Technical Note

The Landuse Emissions Atlas of Ethiopia

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The purpose of the Land Use Emissions Atlas is to measure Greenhouse Gas (GHG) emissions from landuse/land cover change. Accordingly four major map sets with different purposes and functionalities were developed-the national land cover, the carbon stock, the historic emissions, and the scenario emissions map. The web atlas is capable of several basic query options are available to display charts and graphs as well as numbers. All but scenario maps, the scope of the analyses is at the district level of details. Yet, due to lack of high resolution/large-scale input data, and the current project scope, the atlas in its current state may not satisfactory for district level planning. However, it does have the potential and tools that can be readily applied as better quality data emerges. Mitigating the data gap should be taken as main priority moving forward

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1. INTRODUCTION

The purpose of the Landuse Change Emissions Atlas of Ethiopia is to measure GHG emissions from landuse/landcover change. Accordingly four major mapsetswith different capabilities were developed. These are the landcover map, the carbon stock map, the historic emissions map, and the scenario emissions map. Each category of these is described in the methodology section. By simple click on the atlas pages many charts and graphs can be generated and also various basic queries from the maps and their attribute tables are possible. For the most part, the scope of the analyses goes to the district (Woreda) level of details. This being said due to lack of high resolution (large scale) input data and the project scope, the atlas at the current state may not be fully satisfactory to accommodate all necessary local level details that might be needed for local (district) level planning and analyses. Yet, it does have such potential and tools as better quality data emerges. Maintaining and updating the atlas with emerging new relevant data should be a priority moving forward.

2. THE DATASETS

The datasets of national and global origins were used in combination. The core datasets include but not limited to two slightly different versions of landuse maps from ILRI Kenya and ILRI Ethiopia offices, Vegetation Atlas of Ethiopia from Addis Ababa University, Landuse map from Addis Ababa University, Protected area maps from Ethiopian Wildlife Conservation (EWCA) authority, the Global Forest Change (GFC) data from Hansen, University of Maryland, Saatchi biomass carbon HWSD soil carbon dataset. The table below presents the complete list and brief description of the datasets used.

No.	**Dataset**	**Sources & Year of publication**	**How was it used**	**Accessed**	**Strength**	**Weaknesses**	**Notes/remarks**
1	ILRI Nairobi office Landuse map of Ethiopia	ILRI Kenya office, 2004/05	Main input and its description field used to revise the classes	ArcGIS online-posted in 2007	Spatially the best. WBISPP used as in put data & FAO behind it	Scale coarse-too much generalization, old (200/04)	Meeting ILRI staff to verify the details of the Atlas would help
2	ILRI Ethiopia office Landuse map of Ethiopia	ILRI Ethiopia office, unpublished	The attribute fields used for generating new with combination of other dataset	From onsite contact, ILRI Addis Ababa GIS lab,	WBISPP input, Attribute table quantifies the tree cover percent for most classes	Spatially terrible-specially for northern Ethiopia	Only the descriptive text was used not the spatial boundaries
3	Addis Ababa University (AAU),	Addis Ababa University (AAU), Unpublished	Visually to compare the classes in certain	Onsite contact, AAU, Addis Ababa	Some classes like pastoral land	too generalized	Not much used at this stage, but reuse it to improve some

	Landuse map		regions.		compliments other atlases		classes for next version
4	Vegetation Atlas of Ethiopia	Addis Ababa University (AAU), 2011	Union analysis with ILRI map to get new classes and spatial polygons	Onsite contact, AAU, Addis Ababa	Recent and credible, based on 10 volumes of flora study	Potential, and very complex spatial pattern	Very challenging shape, potential vegetation
5	Protected Areas & more	Ethiopian Wildlife Conservation authority (EWCA), 2012	As a mask & off limits for some analysis as needed	Onsite contact, EWCA, Addis Ababa	Latest updated material, very helpful		New proposed areas yet not all included
6	GFC Hansen data from University of Maryland	Hansen et. al, 2013, University of Maryland	Zonal statistics by cover class id is used to improve the classification	Downloaded online from Google Earth Engine	Most thorough tree cover assessment (10yrs)	Undermines scattered trees and young regrowth	
7	Saatchi, NASA carbon stock data	S. Saatchi et. al, 2010	Used in all carbon analysis stage	Accessed Online	National coverage & flexibility	Resolution is coarse	
8	AFOLU IPCC Guidelines	IPCC, 2006 Vol. 4	Used in Scenario emissions Analysis	Accessed online			
9	WBISPP	FRC & Regional Gov., 2004	Used for comparison of results in Carbon Analysis	Regional reports available online, National report obtained from FRC contact	Only nationally available Forest inventory data for Ethiopia so far.	No maps of the project yet found, but the data was used to generated the landuse maps obtained from ILRI offices	About two decades old. Tables and reports are available
10	HWSD	HWSD, 2012	Used in calculation of Scenario emissions analysis	Downloaded online from HWSD site			1km resolution

Table1. an overview of core input datasets

The landuse maps accessed from ILRI offices were developed primarily from the Woody Biomass Inventory Strategic Planning Project (WBISPP) completed in 2003/04 (personal communication with Ethiopia office of ILRI). This is the only national forest inventory ever conducted, supported by FAO. The AAU Vegetation Atlas of 2011 is the latest and most comprehensive product on vegetation of Ethiopia. This atlas was developed based on more than 30 year of flora study of Ethiopia and Eritrea work by Addis Ababa University and Natural History Museum of Denmark. Both lead authors of the atlas Ib Friis and Sebsebe Demissew were also the lead on the flora projects. The GFC data is probably the best freely available global landcover change data being both current (2013) and of high spatial resolution (30m). The protected areas from EWCA includes host of current datasets including parks, reserves, sanctuaries community conservation area etc., published in 2012. To generalize an effort was made to use the best available data that could be accessed under the project circumstances. However, there was limited possibility to access government and some NGO owned datasets and we cannot guarantee the inclusion of all best available data.

3. METHODOLOGY

ArcGIS software was the main application used to develop the atlas. Several geoprocessing steps were applied on the input datasets (table1) described in the previous section to develop the atlas maps. The first step in the atlas development process was generating a re-classified landcover map that will be used as core input in developing all successive carbon analysis maps. The need for new landcover map is due to lack of suitable landcover/landuse map of Ethiopia that can be directly used as an input for carbon analysis. Therefore, using existing landuse/landcover and supplementary data, we needed to come up with a new generalized landcover map with landcover classes of distinguishable mean carbon (t C/ha) from each other.

The next sets of maps are derived by translating the above landcover map into biomass carbon stock (density) map. This was achieved by combining the landcover map with global carbon dataset from Saatchi, NASA. The third sets of maps are historic landcover change emissions over the 2001 to 2012 period. This analysis was done by combining the previous two outcomes with global forest change data from Hansen et. al, 2013 at University of Maryland. The last set is the landuse change scenario emissions map developed more or less independently from the rest. The following sections will describe the major geoprocessing steps implemented to develop the maps of the atlas using the aforementioned input datasets (table1). The maps which are the end result of this geoprocessing work, and the website will be discussed in the results section.

3.1. Union and Join Field Analysis

As mentioned above the first step in the atlas development process was generating landcover map that will be used as core input in developing all successive carbon analysis maps. Several geoprocessing steps were implemented with priority focus on factors that affect the carbon density such as the vegetation cover density and anthropogenic alteration. The end result is aggregation of existing traditional classification- instead of focus on functional roles of landcover types, to come up with generalized landcover categories like forests, grasslands, woodlands which are relevant for carbon analysis.

As a first step here, ArcGIS "union" operation was used to combine the vegetation atlas (4, table1) and the landuse map obtained from ILRI Nairobi office (1, table1). The *union* command computes a geometric union of the input features where all features and their attributes will be written to the output feature class (http://desktop.arcgis.com/en/desktop/latest/tools/analysis-toolbox/union.htm). The two primary fields of interest in the attribute table of the combined product are the *"label"* field referring to the vegetation class names from the vegetation atlas and the "*DESCRIPN*" field referring to the landuse classes from landuse map.

ILRI_Atlas_Dslv_Union_UTM

OBJECTID *	label	DESCRIPN	LANDUSE	NAME	LandCoverT	Area(ha)
32	Acacia-Commiphora woodland and bushland proper (ACB)	Bushed shrubbed grassland	92 0 0 0	Grassland	Shrubbed grassland	9244151.486294
33	Acacia-Commiphora woodland and bushland proper (ACB)	Bushed shrubbed grassland/Wooded grassland	92 92 93 0	Grassland	Shrubbed grassland	1433.307351
34	Acacia-Commiphora woodland and bushland proper (ACB)	Dense bushland	71 0 0 0	Bushland	Dense bushland	3341176.347976
35	Acacia-Commiphora woodland and bushland proper (ACB)	Dense coniferous high forest	41 0 0 0	Forest	Disturbed high forest	44.382666
36	Acacia-Commiphora woodland and bushland proper (ACB)	Dense mixed high forest	42 0 0 0	Forest	Disturbed high forest	143109.756468
37	Acacia-Commiphora woodland and bushland proper (ACB)	Dense shrubland	81 0 0 0	Shrubland	Dense shrubland	5930088.208096
38	Acacia-Commiphora woodland and bushland proper (ACB)	Dense woodland	51 0 0 0	Woodland	Dense woodland	124786.47353
39	Acacia-Commiphora woodland and bushland proper (ACB)	Dense woodland/Perenn. crop cult.	51 51 24 0	Forest	Dense woodland	13352.894783
40	Acacia-Commiphora woodland and bushland proper (ACB)	Dist. high forest/Moderately cult.	43 43 23 0	Forest	Disturbed high forest	8819.369571
41	Acacia-Commiphora woodland and bushland proper (ACB)	Dist. high forest/Perenn. crop cult.	43 43 24 0	Forest	Disturbed high forest	4740.271936
42	Acacia-Commiphora woodland and bushland proper (ACB)	Disturbed high forest	43 0 0 0	Forest	Disturbed high forest	45293.023178
43	Acacia-Commiphora woodland and bushland proper (ACB)	Exposed rock surface	111 0 0 0	Bareland	Barenland with scatt	536876.317502
44	Acacia-Commiphora woodland and bushland proper (ACB)	Exposed rock surface with scattered scrub and grass	115 0 0 0	Bareland	Barenland with scatt	4194180.811697

Table2. The attribute table of union map with two important fields from vegetation atlas and landuse map

The purpose of combining the two was to take advantage of the higher resolution and scientific naming of landcover classes used in the vegetation atlas. Moreover, the atlas is arguably the best available study on vegetation science of Ethiopia. It is the product based on rich experience of the "flora of Ethiopia and Eritrea" studies which spanned more than 20 year and produced 8 volumes of flora books. A new landcover field ("LandCoverT" or "CoverType") was created and editing starts in this attribute table of the union product. The content of this new field for each row was manually edited based the similarity of the names under the "label" and "*DESCRIPN*" columns (highlighted) above together with the visual exploration of underlying high resolution imagery. The first draft classification of landcover field was done in excel after exporting the attribute table ("NameEdits"). The content of new field "LandCoverT" of "NameEdits" was attached back to the map using the *join field* operation of ArcGIS with *OBJECTID*.

