallow shifting cultivation to more intensive, short-fallow (or permanent) systems (Grogan et al., 2013; N. S. Ribeiro, Grundy, et al., 2020). In parallel, post-war agricultural reforms encouraged foreign land investments (Smith et al., 2019; Zaehringer et al., 2018), so Mozambique is today considered a hotspot of large-scale land acquisitions, mainly for commercial agricultural production (Deininger & Xia, 2016; Glover et al., 2016; Joala et al., 2016).

***Indochina dry forests in Cambodia***

The Central Indochina dry forests form a large tropical and subtropical dry broadleaf ecoregion in Southeast Asia, sprawling across Laos, Vietnam, Thailand, and Cambodia. Spanning nearly 500,000 km2, the forests are home to an estimated 80 million people (CIESIN, 2021; Dinerstein et al., 2017). In Cambodia, the ecoregion consists of a mosaic of deciduous dipterocarp forests mixed with semi-evergreen forest habitats, which are critical to the biodiversity of this highly vulnerable forest region (Wikramanayake et al., 2002). Historically, dry forests have been used by several Indigenous groups practicing shifting cultivation, extensive livestock rearing, hunting, and gathering of non-timber forest products under customary tenure arrangements (Bruce, 2012; Leemann, 2021). Over the last two decades, the forest of the entire ecoregion has undergone serious degradation because of illegal logging, large-scale agricultural concessions (Mackenzie et al., 2022), mining operations, and migrations of smallholder farmers who have embraced the production of cash crops for export markets (Diepart & Ngin, 2020; Kong et al., 2019). In a parallel process, the government and international conservation groups have intensified their forest conservation efforts via the expansion and zonation of protected area systems and community-based forest management schemes inside and outside protected areas (Diepart & Oeur, 2023). Agricultural development and conservation efforts are poorly coordinated resulting in a high degree of fragmentation and an increasing number of conflicts over the control of land and forest resources (Diepart & Sem, 2018).

### List of experts

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| **ID** | **Region(s) of expertise** | **Discipline** |
| 1 | Savanna ecosystems in India | Ecology |
| 2 | Dry forests, savannas, and grassland ecosystems in Southern Africa | Geography / Remote Sensing |
| 3 | Chiquitano Dry Forest, Chaco, Bolivia | Ecology / Conservation Science |
| 4 | Indochina Dry Forests; Madagascar; Kenya; Ethiopia; Eritrea | Sustainable Development / Land System Science / Biodiversity and Wellbeing |
| 5 | Deccan Plateau, India | Conservation / Geography / Transformative action |
| 6 | Neotropical dry forests, Mexico, Chiquitano Dry Forest, Bolivia | Geography |
| 7 | Indochina dry forest | Agricultural Economics / Geography |
| 8 | Neotropical dry forests in Mexico, Central America, Colombia and Venezuela | Biogeography / Wildlife Conservation / Systematic Conservation Planning |
| 9 | Global Dry forests | Biogeography / Geography |
| 10 | Dry, wet, and montane Chaco and Espinal Ecoregions | Landscape ecology |
| 11 | Dry Chaco, Paraguay | Ecology |
| 12 | Dry Chaco, Argentina | Land Use / Forest Ecosystems |
| 13 | Chiquitano Dry Forest, Bolivia | Sustainability Governance / Transdisciplinary studies |
| 14 | Savannas, grasslands and dry forests, India; African Savannas- Kenya, Southern Africa | Biogeography / Functional Ecology / Conservation and Management |
| 15 | Dry dipterocarp and evergreen forests, Cambodia and Mekong region | Geo-agronomy |
| 16 | Savannas and dry forests, India | Conservation Biology/ Ecology / Data science |
| 17 | Savannas and grasslands of Africa and India | Community and Ecosystem Ecology / Biogeography |
| 18 | Savannas, grasslands, and dry forests, Madagascar | Social Science / Geography / Ecology |
| 19 | Dry Forests in South America | Biodiversity Conservation / Landscape Ecology |
| 20 | Dry Chaco | Sustainability Sciences |
| 21 | Miombo-Mopane Woodlands | Livestock / Agricultural systems |
| 22 | Caatinga, Brazil | Landscape Ecology |
| 23 | Dry Chaco | Social-ecological systems / Human dimensions of conservation |
| 24 | Gran Chaco | Conservation Science and Practice |
| 25 | Cerrado, Brazil | Ecology / Biodiversity |
| 26 | Miombo and Mopane Woodlands, Mozambique | Forest fire ecology, restoration ecology |
| 27 | Chiquitano Dry Forest, Bolivia | Conservation / Land Use / Forest Ecosystems |
| 28 | Miombo-Mopane Woodlands; Indochina Dry Forest | Geography / Land System Science / Social Science |
| 29 | Dry Chaco | Livestock systems / Agronomy |
| 30 | Miombo-Mopane Woodlands | Geography / Earth Observation |
| 31 | Deccan plateau of India | Ecology / Conservation Science / Landcover mapping |
| 32 | Central India, Eastern Ghats, and Deccan Plateau of India | Land Use Science / Biodiversity & Remote Sensing |
| 33 | Deccan Plateau, India | Social Science / Geography / Interdisciplinary |
| 34 | Dry Chaco | Ecology |
| 35 | Chiquitano Dry Forest and Chaco, Bolivia | Land Use / Deforestation / Biogeography |
| 36 | Dry Chaco | Functional Ecology / Landscape Ecology |
| 37 | Central India, Dry forests, India | Ecology / Socio-ecological systems / Biodiversity / Conservation |
| 38 | Dry Chaco, Argentina | Social-ecological systems / Ecology |
| 39 | Dry Chaco, Argentina | Biodiversity conservation / Human-wildlife conflict/ Agroecosystems |
| 40 | Central India, Eastern Ghats, and Deccan Plateau of India | Landscape ecology / Forest dynamics / Wildlife conservation |
| 41 | Chiquitano Dry Forest, Bolivia | Economy / Local livelihoods / Rural development / Agribusiness / Land use |
| 42 | Australian tropical savannas and dry forests | Land use/ Conservation / Biogeography/ Indigenous land management |
| 43 | Indian dry forests; Indochina dry forest | Biodiversity conservation / Forest Ecology |
| 44 | Indian dry forests | Wildlife conservation / Biogeography / Social science |
| 45 | Dry Chaco and Chiquitano Forest, South America | Land System Science / Conservation Science |
| 46 | Dry Chaco | Human Geography |