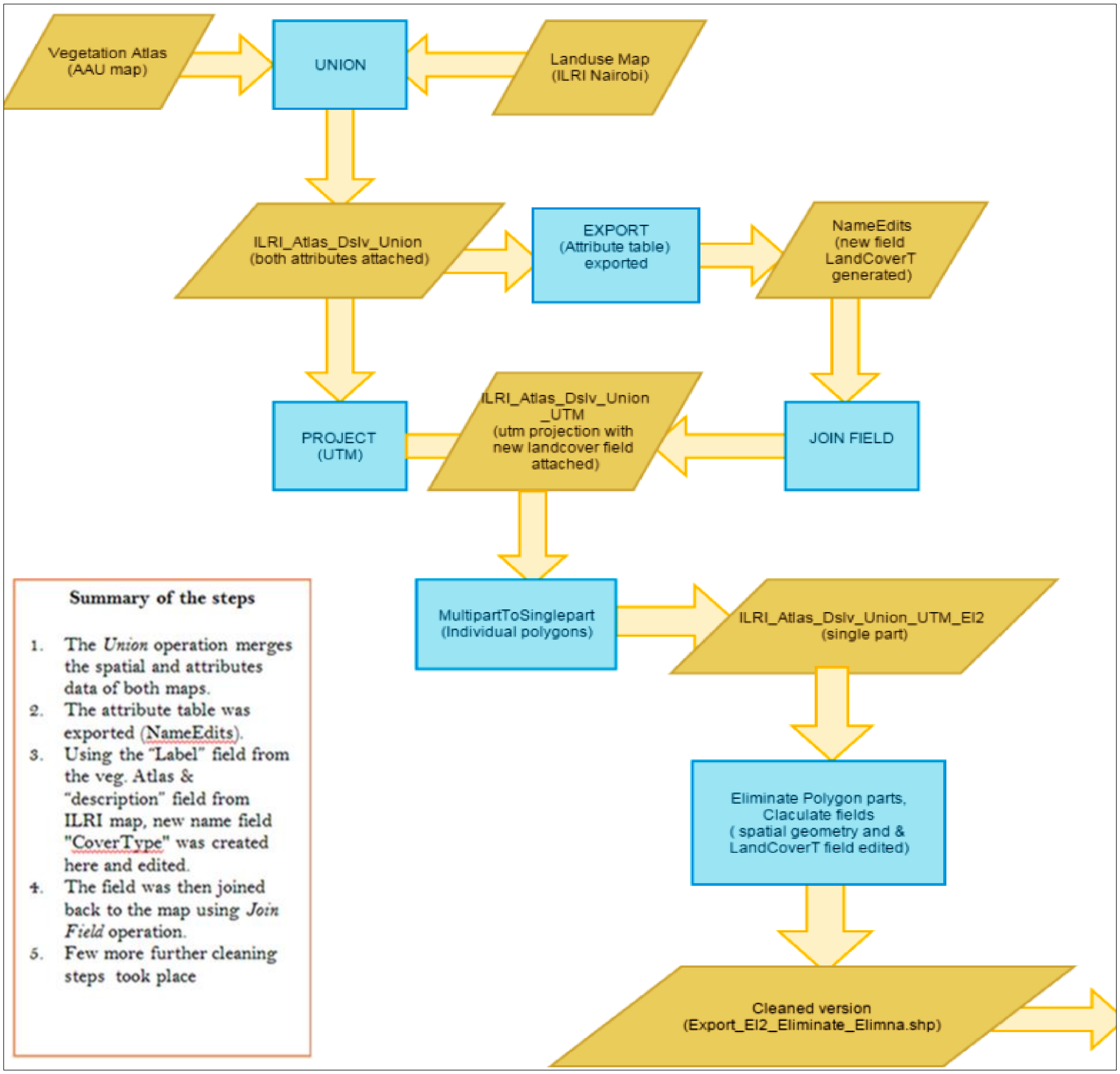

Figure1. The flowchart summary of key geoprocessing steps described in section 4.1 above

3.2. Zonal Statistics and Join Field Analysis

The purpose of this step was to validate and further improve the preliminary classification conducted in the preceding step. To do so the intermediate product from preceding step was combined with the global forest change (GFC) data. The GFC data was produced by Hansen et al. 2013 at University of Maryland (6) and it contains series of relevant quantitative information used in the atlas development. At this stage the tree cover density (percent tree cover) data was of particular interest used to validate the class descriptions. The intermediate product was combined with the 30 m resolution tree cover density layer of GFC (`GFC_treecover_utm)` using zonal statistics tool. The Zonal Statistics as table analysis generates the averaged pixel value within a given polygon boundary (in our case the landcover class). The following step was to use join field tool, to attach the created mean value field from the new table (ZonalSt_ILRI_At1) to the attribute table of the map produced in the preceding step (ILRI_Atlas_Dslv_Union_UTM_El2). However, multiple test versions were produced before reaching at the final two pair on both sides, namely *ILRI_Atlas_GFC_Zonal_Elimina4* & *ZonalSt_ILRI_At3*. The two steps of this process calculates a single mean tree cover density (percent tree cover) value per each landcover class from GFC tree cover layer and attaches as a new field to the attribute table of the preceding product generated at section 4.1 above. Some landcover classes of the new “CoverType” field were then further edited using ArcGIS field calculator. The newly assigned mean tree cover density value and visual inspection of the high resolution imagery was used to do the re-editing landcover classes as deemed appropriate. For instance, the class name was modified to associate as closely as possible with the corresponding mean tree cover percent value of the cell. I.e. if mean tree cover density is 75%, and the old class name was “grassland”, it would be reclassified as mixed natural high forest.

Input1/output1	Process	Input2/output2	Process	Input3/output3	The Purpose
		Vegetation Atlas UNION ILRI-Nairobi Landuse (*ILRI_Atlas_Dslv_Union_UTM_El2*)	ZonalStatisticsAsTable (OID)	*GFC Tree Cover Layer (GFC_treecover_utm)*	Generated the GFC mean tree cover values as table (ZonalSt_ILRI_At1,2 & 3)
Vegetation Atlas UNION ILRI-Nairobi Landuse *(ILRI_Atlas_Dslv_Union_UTM_El2)*	Join Field (OID) & followed by multiple cleaning up	GFC Zonal Statistics Table *(ZonalSt_ILRI_At2)*			Combined the intermediate product with GFC to obtain tree cover density data for validation and re-classification
Vegetation Atlas UNION ILRI-Nairobi Landuse, GFC test *(ILRI_Atlas_GFC_Zonal_Elimina4)*	ZonalStatisticsAs Table (LandCoverT)	*GFC Tree Cover Layer (GFC_treecover_utm)*			
GFC Zonal Statistics Table *(ZonalSt_ILRI_At3)*	Join Field (LandCoverT)	Vegetation Atlas UNION ILRI-Nairobi Landuse *(ILRI_Atlas_Dslv_Union_UTM_El)*			
Vegetation Atlas UNION ILRI-Nairobi Landuse Mean GFC values attached *(ILRI_Atlas_Dslv_Union_UTM_El2)*					

Table3. The summary of geoprocessing steps followed to attach the GFC tree cover density data to the intermediate product. A process applied on the input1/input2/input3 data in the given cells bounding it on the same row (left and right) yields the intermediate product in a cell that is one row below and one column left of it (the process cell in question). See the directions of the arrows above.

3.3. Spatial Join, Intersect and Merge Analysis

Using the ArcGIS spatial join, first the ILRI Addis Ababa (2) source map was joined with the ILRI Nairobi map (1). Using the common id of ILRI Nairobi maps an intersect analysis was done with the intermediate product generated at section 4.2 above. This step brings in the additional quantitative information (vegetation cover %) from ILRI Addis Ababa source map. This dataset originates from the 2001/2004 national forest inventory project -the Woody Biomass Inventory Strategic Planning Project (WBISPP) which was also used as a primary input data for the ILRI Nairobi source map (personal communication with data source at ILRI GIS Lab, Addis Ababa). The attribute table has important quantitative information (% vegetation cover) in the “LC1_MASDES” field (see the highlighted column) of the screenshot.

Contents | Preview | Description

OBJECTID *	Shape *	LC1_MASDES	COUNT_LC1LU_DES	Shape_Length
1	Polygon		1	2799.9991
2	Polygon	Afro-alpine; Erica / Hypericum	2	1222800.4428
3	Polygon	Afro-alpine; Grassland / Moorland	1	1175599.7445
4	Polygon	Bareland; Exposed rock	7	186153080.632132
5	Polygon	Bareland; Exposed sand / soil	8	217445510.537995
6	Polygon	Cultivated Land; Irrigated	3	2901598.4055
7	Polygon	Cultivated Land; Perennial crops; Enset/Root LC System; lightly stocked	2	270400.1831
8	Polygon	Cultivated Land; Rainfed; Cereal Land Cover System; lightly stocked	9	160623918.343637
9	Polygon	Cultivated Land; Rainfed; Cereal Land Cover System; moderately stocked	9	78815178.799728
10	Polygon	Cultivated Land; Rainfed; Cereal Land Cover System; unstocked (woody pl)	6	140246711.827128
11	Polygon	Cultivated Land; Shifting cultivation; lightly stocked	1	5193996.167101
12	Polygon	Cultivated Land; Shifting cultivation; moderately stocked	2	47187963.290011
13	Polygon	Forest; Bamboo; Highland Bamboo; Dense (50-80% crown cover)	1	24531190.983858
14	Polygon	Forest; Bamboo; Highland Bamboo; Open (20-50% crown cover)	1	1919599.1401
15	Polygon	Forest; Lowland semi-evergreen; Closed (>80% crown cover)	2	1980400.875302
16	Polygon	Forest; Lowland semi-evergreen; Dense (50-80% crown cover)	1	272000.1289
17	Polygon	Forest; Lowland semi-evergreen; Open (20-50% crown cover)	2	184400.0888
18	Polygon	Forest; Montane broadleaf; Closed (>80% crown cover)	3	830000.455701

Table4. The partial screenshot view of the ILRI Addis Ababa office attribute table fields

The description and quantitative information (% crown cover) under this column were used in the interpretation and editing of the new landcover field, after joined into the attribute table of the landcover map using this step. The steps of joining the two are summarized in table5 below.

Input1/output1	Process	Input2/output2	Process	Input3/output3	The Purpose
ILRI_Atlas_Dslv_Union_UTM_El2		IRLI_Landuse_1	*Intersect*	WBISPP_LUS	Attached the WBISPP/ILRI Addis landuse map fields with the intermediate product for further refining of the landcover classes
ILRI_Atlas_Dslv_Union_UTM_El2	*Join Field*	IRLI_WBISPP_Intersect			
ILRI_Atlas_Dslv_Union_UTM_El2	Export (after multiple cleaning)				
Export_El2	Delete field, eliminate etc.				
Export_El2_Eliminate	Multiple cleaning steps, calculate field				
		IRLI_Landuse_1_Dissolve	*SpatialJoin*	WBISPP_LUS_Dissolve2_Dissolv	
Export_El2_Eliminate_Elimina	*Join Field* (After multiple Cleaning)	ILRI_WBISPP_Dslv			
Export_El2_Eliminate_Elimna	*Merge*	ILRI_Landuse_Classes (selection)			
Export_El2_Eliminate_Elimna_edit	Multiple cleaning and field edit				
Export_El2_Eliminate_Elimna_11					

Table5. The summary of geoprocessing steps used to combine the ILRI Addis Ababa map attributes to the intermediate product (see the table3 title text for detailed description of the process flow).