### Expert workshops

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| **Study region** | **Participating experts** | **Date** | **Location** |
| Gran Chaco dry forest in Argentina | 9, 10, 12, 19, 20, 23, 24, 29, 34, 36, 38, 39, 45 | 08.09.2022 | Córdoba, Argentina |
| 12, 20, 29, 38, 39, 45 | 20.10.2022 | Berlin, Germany |
| Chiquitano dry forest in Bolivia | 3, 6, 13, 27, 35, 41, 45, 46 | 02.03.2023 | online |
| 3, 6, 13, 27, 41, 45, 46 | 09.03.2022 | online |
| Deccan dry forests in India | 1, 5, 14, 16, 17, 31, 32, 33, 37, 40, 43, 44 | 10.02.2023 | Bengaluru, Karnataka, India |
| 32, 33, 37, 40, 44 | 03.05.2023 | online |
| Miombo-Mopane woodlands in Mozambique | 2, 18, 21, 28, 30 | 25.05.2023 | online |
| 2, 18, 21, 26, 28, 30 | 20.06.2023 | online |
| Indochina dry forest in Cambodia | 4, 7, 15, 28 | 15.06.2023 | online |
| 4, 7, 15, 28 | 19.06.2023 | online |

### Detailed land system description

1. ***Land systems in the*** ***Gran Chaco dry forest in Argentina***

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| --- | --- | --- | --- | --- |
| **Systems** | | Farmer female outline**Actors** | **Tractor with solid fillActivities** | **References** |
| **Industrial annual cropping** | | |  |  |
| A1.I | **Agribusiness cropping** | * Profit-driven, capitalized, large-scale farmers or companies * Oriented toward economic objectives and domestic-to-international markets * Well-organized with high lobbying power * Often linked to agribusiness conglomerates owning several steps of the supply chain * Variance in the use of external services for machinery and technological support | * Highly mechanized and industrialized large-scale cropping * Cultivated crops: mostly oilseeds and cereals, such as soybean, maize, cotton, wheat, sunflower and sorghum * Often mixed with livestock ranching * High input of capital-related inputs * Removal of most natural vegetation (sometimes leaving forest stripes as wind protection) | (Baldi et al., 2015; Faingerch et al., 2021; Gasparri & le Polain de Waroux, 2014; Le Polain De Waroux et al., 2016; Marinaro et al., 2017; Mastrangelo et al., 2019) |
| A1.II | **Irrigated cropping** | * Capitalized medium to large-scale farmers | * Intensive commodity farming of hybrid and highly productive maize, semi-permanent agriculture such as olives * Center-pivot irrigation for large plots or lateral movement irrigation for small paddocks and crops * High capital-related inputs and cultivation frequency * Removal of most natural vegetation | (Baldi et al., 2015) |
| **Capitalized ranching** | |  |  |  |
| A2.I | **Cattle fattening and rearing** | see *Agribusiness cropping* | * Intensive cattle fattening and rearing for beef production * Feeding based on implanted pastures in cleared forests with supplementation (maize or sorghum silage) or feed-lots * Removal of most natural vegetation | (Baldi et al., 2015; Fernandez et al., 2023; Fernández et al., 2020; Gasparri & le Polain de Waroux, 2014; Le Polain De Waroux et al., 2016; Mastrangelo & Gavin, 2012; Torres et al., 2021) |
| A2.II | **Cattle ranching and breeding** | see *Agribusiness cropping,*   * Most of the cattle production is for domestic demand | * Cattle breeding and cow-calf ranching on implanted pasture * Pasture-based feeding in extensive grazing systems * Cleared or partially cleared (silvopasture) forests * Often part of the same farm as *Agribusiness cropping*, where the prevalence of land-use activity is flexible and depends on climate and market dynamics | (Baldi et al., 2015; Fernández et al., 2020; Gasparri & le Polain de Waroux, 2014; Le Polain De Waroux et al., 2016; Magliano et al., 2015; Mastrangelo & Gavin, 2012; Nasca et al., 2015) |
| A2.III | **Dairy production** | see *Agribusiness cropping* | * Cattle dairy production * More land and labor-intensive than beef production * Only in small to medium-scale production units * Fodder is based on irrigated pasture and maize or sorghum silage | (Cheij et al., 2022) |
| **Speculative land holding** | | |  |  |
| A3.I | **Speculative clearing** | * Private companies (often agribusinesses)   Strong integration in the real estate or agricultural markets | * Increasing the market value of land by removing the natural vegetation, and subsequently selling the land for higher prices * Partial clearing by roller chopping, or complete clearing by bulldozers or tractors with chains | (Blum et al., 2022; Cáceres, 2015; Gras & Zorzoli, 2019; Marinaro et al., 2020) |
| **Capitalized tree cropping** | | |  |  |
| **Smallholder farming** | |  |  |  |
| A5.I | **Organized smallholder farming** | * Small-scale farmers, including Indigenous and Criollo populations * Increased competitiveness and political power through organization in cooperatives or civil associations, e.g., MOCASE * Improved access to market information and financial/technical capital (from the Argentinian government) | * Mixed production systems of food crops and vegetables (potato, pepper, onion, etc.) as well as industrial crops (soybean, citrus, rice, peanut) for local markets * Low capital-related inputs and levels of technology * Raising of ruminants (cattle, goats, or sheep) or monogastric livestock (pigs or chickens) for subsistence or local markets | (Baldi et al., 2015; Mastrangelo et al., 2019; Morello, 1981; Wald, 2014) |
| A5.II | **Non-organized smallholder farming** | * Small-scale farmers, including Indigenous and Criollo populations * Lack of financial or technological capacity, and little access to market information * Politically marginalized and as a result generally vulnerable | see *Organized smallholder farming* | (Cotroneo et al., 2021; del Giorgio et al., 2022; Mastrangelo et al., 2019; Morello, 1981; Paz & Jara, 2020; Wald, 2014) |
| A5.III | **Mennonite small-scale farming** | * Ethno-religious communities living in closed agricultural settlements, or colonies * Reject the use of technology and the connection of houses to the electricity grid * Farming is the main livelihood * Different from Mennonite colonies in PAR and BOL | * Small-scale, intensive agriculture * Mixed production, including industrial and grain crops (maize, sunflower, sorghum) and dairy and beef for local to national markets * Intensive fields at the family level with none to low fertilization or technology | (Baldi et al., 2015; Bottos, 2008) |
| **Shifting cultivation** | |  |  |  |
| **Pastoralism** | | |  |  |
| A7.I | **Forest-dependent grazing** | * Forest-dependent smallholders (often referred to as “criollos” or “puesteros”) * Homesteads inside forests are typically inhabited by a single family * Rely on forests for their livelihoods and economic activity * Often live under irregular tenure situations * Occasionally integrated to local markets through other actors * High susceptibility to human-wildlife conflict because of carnivores threatening their livelihoods by predation | * Livestock (mainly cattle, goats, sheep, swine, and poultry) ranching (animals roam freely in the forests surrounding the homestead, relying on a combination of local grasses and tree foliage for food) * Small subsistence crop fields or vegetable gardens * Land use depends on the presence of natural or artificial water sources * Use of forest products for the collection of firewood for charcoal production, fence posts, and occasionally timber, subsistence hunting, and the collection of non-timber forest products (plants, honey, fruits…) * No removal of natural vegetation but forest degradation through freely roaming livestock | (Abt, 2001; Coirini et al., 2010; Fernández et al., 2020; Karlin et al., 2013; Levers et al., 2021; Marinaro et al., 2017; Murray et al., 2016; Nanni et al., 2021) |
| **Forest-dwelling** | |  |  |  |
| A8.I | **Indigenous forest use with secure land tenure** | * Forest-dependent Indigenous communities * Diverse ethnic groups and communities * Highly depend on natural resources for their survival and cultural roots * Formalized land rights for their territories (but limits of the recognized properties usually smaller than their historical territories, thus not embracing the needs of their traditional nomad lifestyle) | * Hunting and harvesting of wild species * Fishing for diet and local market, if close to a river * Goat keeping for subsistence * Traditionally nomadic-seasonal practices, which are under restriction today | (Altrichter, 2006; Camino et al., 2018, 2023; Jiménez-Escobar & Martínez, 2019; Marinaro et al., 2017) |
| A8.II | **Indigenous forest use on non-formalized lands** | see *Indigenous forest use with secure land tenure*,   * but no titles to the land they occupy, i.e., they are compromised on fiscal land or live on land under conflict * Among the poorest members of Argentinian society and commonly dependent on social subsidies | see *Indigenous forest use with secure land tenure* | (Altrichter, 2006; Camino et al., 2018, 2023; Jiménez-Escobar & Martínez, 2019) |
| **Forest plantations** | |  |  |  |
| **Forestry in native forests** | | |  |  |
| A10.I | **Charcoal production** | * Profit-driven, capitalized, large-scale forestry enterprises * Specialized in hardwood exploitation for local (construction of buildings, floors, and fences) and distant markets (mainly for the furniture industry) * Typically under contract of the ranchers or farmers owning the land | * Commercial charcoal production * Both as the main cause of deforestation or as a side product of land development | (Rueda et al., 2015) |
| A10.2 | **Commercial logging** | see *Commercial charcoal production* | * Selective logging of hardwood * Partial removal of natural forests which can lead to forest degradation | (Blum et al., 2022; Morello, 1981) |
| **State conservation** | |  |  |  |
| A11.I | **Strict state area protection** | * Public (state, province, municipal) conservation agencies | * Strict landscape and biodiversity protection by preventing extractive economic activities and limiting access (IUCN category I-II) * Managed to be maintained without other alterations than those necessary to ensure their control and visitor attention * Economic exploitation is prohibited (except for tourism) * Generally high enforcement and effectiveness | (Brown et al., 2006; Matteucci & Camino, 2012; Sabatini & Rodríguez Iglesias, 2001) |
| A11.II | **Less restrictive state area protection** | * Public (state, province, municipal) conservation agencies | * Less strict area protection in terms of access and productive land uses, e.g., integrated management zones (IUCN category III-VI) * Varying effectiveness (usually no drastic land-use changes, but subtle activities often happen, such as logging or hunting) | (Aguiar et al., 2018) |
| **Private conservation** | |  |  |  |
| A12.I | **Private reserves** | * NGOs or private actors | * Diverse forms of area protection * Various goals, including biodiversity conservation as well as economic gains from tourism (including hunting reserves) * Often more efficient in restricting access and resource exploitation than public area-based conservation because of strong mechanisms of control * Long-term protection depends on the owner’s will and is thus not guaranteed | (Busscher et al., 2018) |
| **Community conservation** | | |  |  |
| **Energy land uses** | |  |  |  |
| **Mining & construction** | |  |  |  |