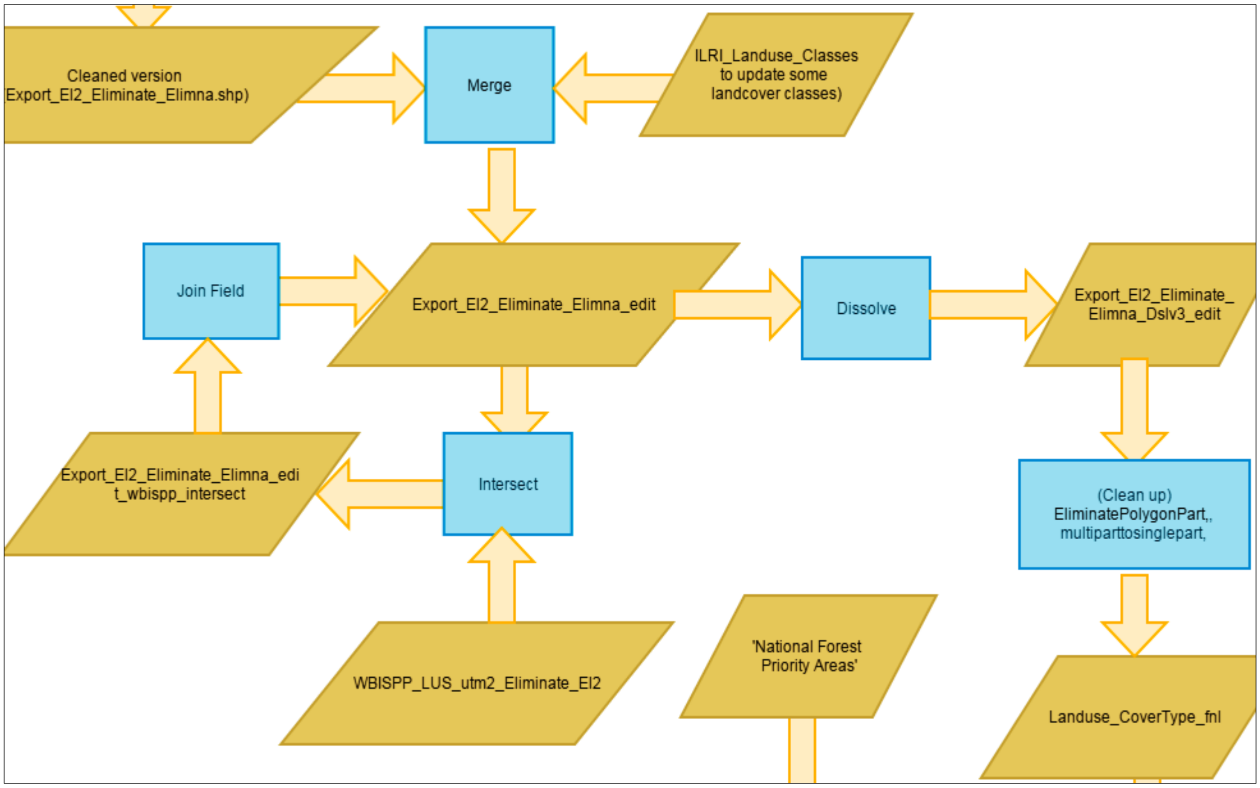

Figure2. The flowchart summary of key geoprocessing steps described in section 4. 2 and Table5 above. This is a continuation of further geoprocessing applied on the intermediate product described on Figure1. The first input here is the same as the output of the flowchart process in figure1.

At this stage, all necessary attribute fields for further editing of the new landcover field ("LandCoverT") are attached to the intermediate landcover map under development (see table6 below).

Export_EI2_Eliminate_Elimna_

OBJECTID *	label	DESCRIPN	LandCoverT	MEAN	LC1_MASDES
260	Salt Pans, Saline/brackish and Intermittent wetlands and Salt	Exposed sand soil surface	Barenland with scattered scrub and gras	0.1	Grassland; unstocked (woody plant)
266	Salt Pans, Saline/brackish and Intermittent wetlands and Salt	Seasonal marsh	Wetland	13	Grassland; unstocked (woody plant)
273	Transitional Rain Forest (TRF)	Intensively cultivated	Intensively cultivated	8.2	Grassland; unstocked (woody plant)
25	Acacia-Commiphora woodland and bushland proper (ACB)	Open shrubland/Moderately cultivated	Moderately cultivated Open shrubland	2.5	Shrubland; Dense (>50% woody cover)
72	Afro-alpine vegetation (AA)	Open shrubland/Moderately cultivated	Moderately cultivated Afro alpine open shr	2.3	Shrubland; Dense (>50% woody cover)
105	Combretum-Terminalia woodland and wooded grassland (CT	Open shrubland/Moderately cultivated	Moderately cultivated Open shrubland	2.5	Shrubland; Dense (>50% woody cover)
172	Dry evergreen Afro-Montane Forest and Grassland complex	Open shrubland/Moderately cultivated	Moderately cultivated Open shrubland	2.5	Shrubland; Dense (>50% woody cover)
198	Ericaceous Belt (EB)	Open shrubland/Moderately cultivated	Moderately cultivated Open shrubland	2.5	Shrubland; Dense (>50% woody cover)
31	Acacia-Commiphora woodland and bushland proper (ACB)	Salt flats	Barenland with scattered scrub and gras	0.1	Shrubland; Open (20-50% woody cover)
132	Desert and Semi-desert Scrubland (DSS)	Salt flats	Salt flats	0	Shrubland; Open (20-50% woody cover)
256	Salt Lake open water vegetation (SLV/OW)	Salt flats	Salt flats	0	Shrubland; Open (20-50% woody cover)
265	Salt Pans, Saline/brackish and Intermittent wetlands and Salt	Salt flats	Salt flats	0	Shrubland; Open (20-50% woody cover)
28	Acacia-Commiphora woodland and bushland proper (ACB)	Perennial marsh	Wetland	13	Wetland; Open water
35	Acacia-Commiphora woodland and bushland proper (ACB)	Water body	Water Body	1.9	Wetland; Open water
51	Acacia wooded grassland of the Rift Valley (ACB/RV)	Water body	Water Body	1.9	Wetland; Open water

Table6. The screenshot an attribute table with all four fields from four datasets (vegetation atlas, GFC & two ILRI origin landuse maps) attached.

The next step is to edit the *"LandCoverT"* field based on the combined interpretation of all the fields joined. Various attribute table query options are possible to manually update the *"LandCoverT"* field which will the new landcover class field. The screenshot preview below shows multiple ArcGIS windows during a query example.

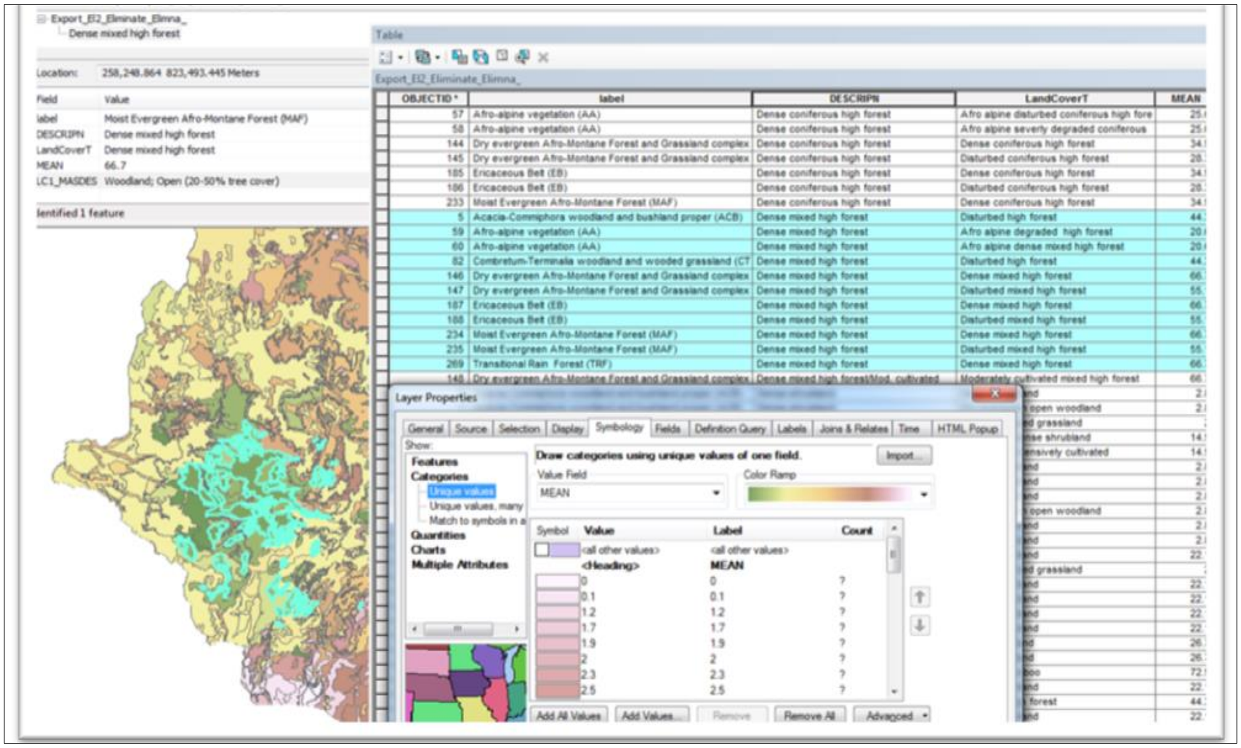

Figure3. Screenshot of multiple ArcGIS windows open while doing the editing of the "LandcoverT" field in the landcover map.

3.4. Cleaning Operations

The last step in the landcover map development was to incorporate various sub-national (project based), data such as protected areas from (5) Ethiopian Wildlife Conservation Authority (EWCA), the National Forest Priority Areas (NFPA), and few major cities based on population density. ArcGIS operations like *update*, *union, clip* and calculate field on *attribute table,* were applied to update the landcover classes accordingly. The chart below summarizes these remaining steps that yielded the first landcover map tested for carbon analysis. This version was revised based on the test results and a final map with 14 landcover classes with clearer mean carbon differences among the landcover classes was generated.

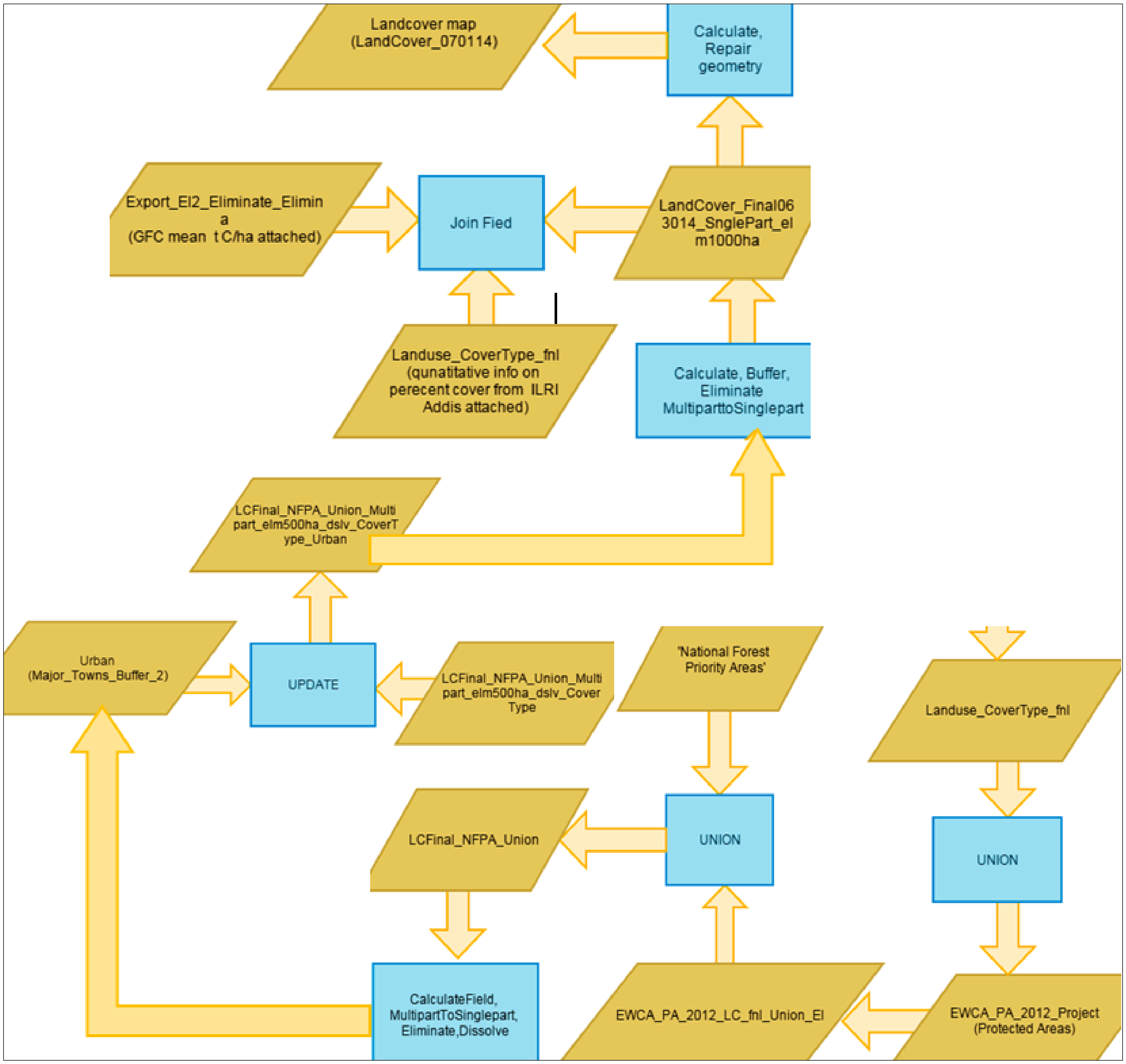

Figure4. The flowchart summary of key geoprocessing steps described in section 4.4 above. Note again this is a continuation of further geoprocessing applied on the intermediate product described on Figure2. The first input here is the same as the output of the flowchart process in figure2.