1. ***Land systems in the Chiquitano dry forest in Bolivia***

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| --- | --- | --- | --- | --- |
| **Systems** | | **Actors** | **Activities** | **References** |
| **Industrial annual cropping** | | |  |  |
| B1.I | **Agribusiness cropping** | * **Farmer female outline**Profit-driven, capitalized farmers or companies * Oriented toward economic objectives and domestic-to-international markets * Many international actors (mostly from Brazil or Argentina) * Variance in farming culture, such as the use of external services for machinery and technological support * Well organized with high market and lobbying power | * **Tractor with solid fill**Large-scale industrialized, input-intensive farming * Cultivated crops: mostly soybean in rotation with winter crops (sorghum, sunflower), sugarcane, corn * Often mixed with livestock ranching * High input of capital-related inputs * Removal of most natural vegetation (sometimes leaving forest stripes as wind protection) | (Augstburger & Rist, 2020; Baldi et al., 2015; Colque, Gonzalo, 2022; de la Vega-Leinert & Huber, 2019; Le Polain De Waroux et al., 2016; Maillard et al., 2024; McKay & Colque, 2016; Müller et al., 2014; Redo, 2013; Vadez et al., 2008) |
| B1.II | **Mennonite farming** | * Ethno-religious communities living in closed agricultural settlements, or colonies * Highly capitalized and thus different from Mennonite colonies in ARG | * Mechanized farming of industrial and grain crops (mostly soybean, sunflower, corn) * Semi-intensive cattle-ranching for dairy and beef for local to national markets * Removal of most natural vegetation (sometimes leaving forest stripes as wind protection) | (Baldi et al., 2015; Colque, Gonzalo, 2022; Kopp, 2015; le Polain de Waroux et al., 2021; Müller et al., 2014) |
| **Capitalized ranching** | |  |  |  |
| B2.I | **Cattle fattening and rearing** | * Capitalized, large-scale farmers (often referred to as Ganaderos)   many international actors (mostly from Brazil or Argentina) | * Intensive cattle fattening and rearing for beef production * High intensity * Feeding based on implanted pastures in cleared or partially cleared (silvopasture) forests   Removal of most natural vegetation | (Baldi et al., 2015; de la Vega-Leinert & Huber, 2019; Le Polain De Waroux et al., 2016; Maillard et al., 2024; Müller et al., 2014; Redo, 2013) |
| B2.II | **Cattle ranching and breeding** | * Capitalized, medium to large-scale farmers (often referred to as Ganaderos) | * Cattle breeding and cow-calf ranching in natural and planted pasture * Pasture-based feeding in extensive grazing systems in cleared or partially cleared (silvopasture) forests * Land use is more extensive and traditional   Often part of the same farm as *Agribusiness cropping*, where the prevalence of land-use activity is flexible and depends on climate and market dynamics | (Baldi et al., 2015; Colque, Gonzalo, 2022; de la Vega-Leinert & Huber, 2019; Le Polain De Waroux et al., 2016; Maillard et al., 2024; Müller et al., 2014) |
| **Speculative land holding** | |  |  |  |
| B3.I | **Speculative clearing** | * Private companies (often agribusinesses) * Strong integration in the real estate or agricultural markets   Sometimes occurs on land officially dedicated to community areas according to the PLUS (= Ghost communities) | * Increasing the market value of land by removing the natural vegetation, and subsequently selling the land for higher prices * Partial clearing by roller chopping, or complete clearing by bulldozers or tractors with chains * As a side product often linked to charcoal production or selling of valuable timber | (Colque, Gonzalo, 2022; Vos et al., 2020) |
| **Capitalized tree cropping** | |  |  |  |
| **Smallholder farming** | |  |  |  |
| B5.I | **Mechanized peasantry** | * Peasant communities of Andean origin, who settled on fiscal or undesignated land in the lowlands (generally supported by the government, church institutions or international NGOs / Aid Agencies) * Generally affiliated to a peasant organization (e.g., CSTUCB) * Small-scale rural farmers from the Bolivian lowlands * Generally, individual access to land within formally communal tenure, although internal arrangements may treat land as private property | * Medium-scale, mechanized agriculture (for instance, corn, soy, rice) for local-national markets * Agroforestry based on bananas, plantains, fruits * Livestock ranching (mainly cattle, goats, sheep, swine, and poultry) * Commercial timber and harvest at a small scale | (Augstburger & Rist, 2020; Baldi et al., 2015; Colque, Gonzalo, 2022; de la Vega-Leinert, 2020; Müller et al., 2014; Redo, 2013) |