As described above, combine analysis followed by intersect analysis was used combine the landcover map with biomass carbon data from Saatchi, NASA (Saatchi et al. 2011). The combine tool will attach the pixel carbon values of the Saatchi carbon data that will be averaged over each landcover class to obtain the landcover class mean carbon content. The intersect analysis will breakdown the national carbon stock map into districts showing which landcover classes exist in a given district and hence their respective mean carbon values.

3.5. Combine Analysis

The landcover map produced in the preceding section needs to be converted into carbon map. To achieve this at national and sub-national scale, multiple geoprocessing steps were implemented. First combine analysis was used to merge the landcover map with carbon dataset. The combine tool uses unique IDs of the input raster datasets to combine the attributes of multiple datasets into single output file. In our case the combine analysis attaches the pixel values of the Saatchi biomass carbon data to the landcover map layer. Here the interest is to calculate the mean carbon value (t C/ha) of each landcover class. Therefore, all pixel values of Saatchi biomass carbon that fall inside a given landcover class (multipart/dissolved polygon) will be averaged and the average will be assigned to that landcover class as a single value. This implies that, regardless of where, all polygon parts of a given landcover class are located, they will all assume the same mean carbon value (t C/ha). This step yielded the landcover based (national) carbon stock (density) map, which gives the national overview of landcover carbon content, the mean (t C/ha) and the total per area covered by respective landcover class.

3.6. Intersect Analysis

Using ArcGIS intersect analysis with the districts shape file; the above result was further disaggregated to districts. The intersect analysis extracts the landcover classes that exist in each district and their corresponding attributes from the national carbon stock map including the mean carbon value, and area cover by each of existing landcover classes in a district. The resulting map will enable users to extract information that was not available at national carbon stock map.

The next sets of maps to be developed are historic emissions maps both at national and sub-national scale. To generate those, first ArcGIS combine tool was used in a similar manner as in section 4.5 that would merge the carbon stock map (generated above) with the forest change layer of global forest cover change (GFC) data from Hansen et al. 2013. ArcGIS zonal statistics tool was used to average those individual pixel values generated from combine tool as single mean vale per each landcover class (see section 4.2). This step was followed by multiple geoprocessing and excel calculations to yield a map with rich attribute information from the landcover, the carbon stock and the GFC data was built (tabel9).

National Historic Emission

Landcover	Cover Type	t C (ha)	Deforested Area(ha)	Total Carbon (t C)	CO2 Lost (t CO2)	Loss Year
3	Cultivated Accacia Woodland	16	44	707	2592	2006
12	Urban	29	13	391	1435	2006
8	Intact Mixed High Forest	95	1590	151054	553854	2006
9	Lowland Bamboo Forest	49	79	3882	14235	2006
4	Cultivated Montane Grassland	20	495	9894	36278	2007
6	Disturbed Mixed High Forest	51	12471	636039	2332102	2007
10	Open Woodland	36	11074	398677	1461787	2007
7	Grassland	14	864	12097	44354	2007
1	Alpine Vegetation	21	414	8686	31849	2007
2	Barren Land	4	4	17	61	2007
11	Shrubland	25	84	2095	7681	2007
14	Wetland	17	779	13236	48533	2007
3	Cultivated Accacia Woodland	16	104	1665	6106	2007
12	Urban	29	15	436	1600	2007
5	Cultivated Montane Woodland	24	1660	39832	146047	2007
8	Intact Mixed High Forest	95	4554	432601	1586174	2007
9	Lowland Bamboo Forest	49	111	5452	19991	2007
13	Water Body	5	17	87	319	2007
4	Cultivated Montane Grassland	20	356	7115	26088	2008
6	Disturbed Mixed High Forest	51	8233	419870	1539495	2008
10	Open Woodland	36	15283	550187	2017314	2008
2	Barren Land	4	29	115	422	2008

Table7. Partial view of the historic emissions map attributes table fields

The area deforested and affected landcover types, their respective carbon content and years of deforestation (loss year) is critical information needed to conduct historic emissions calculation, which are all available in this table now. The corresponding map product of this step is called national historic emissions map that will be described in the results section.

Using ArcGIS intersect analysis as in section 4.6; the national historic emissions map was breakdown into districts. Similarly, the calculation was also conducted disaggregated against loss years and landcover classes. This step enables answering queries like how much of which landcover type in a district was deforested in a given year. Hence, the amount of carbon lost due to the deforestation of a certain landcover type in a given year, or total over the study period can be answered at a district level details. Answers to such questions are indeed critical as they explain how much area is being lost annually and hence the rate of deforestation and associated carbon loss from the phenomena.

3.7. Landuse Change Scenario Emissions

What about the future landuse change scenario related emissions? Can we predict the scenarios? The landuse change scenario map deals with this question. The primary step in developing the scenario emissions map was building the landuse change scenario map based on suitability analysis of multiple landuses over the overlapping regions. This map was developed independent from the preceding maps as described below. The term "landuse change scenario" is being used here to suggest the potential (choice) use of a given piece of land for multiple uses due to observed overlap (conflict) of two or more of the selected four landuse types described below. The assumption is that the overlap (conflict) zone indicates the potential (suitability) of that land for either of the overlapping landuse types identified and hence, the potential scenario for conversion among those choices.

Those regions were identified from four different input data as follows.
The area feasible for livestock (grassland) was extracted from Addis Ababa University landuse map (3, table1) which covers dominantly the Somalia and Afar regional states.

Area feasible for agriculture was extracted from the crop cover map, which contains the percent crop cover of a given district accessed from ArcGIS online. The higher the percent cover values, the more suitable the district is for rain-fed agriculture.

Potential irrigable land area was extracted from three different maps extracted by multiple geoprocessing of slope, major rivers with high potential for irrigation, and their basin maps at lower altitudes. The assumptions is that the relatively plain regions of the major river basins (catchments) of high irrigation potential rivers like Omo and Awash were candidates for irrigation expansion, and they were clipped out based on the slope (the gentler the slope the more suitable the basin area would be for irrigation) and buffer distance from their tributaries.

The map of restoration potential (forest) was developed by extracting certain forest definitions of forest conditions layer (figure 5) of the WRI Atlas of Forest Landscape Restoration Opportunities (FLR). The regions of interest are within the following three forest condition definitions **degraded, fragmented** or **deforested** (figure 5). This region presents an opportunity for restoration and the current scenario emissions map targets only this region. The proposed restoration scenarios are based on which of the three definitions of forest conditions is a given landmass located in?

- If the land is located in the region with "*degraded"* forest definition; then restoring it into *natural high forest* is possible.
- If it is located in the region with "*deforested*; restoring it into *woodlands* should be possible, and
- If it is located within the "*fragmented*" definition then; it can be restored into either of the above two choices. At the moment, land under the 3rd category is set as *transition zone*.

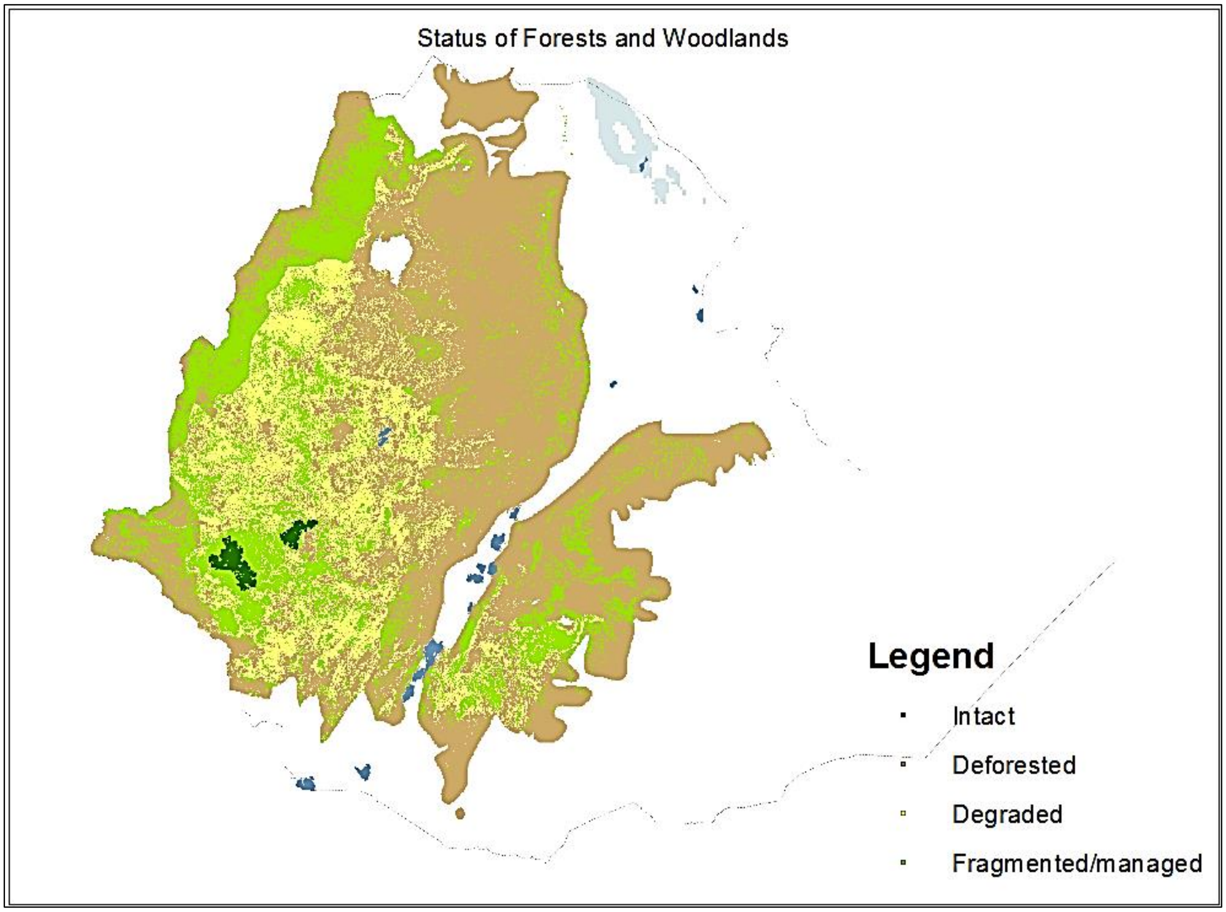

Figure5. Map of forest conditions of Ethiopia (WRI-World Resources Institute)

At the end each of the aforementioned four maps were merged into single shape file the areas (ha) were calculated for each landuse type. This map was combined with the Harmonized World Soil Database (HWSD) and Saatchi NASA biomass carbon maps, using the ArcGIS combine tool. This attached the respective soil carbon (table8) and biomass carbon vales to the attribute table of the landuse change scenario map as new fields. For the current atlas, the scenario emissions calculation was conducted only for the region of the country with potential restoration opportunity as shown in figure 5 above.

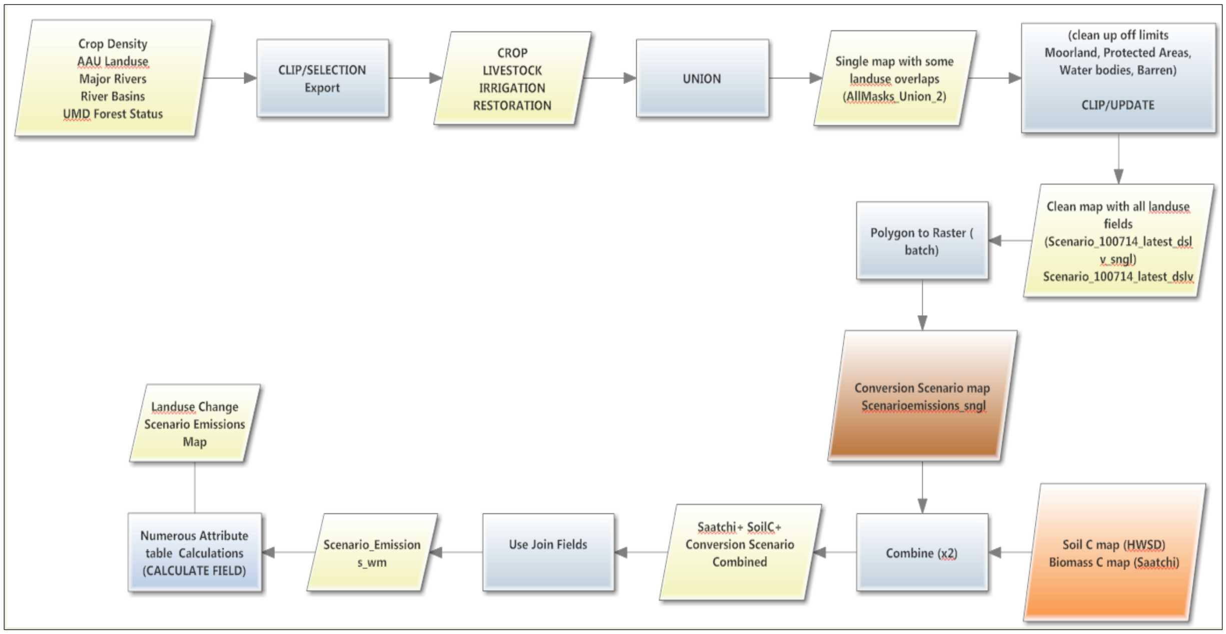

Figure6. Major Geoprocessing steps of the Landuse Change Scenario Emissions map

Finally the landuse change scenario map produced here used the IPCC AFOLU default values to calculate changes in biomass and soil carbon stocks due to the activity specified by the user. This involves estimating the change in biomass and soil carbon stocks prior and post conversion, and multiplying this change by the area of conversion. The map relies on carbon stock data from Saatchi et al. 2011 to estimate emission factors from change in biomass due to conversion. The soil carbon constants from HWSD soil categories found in Ethiopia and IPCC default emission factors are used to estimate the change in soil carbon stocks (table9). Details about each conversion scenario analysis follow here below.

3.7.1. Livestock (grassland)

Biomass carbon (AGB+BGB)-we assume AG and BG biomass carbon stocks are reduced to 13.5 T C / ha, the average carbon content of grasslands (Grasslands=livestock regions) in Ethiopia, and the difference is emitted at the year of conversion. The soil carbon- the soil reference carbon stock (*table8*) is multiplied by the stock change factor for livestock management (default factor = 0.97). These change factors are based on the assumption that no inputs are applied (fertilization or irrigation) and that management results in moderate degradation of soil. The difference between the reference carbon stock and the carbon stock is assumed to be emitted over a 20 year period.

3.7.2. Rain-fed Agriculture

Biomass carbon-we assume 100% of AG and BG biomass carbon stocks are emitted at the year of conversion to agriculture. Soil carbon- the soil reference carbon stock (*table8*) is multiplied by the stock change factor for agriculture (default = 0.88). These change factors are derived from Table 5.5 of the IPCC (2006), and are based on the assumption that full tillage is used, that low inputs are applied (residues are removed, nitrogen fixing species are not grown, and manure is not applied), and that land is put into a short fallow rotations (reasonably true). The difference between the reference carbon stock and the carbon stock is assumed to be emitted over a 20 year period.

3.7.3. Irrigable Land

Biomass carbon- we assume 100% of AG and BG biomass carbon stocks are emitted at the year of conversion to irrigation. Soil carbon -soil reference carbon stock (*table8*) is multiplied by the stock change factor for irrigation agriculture (default = 0.92). These change factors are derived from Table 5.5 of the IPCC AFOLU (2006).

3.7.4. Restoration Potential Land

Biomass Carbon-we assume that original AG and BG biomass carbon stocks remain unchanged, and AGB+BGB increases in one of the three magnitudes according to table9, depending into which category (natural high forest, woodlands or the transition zone) the land would be converted (table9, MAI field for each default value). Soil carbon-we assume no changes in soil carbon.

Soil Classification	Carbon in the top 30 cm (t C / ha)
Acrisols	35
Alisols	38
Andosols	50
Arenosols	31
Anthrosols	35
Chernozems	38
Calcisols	38
Cambisols	35
Fluvisols	35
Ferralsols	35
Gleysols	35
Greyzems	35
Gypsisols	38
Histosols	35
Kastanozems	38
Leptosols	38
Luvisols	38
Lixisols	35
Nitisols	35
Podzoluvisols	35
Phaeozems	35
Planosols	35
Plinthosols	35
Podzols	35
Regosols	35
Solonchaks	35
Solonetz	35
Vertisols	38

Table8. Soil reference Map for mineral soils in dry tropical climates (adapted from 2006 IPCC Guidelines for National Greenhouse Gas Inventories)

Landcover	Reference biomass carbon stock from Saatchi (t C/ ha)	Biomass carbon change (description)	MAI in C (t C /ha/ yr)	Net Biomass Conversion (t C / ha/20 yrs)	Reference soil carbon stock (t C/ha)	Soil conversion factor	Net Soil Carbon Conversion (t C/ha)	TOTAL NET CARBON CHANGE (t CO2/ ha/YR)
Rainfed Agriculture	Saatchi value	all biomass C lost in conversion	0	(-saatchi value)	HWSD value	0.88	HWSD *0.88	[((-saatchi value)+((HWSD*0.88) - HWSD)))*3.666]
Irrigated Agriculture	Saatchi value	all biomass C lost in conversion	0	(-saatchi value)	HWSD value	0.92	HWSD *0.92	[((-saatchi value)+((HWSD*0.92) - HWSD)))*3.666]
Grassland (Livestock)	Saatchi value	biomass C reduced to 13.5 t C / ha	0	(-saatchi value) + 13.5	HWSD value	0.97	HWSD * 0.97	[((-saatchi value+13.5)+((HWSD*0.97) - HWSD)))*3.666]
High forest (Restoration)	Saatchi value	no change to original C + MAI	7.74	0 + (7.74)*20	HWSD value	1 (no change)	HWSD * 1	[+(MAI*20)*3.666]
Woodland (Restoration)	Saatchi value	no change to original C + MAI	2.73	0 + (2.71)*20	HWSD value	1 (no change)	HWSD * 1	[+(MAI*20)*3.666]
Tranzition Zone (Restoration)	Saatchi value	no change to original C + MAI (the MAI here is the average of the WL& NHF)	5.24	0 + (2.71)*20	HWSD value	1 (no change)	HWSD * 1	[+(MAI*20)*3.666]

Table9. The default IPCC conversion Factors from 2006 IPCC Guideline for National Greenhouse Gas Inventories

4. RESULTS

The two main results are the maps that constitute the atlas and the website hosting the atlas and its database. The main focus of the result section will be in describing the maps developed from in the preceding sections under methodology. However, let's describe the website briefly before starting with maps as we will often refer to the site functionalities and display materials.

4.1. The Atlas Website

All the final maps developed including the landcover map are published as an interactive atlas on the website. The user can interact with each map using the website capabilities to generate detailed information from each map. The main sections of the atlas website are the navigation panel (1), the map window (2), the chart window (3) and the legend window (4) as in seen figure6 below. The navigation pane (table of content) is where one would start the atlas exploration. The navigation pane contains 9 accordions thematically ordered. Each accordion can be expanded to display the sub-layers that constitute list of individual maps. Unlike the display in figure6, by default the "Carbon Analysis" accordion will be expanded when the website is first opened. All carbon analysis maps underneath are visible with district carbon stock map automatically selected. Figure6 presents the the website version of the landcover map. Note the various windows of the website as described above.

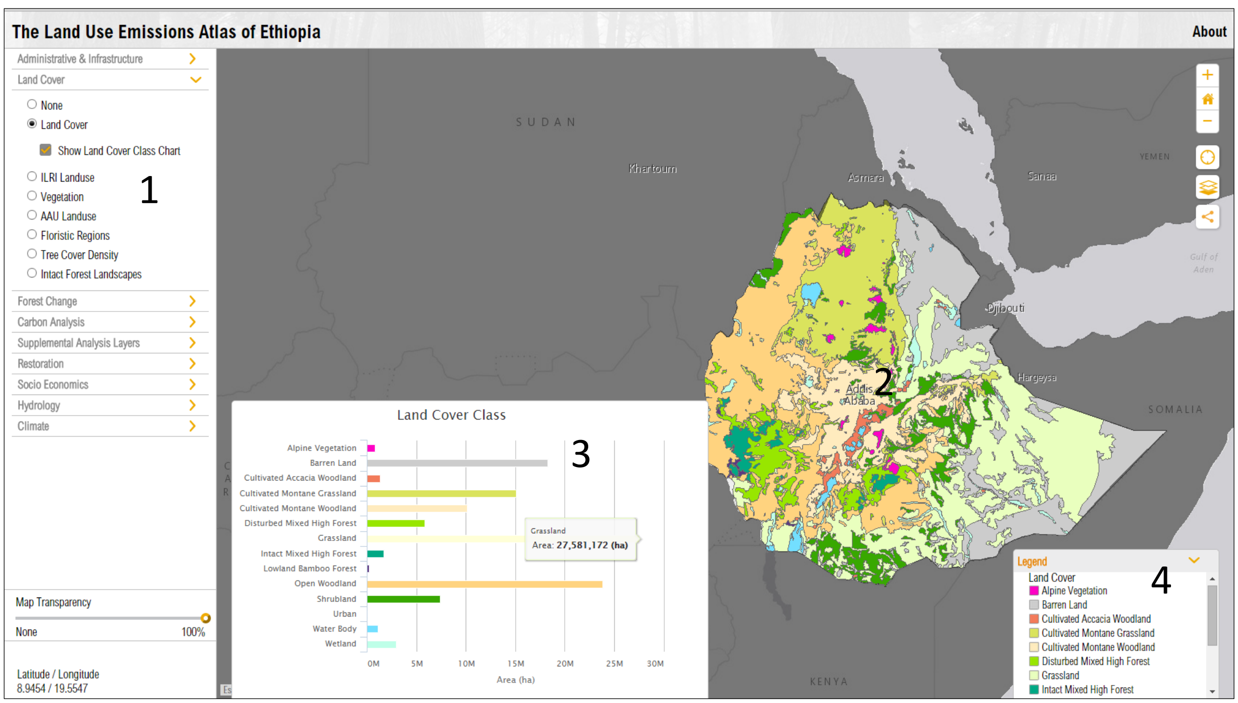

Figure7. The Landcover map above as it appears on the atlas website. The numbered sections are referring to the key windows of the atlas site. The "About" button on the upper right section of the site contains the url to this atlas document.

The analysis and dynamic capabilities of the web atlas is limited at the current stage. However, if the user has access to the database, all GIS analysis can be conducted on the background database using GIS software and also statistical analysis. Such analysis can be conducted at a national or disrict level.

4.2. The Atlas Maps

The atlas has four thematic map categories with national and sub-national (districts) scale of spatial resolution. The mapsets are namely: the *landcover, carbon stock, historic emissions, and scenario emissions* mapsets. The following sections will describe each one briefly.

4.2.1. The Landover

The dominant landcover category is grasslands followed by open woodlands. The national landcover map also contains a vast area of landcover category classified as barren lands (devoid of any significant vegetation) in Afar and Somalia regional states that contains.