| B5.II | **Traditional peasantry** | see *Mechanized peasantry*   * but less material capacities (settlers generally start as traditional peasantry and, depending on their means, can move up to the mechanized peasantry category) | * Traditional, small-scale agriculture (for instance, cassava, corn, fruits) for local-national markets * Agroforestry based on bananas, plantains, fruits * Low capital-related inputs and levels of technology * Livestock ranching (mainly cattle, goats, sheep, swine, and poultry) * Timber harvest at small scale | (Augstburger & Rist, 2020; Colque, Gonzalo, 2022; de la Vega-Leinert, 2020; Müller et al., 2014; Thiele & Nostas, 1994) |
| **Shifting cultivation** | | |  |  |
| B6.I | **Indigenous communal farming** | * Lowland Indigenous communities settled on communal land, which has not been included in an Indigenous Communal Territory (TIOC) * Generally affiliated to the indigenous organization (CIDOB) * Collective ownership in community systems | * Land management based on rotational traditional Chiquitano land use: communal land is allocated to families, who cultivate it for a few years before leaving it to fallow and secondary forest regeneration * Use of fire to clear plot * Small subsistence crop fields or vegetable gardens (for instance, cassava, corn, fruits) * Low capital-related inputs and levels of technology * Livestock ranching (mainly cattle, goats, sheep, swine, and poultry) * Collective access/use of forest for hunting, harvest of NTFP (plants, honey, fruits…), selective logging | (Baldi et al., 2015; de la Vega-Leinert, 2020) |
| **Pastoralism** | | |  |  |
| **Forest-dwelling** | | |  |  |
| B8.I | **Indigenous community territories** | * Indigenous groups with access to territories classified as Indigenous Communal Territory (TIOC) (but limits of the recognized properties usually smaller than their historical territories) * Traditionally semi-nomadic but mostly settled today * Exclusive rights to forest resource use (but may not have the means to protect them) | * Collective access/use of land for hunting, harvest of NTFP (plants, honey, fruits…), selective logging, charcoal production * Small subsistence crop fields or vegetable gardens * Livestock ranching (mainly cattle, goats, sheep, swine, and poultry) | (Baldi et al., 2015; CEDLA, 2011; Colque, Gonzalo, 2022; de la Vega-Leinert, 2020; Fundación Tierra, 2011; Müller et al., 2014) |
| B8.II | **Indigenous isolated hunting-gathering** | * Indigenous groups who live in voluntary isolation in the forest in Indigenous Communal Territory (TIOC) | * Semi-nomadic lifestyle: Periodic migration back and forth to northern Paraguay * Subsistence hunting and collection of NFTPs * Rain fed subsistence farming at micro-scale | (Brackelaire, 2006) |
| **Forest plantations** | |  |  |  |
| **Forestry in native forests** | | |  |  |
| B10.I | **Commercial logging** | * Usually private forestry companies * Based on forestry concessions, although many of them are currently running out | * Selective timber harvesting for commercial purposes | (Müller et al., 2014) |
| **State conservation** | |  |  |  |
| B11.I | **Strict state protected areas** | * Public (mostly state) conservation agencies | * Strict landscape and biodiversity protection by preventing extractive economic activities and limiting access (IUCN category I-II) * Managed to be maintained without other alterations than those necessary to ensure their control and visitor attention * Economic exploitation is prohibited (except for tourism) * Varying enforcement and effectiveness * Forest area changes in central India (excludes non-forest tree categories including commercial plantations) | (FCBC, 2015) |
| B11.II | **Less restrictive state protected areas** | * Public (mostly departmental, municipal) conservation agencies | * Less strict area-protection in terms of access and productive land uses, e.g., integrated management zones (IUCN category III-VI) * Varying enforcement and effectiveness | (FCBC, 2015) |
| **Private conservation** | |  |  |  |
| B12.I | **Private reserves** | * NGOs or private actors involved in conservation or agriculture | * Diverse forms of area protection, e.g. private wildlife refuges or integrated management zones; e.g. Alta Vista by FCBC * Various goals, including biodiversity conservation as well as economic gains from tourism | (FCBC, 2015) |
| **Community conservation** | |  |  |  |
| B13.I | **Indigenous reserves** | * Indigenous administration or government | * Designation of communal protected areas within Indigenous territories * Restriction of logging and hunting * Receive funding and support from conservation NGOs | (CEDLA, 2011; Fundación Tierra, 2011) |
| **Energy land uses** | |  |  |  |
| **Mining & construction** | |  |  |  |
| B15.I | **Large-scale resource extraction** | * State or private companies | * Large-scale mineral mining (gold, silver, copper, and zinc) or gas extraction * Has the potential to increase in the future, as access to "protected" areas is opened | (Müller et al., 2014; Soruco, 2011) |
| B15.II | **Small-scale mining** | * Cooperatives of Indigenous peoples or peasants | * Legal or illegal small-scale mining (mostly gold) on Indigenous or peasant territories | (Müller et al., 2014; Soruco, 2011) |

1. ***Land systems in the Deccan dry forests in India***

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| **Systems** | | **Actors** | **Activities** | **References** |
| **Industrial annual cropping** | | |  |  |
| C1.I | **Commodity cropping** | * Farmer female outlineCapitalized farmers or companies * Oriented towards domestic to international markets | * **Tractor with solid fill**Medium to large-scale, input-intensive farming * Irrigation (dependent on groundwater) * Cultivated crops: sugarcane, cotton, banana | (Anantha et al., 2021; Ashutosh Kumar Mishra et al., 2021; Mugal et al., 2021; Quamar et al., 2020; Shukla et al., 2022) |
| **Capitalized ranching** | |  |  |  |
| **Speculative land holding** | |  |  |  |
| **Capitalized tree cropping** | |  |  |  |
| C4.I | **Tree-crop plantations** | * Capitalized farmers or companies * Oriented towards domestic to international markets | * Medium to large-scale, input-intensive farming * Irrigation (dependent on groundwater) * Cultivated trees: rubber, coconut, orange, grapes, mango, mulberry, gooseberry | (Ashutosh Kumar Mishra et al., 2021; Mugal et al., 2021; Quamar et al., 2020; Shukla et al., 2022) |
| C4.II | **Horticultural agroforestry** | * “Progressive” farmers with access to technology | * Agroforestry: combining fruit trees with commercial crops or vegetables | (Dhyani et al., 2021; Shukla & Dhyani, 2023) |
| **Smallholder farming** | |  |  |  |
| C5.I | **Agropastoral systems** | * Smallholders owning the land | * Mixed rainfed farming * Integrating trees or shrubs (for fruits, nuts, fuelwood, timber, and shadow) with growing vegetables, medicinal plants, herbs, and spices * Livestock rearing: grazing and fodder cultivation in the forest/tree plantation | (Dadas, 2023; Patil et al., 2012) |
| C5.II | **Marginalized farming** | * Marginalized smallholders with low socioeconomic capacities * Often landless farmers cultivating the land owned by others | * Mixed rainfed farming with traditional crops and cropping practices * Cultivated crops: cereals, paddy, millet, vegetables * Use of timber and NTFP from adjacent forests | (DeFries et al., 2016, 2023; Ghate et al., 2009; Yadav et al., 2022) |
| **Shifting cultivation** | |  |  |  |
| **Pastoralism** | |  |  |  |
| C7.I | **Migratory pastoralism** | * Marginalized smallholder communities with low socioeconomic capacities | * Extensive, transhumant herding along traditional routes with cattle and goat | (Centre for Pastoralism, 2021; Dadas, 2023; Patil et al., 2012; Siripurapu et al., 2020) |
| **Forest-dwelling** | | |  |  |
| C8.I | **Forest-dwelling on recognized lands** | * Indigenous communities and forest dwellers * Live on formalized territories within the reserve or protected forests * Exclusive rights to forest resource use | * Gathering of NTFP (plants, honey, fruits…) for personal use and local markets * Use of timber and leaf litter for fuelwood and fodder * Subsistence hunting * Use of fire as management (for NTFP or burning of litter for new grazes) | (Date & Lele, 2023; Kumar et al., 2022; Lele et al., 2015; Prasad et al., 2008) |
| C8.II | **Forest-dwelling without land rights** | * Indigenous communities and forest dwellers * Live illegally within reserve forests | * Gathering of NTFP (plants, honey, fruits…) for personal use and local markets * Use of timber and leaf litter for fuelwood and fodder * Subsistence hunting * Use of fire as management (for NTFP or burning of litter for new grazes) | (SCSTRTI, 2022) |
| **Plantation forestry** | |  |  |  |
| C9.I | **Private forestry** | * Individuals and private companies | * Large-scale, timber harvesting from tree plantations * Common tree species: teak, sal tree, rosewood, bamboo, poplar | (Meiyappan et al., 2017; Roy, Roy, et al., 2015) |
| **Forestry in native forests** | | |  |  |
| **State conservation** | |  |  |  |
| C11.I | **State protected areas** | * State conservation agencies | * Public area-based conservation for ecosystems and biodiversity * Restriction of extractive activities, such as logging, grazing, hunting, mining, quarrying and farming | (Meiyappan et al., 2017; Srivathsa et al., 2023) |
| C11.II | **Reserve forests** | * Public (state, province, municipal) conservation agencies | * Forests protected under the Indian Forest Act, 1927 * Forests are the property of the state and are managed by the Forest Department * Exclusive use rights for recognized forest villages inside the forests | (Ramachandran et al., 2018) |
| **Private conservation** | |  |  |  |
| **Community conservation** | |  |  |  |
| C13.I | **Communal forests** | * Management by local communities * Co-administration by local government | * Joint forest management by local community and state government (sometimes marked areas in reserve forests or protected areas) * Exclusive use rights for collection of NTFPs or selective logging * Sometimes part of community afforestation schemes | (Bhattacharya & Basnyat, 2003; Jayalakshmi, 2018) |
| C13.II | **Sacred groves** | * Indigenous Peoples or local communities | * Community forest protection on a religious basis * Taboos and restrictions of using natural resources follow cultural norms of worshiping deities or ancestral spirits | (Dar et al., 2022; Kulkarni et al., 2018) |
| **Energy land uses** | |  |  |  |
| C14.I | **Water reservoirs and dams** | * State-owned or private companies | * Water reservoirs for irrigation, drinking, and household use of water and electricity | (Unni, 1985) |
| C14.II | **Electric power structures** | * State-owned or private companies | * Wind farms, solar parks, nuclear plants, thermal power plants | (Khan et al., 2023) |
| **Mining & construction** | |  |  |  |
| C15.I | **Mining** | * State-owned/private companies or smallholders | * Mining of sand, metal, coal and rocks | (Ranjan, 2019; Thakur et al., 2022) |
| C15.II | **Infrastructure development** | * Government agencies and private companies | * Construction of roads, rails and energy distribution facilities, factories |  |