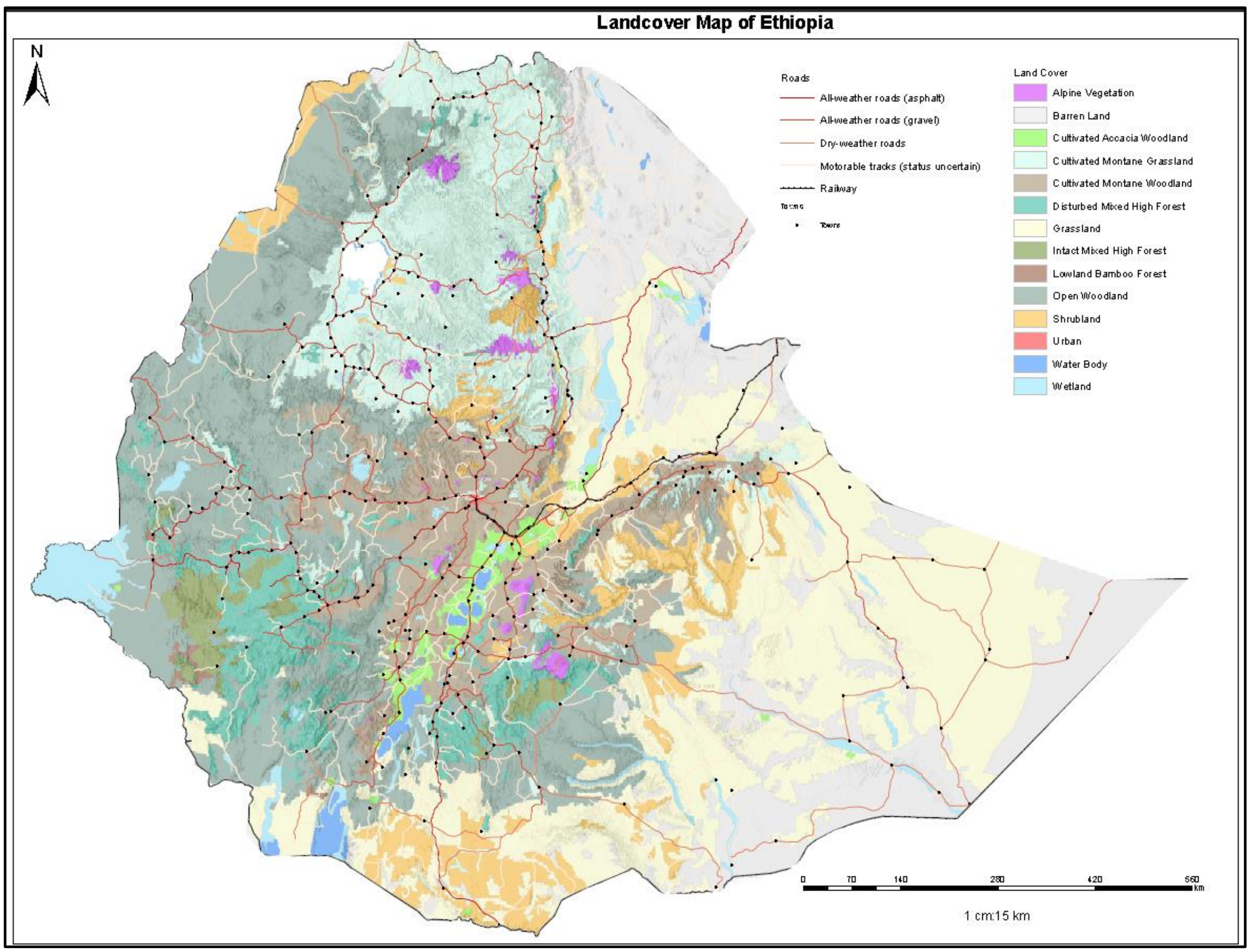

Figure8. The final landcover map developed using the geoprocessing steps described under sections 4.1 to 4.4. This map was used as a core input for the carbon analysis in the following sections.

4.2.2. Carbon Stock

The purpose of the carbon stock maps is to estimate the carbon content of the landcover at different spatial resolution. The result from the carbon stock analysis yielded two maps, namely the national and district carbon stock maps. While the national map is important to draws a national picture of the landcover carbon content which, could be of policy relevance, the information at a district level is critical for local level project planning, implementation and monitoring in landcover/landuse carbon dynamics (emissions and sequestration). Climate change adaptation and mitigation projects that address landuse/landcover changes can be only realistically addressed if we are equipped with relevant baseline information and monitoring tools as close to the ground as possible. Both maps are briefly described in the following sections.

4.2.3. The National Carbon Stock

At a national scale, the mean carbon density per landcover class (ton C/ha) and the total per area covered by each landcover class was calculated. The highest mean carbon density was for intact mixed high forest, as expected. However, due to very small size of the area remaining as intact forest the most carbon is stored in the open woodland landcover category, which is the second biggest in area after grasslands.

Landcover	Mean C (t C/ha)	Area (ha)	Total C (t C/Area)
Alpine Vegetation	21	837,210	17,240,341
Barren Land	4	18,299,413	73,300,254
Cultivated Accacia Woodland	16	1,296,699	20,485,175
Cultivated Montane Grassland	20	15,107,948	300,450,190
Cultivated Montane Woodland	24	10,117,083	247,546,511
Disturbed Mixed High Forest	51	5,856,563	300,540,269
Grassland	14	27,581,172	372,381,384
Intact Mixed High Forest	95	1,705,122	163,301,989
Lowland Bamboo Forest	49	190,881	9,296,894
Open Woodland	36	23,873,842	866,202,272
Shrubland	25	7,372,241	183,140,577
Urban	29	48,930	1,417,840
Water Body	5	1,132,799	6,193,461
Wetland	17	2,979,784	51,302,060

Table10. The attribute table of carbon stock map presents the summary of the landcover map showing ton of /ha/landcover, total area cover by each landcover class and their corresponding carbon per whole area.

This is the website version of the national carbon stock map that a user will be able to access. The symbology of graduated color gradient corresponds to the magnitude of the mean carbon (t C/ha) values of the landcover classes. Green represents the highest (96 t C/ha) for intact mixed natural high forest and pale pink being the least (4 t C/ha) assigned to barren lands. Just by checking the "Show Emissions Chart" button in the navigation panel, a chart with mean carbon (t C/ha) values will be shown. Moreover, by hovering over the chart bars, the landcover name, its corresponding total area (ha), and total carbon content per total area are shown.

This map can be very helpful in developing national landuse planning and biomass carbon analysis on landuse/landcover and its dynamics from landuse conversions in combination with change data.

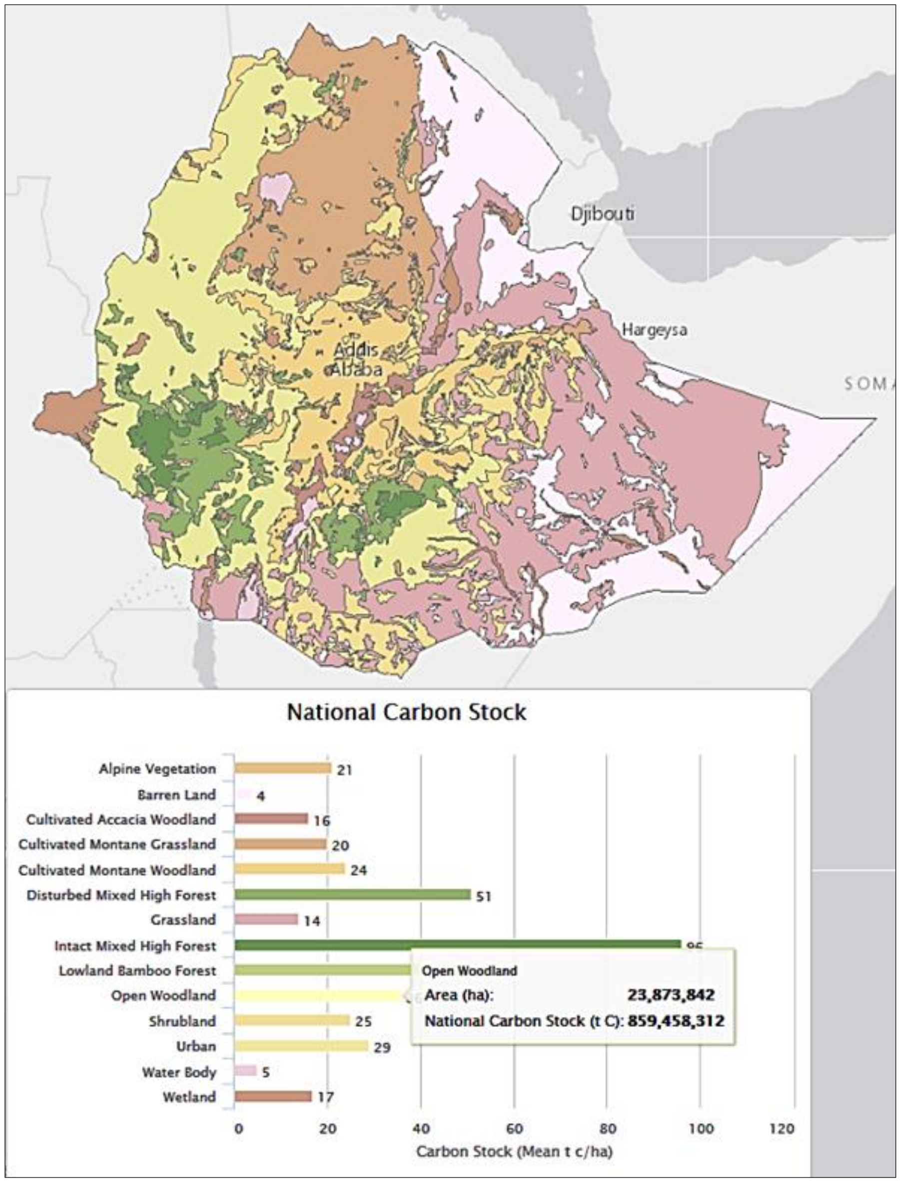

Figure9. The national carbon stock map presents 14 landcover classes and their respective mean carbon content in tons (t C/ha).

4.2.4. The District Carbon Stock

District maps can be particularly relevant if locally produced data and high resolution imagery analysis are incorporated to update the application on a regular basis.

REGIONNAME	ZONENAME	WOREDANAME *	Cover Type	MEAN	Landcover Area	% Area (of district)	Total Carbon (t C/area)
Afar	Zone 2	Ab Ala	Barren Land	4	72126.4	59.4	307119.3
Afar	Zone 2	Ab Ala	Cultivated Montane Grassland	19.9	13159.5	10.8	278376.5
Afar	Zone 2	Ab Ala	Grassland	13.5	36074	29.7	517813.7
Oromia	Horo Guduru	Ababo	Cultivated Montane Grassland	19.9	6373.1	6.3	131290.9
Oromia	Horo Guduru	Ababo	Cultivated Montane Woodland	24.5	20043.9	19.7	508142
Oromia	Horo Guduru	Ababo	Disturbed Mixed High Forest	51.3	1085.4	1.1	57738.5
Oromia	Horo Guduru	Ababo	Open Woodland	36.3	74361.6	73	2797368.9
Oromia	Horo Guduru	Abay Chomen	Cultivated Montane Woodland	24.5	61001.1	80	1545983.2
Oromia	Horo Guduru	Abay Chomen	Open Woodland	36.3	8828.5	11.6	332187.7

Table11. The Attribute table of district carbon stock map

As it can be seen from table11 and figure10, the attribute data contains very important fields like landcover type(s), their respective mean carbon stock values (t C/ha), the total area (ha) covered by each of the existing landcover, and the proportion/percent of the district area under each of the landcover categories present in a district.