1. ***Land systems in the Miombo-Mopane woodlands in Mozambique***

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| **Systems** | | Farmer female outline**Actors** | **Tractor with solid fillActivities** | **References** |
| **Industrial annual cropping** | |  |  |  |
| D1.I | **Commodity cultivations** | * Capitalized private actors * Oriented towards domestic to international markets * Often investors from abroad | * Medium to large-scale industrialized, input-intensive farming * Commodity cropping (maize, soybean, cotton) and horticulture (fruits, vegetables, flowers) * Usually irrigated (center pivot system) | (Abeygunawardane et al., 2022; Baumert et al., 2019; Bey et al., 2020; Deininger & Xia, 2016; Matteo & Schoneveld, 2016; Röder et al., 2015; Zaehringer et al., 2018) |
| **Capitalized ranching** | | |  |  |
| D2.I | **Commercial cattle ranching** | * Profit-driven, capitalized farmers or companies * Oriented towards domestic/regional markets (livestock not disease-free) * Often investors from abroad | * Cattle breeding and cow-calf ranching on implanted pasture * Cleared or partially cleared forests * Often part of the same farm as *Commodity cultivation* system, where the prevalence of land-use activity is flexible and depends on climate and market dynamics | (Kronenburg García et al., 2022) |
| **Speculative land holding** | | |  |  |
| **Capitalized tree cropping** | |  |  |  |
| D4.I | **Commercial tree crop plantations** | * Capitalized private actors * Oriented towards domestic to international markets * Often investors from abroad | * Medium to large-scale, input-intensive farming * Cultivated trees: sugar cane, banana, macadamia, citrus fruits, avocado * Plantations are often very large-scale and require substantial investment * Sometimes part of *Commodity cultivation* system, whereby crops (e.g. maize) are planted to finance the development of large-scale tree crop plantations * Irrigation depending on available capital and water (center pivot system) | (Bey & Meyfroidt, 2021; Kosenius et al., 2019; Kronenburg García et al., 2022) |
| **Smallholder farming** | |  |  |  |
| D5.I | **Medium-scale farming** | * Capitalized actors: urban-based investors or influential rural people who started as small-scale farmers and successfully expanded their operations * Access to capital and technologies * Oriented towards domestic to international markets * Tend to dominate farm lobby groups and influence agricultural policies and public expenditures in their favor | * Medium-scale, mechanized farming * Use of machinery * Cultivation of marketable crops: soy, beans, potatoes * Change market conditions in the area: attract large-scale grain traders and mechanization rental services * Rapidly growing number of medium-scale holdings | (Jayne et al., 2016; Nolte, 2014; Röder et al., 2015) |
| **Shifting cultivation** | |  |  |  |
| D6.I | **Semi-subsistence smallholding** | * Smallholders with low material capacities * Gradient of surplus production that is sold on markets (hardly any “pure” subsistence systems * Gradient of land availability to expand production (largely depending on local population density) | * Small-scale rotational farming on multiple small plots in several kilometers distance from settlements: land is cleared by cutting and burning vegetation, and crops are cultivated for 4-5 years before moving to a different plot of land, allowing the previous plot to regenerate for 8-10 years (increasingly shorter due to higher levels of population density) * Traditional, not-mechanized, rainfed, low-input farming practices * Cultivated crops: food crops (mainly maize, beans, cassava, millet sorghum, vegetables) and cash crops (cashew, tobacco, citrus fruits, mango, papaya) * Combination of trees and annual crops on the same field * Specific riverbed agriculture where small wet patches allow dry season agriculture and cultivation of tomatoes, potatoes, rice * Animal rearing for income as a safe net: goat, chicken, and, in the South (free of tsetse fly), cattle * Use of adjacent, remaining forest patches for timber, charcoal (mostly for income as a safety net), NTFP (fruits, nuts, honey, medicinal plants), and subsistence hunting | (Bey et al., 2020; Jayne et al., 2016; Leonardo et al., 2018; Nhiuane et al., 2024; Nolte, 2014; Röder et al., 2015; Rufino et al., 2011; Schneibel et al., 2016, 2017; Silva et al., 2019; Temudo & Silva, 2012; Woittiez et al., 2013; Woollen et al., 2016) |
| **Pastoralism** | |  |  |  |
| **Forest-dwelling** | | |  |  |
| **Forest plantations** | |  |  |  |
| D9.I | **Commercial timber plantations** | * Capitalized private actors and forestry companies | * Large-scale planting and harvesting of trees for markets * Fast-growing species: eucalyptus and pine | (Bey & Meyfroidt, 2021; Kosenius et al., 2019; Kronenburg García et al., 2022) |
| **Forestry in native forests** | |  |  |  |
| D10.I | **Concessions-based logging** | * Commercial private, often international, actors * Oriented towards national and international (China, Europe) markets * Based on concessions for large areas (more than 50,000 ha) and a 50-year lease * Requires government-approved management plan and annual harvesting licenses | * Selective extraction of valuable timber in production forests * Gradient of ecological impact | (Herdieckerhoff et al., 2023; Wertz-Kanounnikoff et al., 2013) |
| D10.II | **License-based logging** | * Commercial private actors * Oriented towards national markets * Based on simple licenses at smaller scale and for 5 years * Harvesting permit, with a maximal annual harvesting quantity * No formal specification or guidelines for management | * Selective extraction of valuable timber in production forests * Temporary permits but often illegal extraction, e.g., rosewood * High harvest quantities with strong ecological impact | (Parduhn & Frantz, 2018) |
| **State conservation** | |  |  |  |
| D11.I | **Strict state protected areas** | * State conservation agencies, usually in partnership with private actors (NGOs) for funding and governance | * Restrictive area-based conservation core zones: Strict protection by banning any forest use (IUCN category I and II) * Management plan and state budget * Legally public, but with a lot of private funding, governance, and (ecotourism) activities |  |
| D11.II | **Less restrictive state protected areas** | * State conservation agencies, usually in partnership with private actors (NGOs) for funding and governance | * Less strictly protected forest reserves and conservation buffer zones: less strict in terms of land uses, such as collection of NTFP and subsistence hunting * Existing management plan, but varying enforcement and effectiveness * Often unclear boundaries | (Mananze et al., 2016; N. Ribeiro & Matediane, 2019) |
| **Private**  **conservation** | |  |  |  |
| D12.I | **Safari reserves** | * Private actors or tourism companies * Temporary (usually 50 years) land concessions from the state * Often considerable political influence and power | * Safari and ecotourism activities * Often in the buffer zones of state protected areas | (Buckley & Mossaz, 2018) |
| D12.II | **Game reserves** | see *Safari reserves* | * Game hunting and ecotourism activities * Often in the buffer zones of state protected areas | (Mbaiwa, 2018) |
| **Community conservation** | |  |  |  |
| D13.I | **Sacred forests** | * Local smallholder communities | * Worshiping and protecting Nature and Forests for deities or ancestral spirits * Restrictions on using natural resources follow cultural norms | (Galvin et al., 2018; Mbaiwa & Kolawole, 2013; Virtanen, 2002) |
| **Energy land uses** | |  |  |  |
| **Mining and construction** | |  |  |  |
| D15.I | **Large-scale mining** | * International companies | * Large-scale open-pit mining for gold, graphite * Inland infrastructure for offshore oil, gas, and sand extraction * Small spatial footprint but a large impact on surrounding areas | (Wiegink & Kronenburg García, 2022) |
| D15.II | **Artisanal mining** | * Small-scale actors | * Artisanal mining for gold, gemstones, tantalite | (Hilson et al., 2021) |