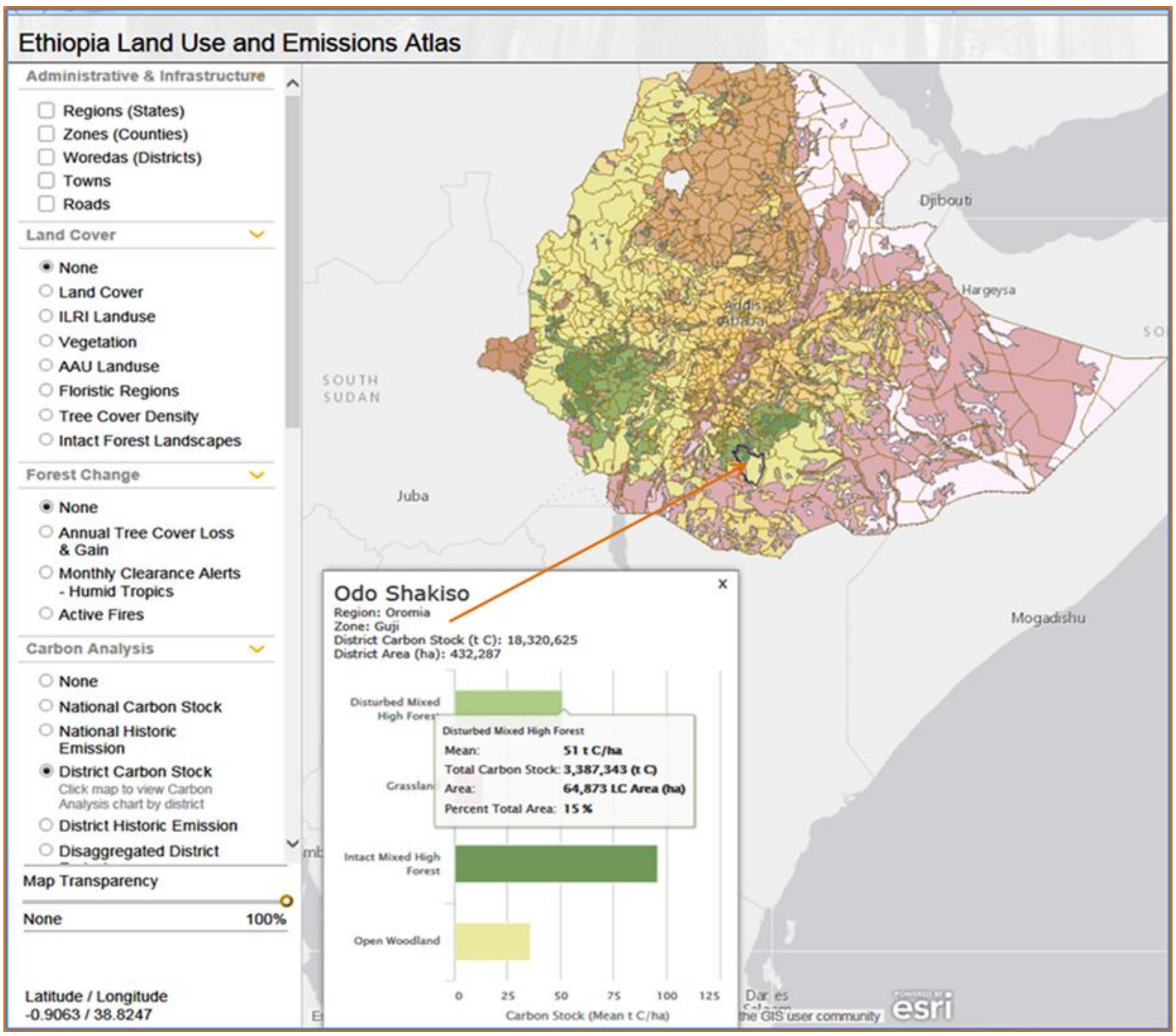

Figure10. An example view of Odo Shakiso district of district carbon stock map

When the user selects a district by just clicking on any of them, a chart window pops up with detailed district information for the selected district such as its name, the region and zone where the district is located, its area as well as the total carbon stock of the district populated as a chart heading. The chart window also contains bar chart(s) representing the present landcover class(s) in that selected district, which could be one or more. By hovering over each bar chart, additional information about respective landcover classes can be displayed for the district under question. For example, explore the additional information displayed by hovering over the *Disturbed Mixed High Forest* bar chart for Odo Shakiso district. Various query analyses can be conducted on these parameters to assist in planning, implementation and monitoring of projects. Projects can be planned to achieve certain goals based on such baseline information like the mean carbon content of the given landcover type that is present in the district and the total area covered. The CRGE goals in landuse sector can be evaluated and landuse management plans can be drawn using such maps.

4.2.5. Historic Emission

The purpose/function of historic emissions map is to measure the biomass carbon loss from deforestation/landcover conversion during the 2000 to 2012 time period. The analysis resulted in national and sub-national maps. But they were also disaggregated against the years and landcover classes.

4.2.5.1. National Historic Emissions

According to the analysis, year 2012 ranks 1st being the year with biggest area deforested; followed by 2009, and 2007. Similar order holds true for amount of respective carbon loss. However, it is not necessarily always true that the bigger the area the higher the carbon loss is. The total carbon lost (t C/area) is a function of the mean carbon content (t C/ha) of the landcover types participated in deforestation and their respective deforested area sizes (ha). Therefore, it will be affected by the mean carbon content of the participating landcover classes in the deforestation. I.e. equal area of grassland will not emit equal amount carbon as from intact natural high forest.

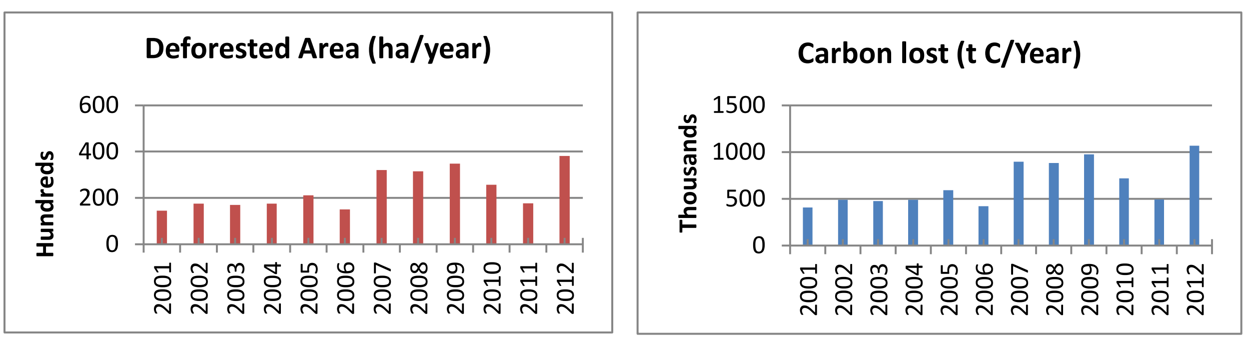

Figure11. The national overview of deforestation area (ha) and associated loss of carbon (t C/area) per year

The map and associated chart in figure12 below presents the details of the national historic emissions map and attribute table contents in table7 under methodology section. Parameters like the deforested area, years of deforestation occurrences and the proportion of each landcover class that constitutes the total yearly loss are presented on the chart window. The map symbology colors correspond to each of the 12 years (2001 to 2012), over which the emission was analyzed. The “show emissions chart” button needs to be checked/selected in the navigation pane to be able to see the disaggregated analysis results against year and landcover class (t CO_2 /year/landcover). The bar charts represent million ton of CO2 lost in a given year and sections along a given bar constitute the proportion of the CO2 lost by respective landcover class, participating in deforestation for a given year.

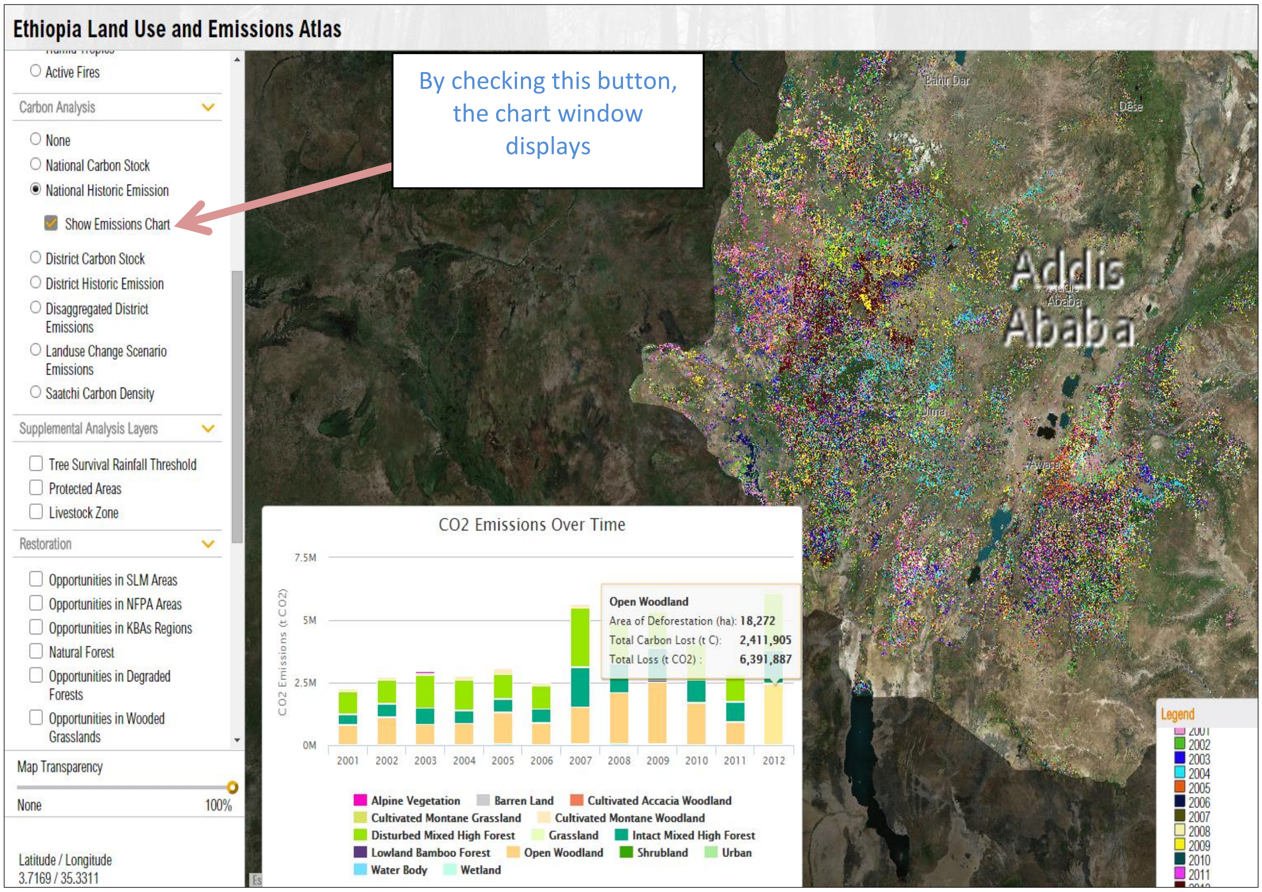

Figure12. The screenshot of the national historic emissions map window using the atlas website navigation

Hovering over the chart bars, additional information window pops up with details on three parameters and the landcover name in question. This information corresponds to only the section of the bar, which is equal to single landcover class. The first two of the three parameters are variable among the sections (landcover classes) of the chart bar while the third –"total loss" (t CO2/landcover), referring to a yearly total loss aggregated (t CO2/Year) for all landcover classes for the given year remains constant over the bar.

4.2.5.2. District Historic Emissions

There are two categories of maps generated at a district level. The first is a general overview of deforested area (ha) and the year when the phenomena is happening, without considering that landcover classes involved. The second map however, takes into account the landcover classes affected by deforestation and hence, estimates the amount of carbon lost due to the deforestation.

Figure13 below presents the general map where the degree of redness of the district corresponds to the severity of the deforestation measured in areas (ha). Accordingly, “Odo Sakisho” has the biggest area of deforestation, of which the most occurred in year 200. Over four thousand hectares was deforested in this year.