1. ***Land systems in the Indochina dry forests in Cambodia***

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| **Systems** | | Farmer female outline**Actors** | **Tractor with solid fillActivities** | **References** |
| **Industrial annual cropping** | |  |  |  |
| E1.I | **Agribusiness farming** | * Private companies * Oriented towards international markets * Land use based on economic land concessions (can be attributed inside protected areas (in the “sustainable use zone”). | * Medium to large-scale industrialized, input-intensive farming * Cultivated crops: mostly sugarcane, cassava, and irrigated rice (emerging) | (Diepart et al., 2022; Diepart & Sem, 2018) |
| **Capitalized ranching** | | |  |  |
| **Speculative land holding** | | |  |  |
| **Capitalized tree cropping** | |  |  |  |
| E4.I | **Commercial tree crop plantations** | * Capitalized private actors or companies * Oriented towards domestic to international markets * Land use based on economic land concessions (can be attributed inside protected areas (in the “sustainable use zone”). | * Medium to large-scale, input-intensive farming * Cultivated trees: rubber, cashew, oil palm | (Diepart & Sem, 2018) |
| **Smallholder farming** | |  |  |  |
| E5.I | **Commercial smallholding** | * Smallholders with high market access and high material capacities * Access to high-value crops and technologies * Sometimes in the “Community zone” of protected areas (eligible for titling) | * Small-scale agriculture for domestic and export markets (cultivated crops: paddy rice, maize, cassava, pepper, rubber, cashew, coffee and high-quality vegetables) | (Diepart et al., 2023) |
| E5.II | **Semi-subsistence smallholding** | * Smallholders with low material capacities * Sometimes in the “Community zone” of protected areas (eligible for titling) | * Mixed livelihood strategies including   + Small-scale mixed farming (cultivated crops: rice, maize, cassava, vegetables); and to a lesser extent animal rearing (chicken, pigs)   + Aquacultures and fishing   + Use of adjacent forests for timber, NTFP and subsistence hunting   + Remittances from labor migration into cities * No capital-intensive inputs or machinery, oxen, or water buffalos for traction | (Kong et al., 2019) |
| **Shifting cultivation** | |  |  |  |
| E6.I | **Communal Indigenous land use** | * Indigenous ethnic minority communities * Tenure rights are usually based on the “Indigenous communal land” category | * Both subsistence shifting cultivation (upland non-flooded rice) and permanent commodity cultivation for export markets (maize, cassava, pepper, rubber, cashew, coffee, and high-quality vegetables) * Forest use for timber, NTFP, and subsistence hunting | (Diepart & Sem, 2018; You et al., 2015) |
| **Pastoralism** | |  |  |  |
| **Forest-dwelling** | | |  |  |
| **Forest plantations** | |  |  |  |
| E9.I | **Commercial timber plantations** | * Capitalized private actors and forestry companies with economic land concessions | * Large-scale planting and harvesting of trees for national and international markets * Fast-growing species (acacia, eucalyptus) and teak | (So et al., 2010) |
| **Forestry in native forests** | |  |  |  |
| E10.I | **Informal, commercial** l**ogging** | * Capitalized private actors and forestry companies * No active forest concessions anymore since the log ban in 2001 * Logging companies bypass the logging ban by logging inside economic land concessions | * Forest clearcutting * Obtain concessions for agricultural land use but do not cultivate the land after clearing | (Milne, 2015; Work et al., 2023) |
| **Conservation land uses** | |  |  |  |
| E11.I | **Conservation core zones** | * State Ministry of Environment | * Protected area core zones: Banning any forest use besides conservation and research * Protected area conservation zones: Restriction of extractive land uses but the collection of NTFP allowed with a permit | (Diepart & Oeur, 2023) |
| E11.II | **Sustainable use zone** | * State Ministry of Environment | * Protected area zone where several land uses are permitted: Indigenous communal lands, industrial agriculture, hydropower reservoirs, or mining concessions | (Diepart & Oeur, 2023) |
| **Privat conservation** | |  |  |  |
| **Community conservation** | |  |  |  |
| E13.I | **Community forestry** | * Smallholder communities using production forest (co-management with the Forestry Administration) * Supported by NGO’s | * Collection of NTFPs, resin tapping, and subsistence hunting * Selective logging, if approved by the forestry administration | (Lambrick et al., 2014) |
| E13.II | **Indigenous sacred forests** | * see *Indigenous communal land use* | * Forests set aside for Indigenous spiritual and burial uses | (Diepart & Oeur, 2023) |
| **Energy land uses** | |  |  |  |
| E14.I | **Water reservoirs** | * Private companies * Located in “sustainable land use” zone of protected areas | * Water reservoirs for hydropower | (Milne, 2015) |
| **Mining and construction** | |  |  |  |
| E15.I | **Large-scale mining** | * Private companies * Located in “sustainable land use” zone of protected areas | * Large-scale open-pit mining for gold and minerals (e.g., bauxite) * Mostly still in the exploration phase | (Spiegel, 2016) |
| E15.II | **Artisanal mining** | * Smallholders | * Informal small-scale mining | (Spiegel, 2016) |

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