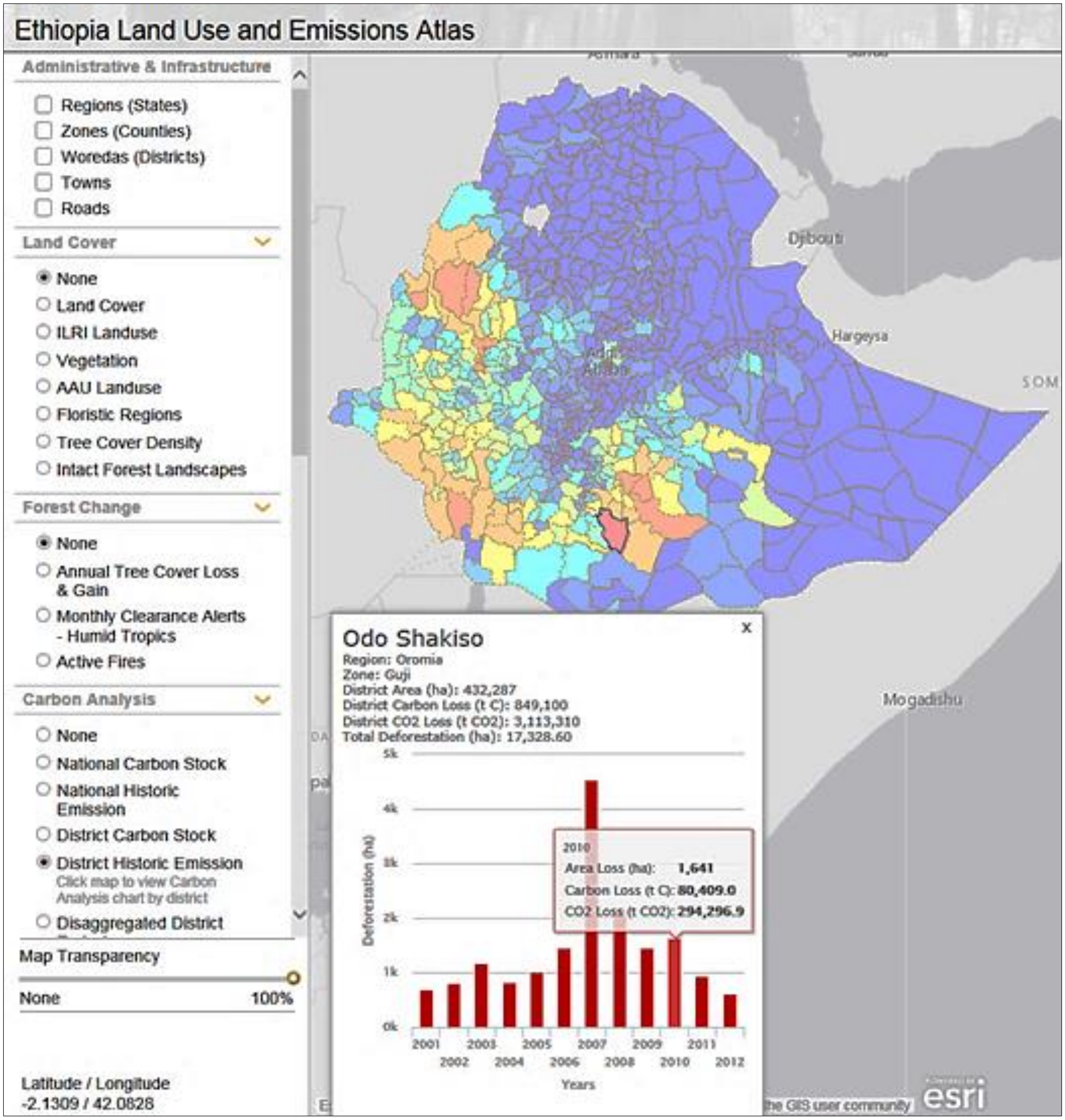

Figure13. The screenshot of the map window from district historic emissions map for Odo Shakiso district

At this stage it is not possible to identify which landcover classes suffered most deforestation and hence, it is also not possible to calculate the carbon lost. Only area deforested is known here, but it is not the indicator of the carbon lost. Further disaggregation against landcover types will resolve this problem as presented on figure14 below.

4.2.5.3. District-Landcover-Year Disaggregate Historic Emissions

The disaggregated district emissions map shows not only the degree of deforestation by area but also the landcover types affected by the deforestation across the years assessed (2001 to 2012). Looking at *Odo Shakiso* again, the disaggregated district emissions map below shows that, the most carbon was lost from intact mixed natural high forest. The chart also presents all participating landcover classes and the magnitude of carbon lost from each landcover class corresponding to a section of the bar on the bar chart for each year. Again, we should recall that the total carbon loss per area (each section size) is affected by both deforested area (ha) and the mean carbon content of that landcover class (t C/ha) involved.

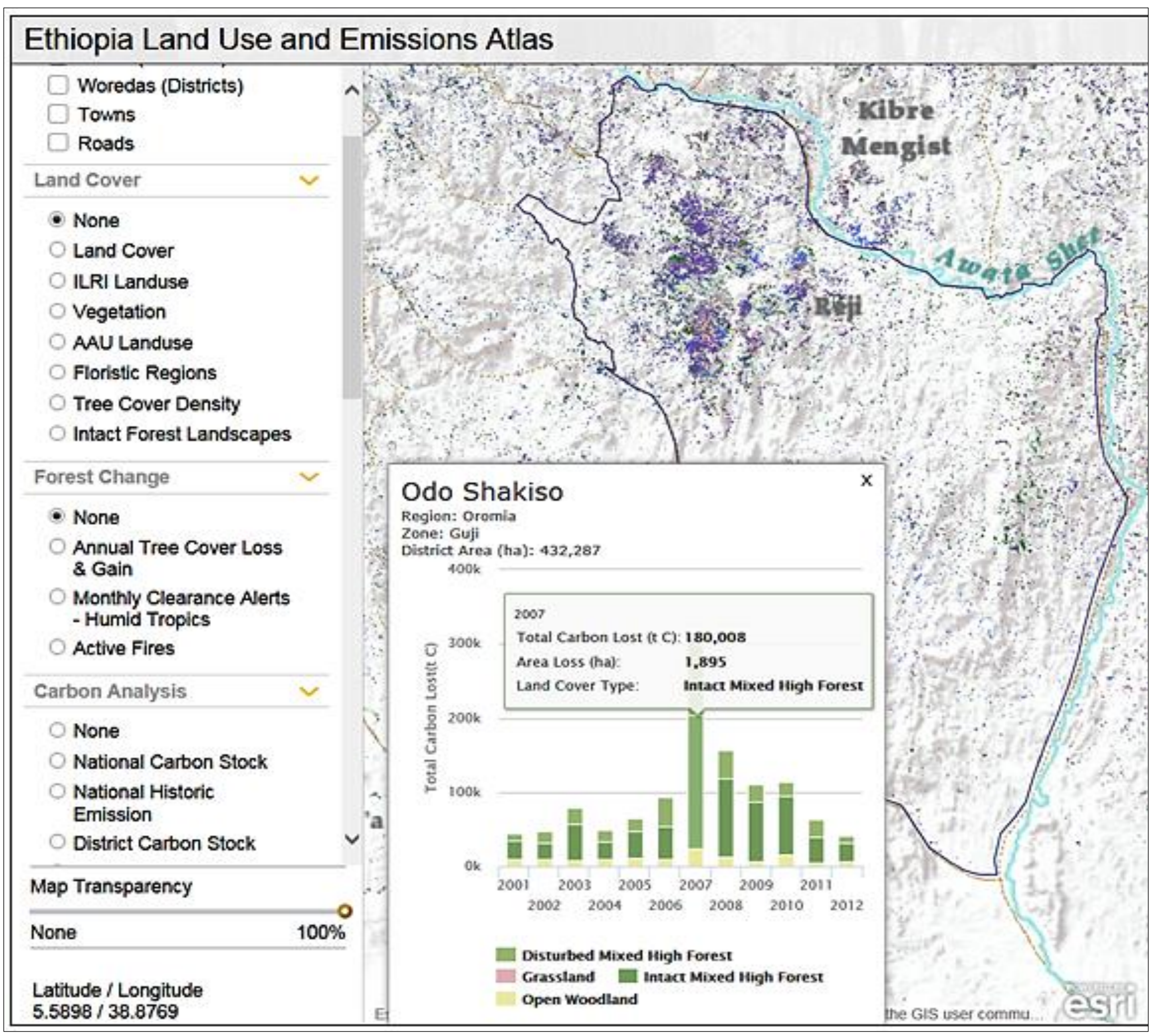

Figure14. The map window and chart from Disaggregated District Historic Emissions map for Odo Shakiso

Again such information is extremely valuable to understand the details of the landcover change impacts on carbon dynamics and based up on such baseline information plans can be drawn, implemented and monitored for progress.

4.2.6. Scenario Emissions

The scenario emissions map of the atlas calculates yearly estimates of emitted and/or sequestered greenhouse gases (GHGs), reported in tons CO2 annually over a 20 year period, resulting from changes in land use for four activities: rain fed agriculture, livestock management, and forest restoration, irrigated agriculture. These activities are constrained to areas where there is biophysical potential for the activity with the exception of off limits clipped out using available project based datasets such as all protected areas based on datasets obtained from Ethiopian Wildlife Conservation Authority (EWCA). The analysis does not take into account social, economic, or cultural limitations which may also have implications on decisions making of what activity is feasible where in addition to the biophysical factors.

The final landuse change scenario emissions map contains an attribute table fields representing each of the four landuse types (the first four fields in table12). Only the restoration field is fully populated, because the focus of this analysis is the region of restoration potential only (figure5).

Scenario_Emissions_wm

Livestock	Cropland	Restoratio	Irrigable	Soicl Carbon (t C/ha)	Saatchi Carbon (t C/ha)	BCC Description
Livestock		Woodlands		38	16	Change to original C+ MAI
Livestock		Woodlands		35	20	Change to original C+ MAI
Livestock		Woodlands		35	9	Change to original C+ MAI
Livestock		Woodlands		38	5	Change to original C+ MAI
Livestock		Woodlands		35	4	Change to original C+ MAI
Livestock		Woodlands		35	10	Change to original C+ MAI
Livestock		Woodlands		38	2	Change to original C+ MAI
Livestock		Woodlands		38	0	Change to original C+ MAI
Livestock		Woodlands		35	0	Change to original C+ MAI
Livestock		Woodlands		35	13	Change to original C+ MAI
Livestock	Cereals	Woodlands		38	8	Change to original C+ MAI
Livestock	Cereals	Woodlands		38	7	Change to original C+ MAI
Livestock	Cereals	Woodlands		38	7	Change to original C+ MAI
Livestock	Cereals	Woodlands	Irrigable	38	24	Change to original C+ MAI
Livestock		Woodlands		35	29	Change to original C+ MAI
Livestock		Woodlands		35	29	Change to original C+ MAI
		NHForest		38	52	Change to original C+ MAI
		NHForest		38	49	Change to original C+ MAI
		NHForest		38	48	Change to original C+ MAI
		NHForest		35	58	Change to original C+ MAI
		NHForest		35	95	Change to original C+ MAI
		NHForest		35	57	Change to original C+ MAI
		NHForest		35	52	Change to original C+ MAI
		NHForest		38	77	Change to original C+ MAI

Table12. The partial view of Scenario Emissions map attribute table

The row with values in multiple cells (see the selection in table12) means the presence of overlapping landuse types in a given piece of land (each cell represents a polygon/piece of land). This in turn means that, landuse conversions among the overlapping landuse types would be possible (choice). Accordingly, the scenario emission/sequestration was claculated for each cell in ton of CO2/ha/yr depending on the direction of landuse coversion. More information can be retrieved from the attribute table using simple click in the map window of the atlas website site. A polygon (representing a piece of land) will be selected when clicked on the map, and some of the above attribute table values can be viewed. Emission (converted from forest category to non-forest) or sequestration (conversion from non-forest to forest) values will be mapped on the Y-axis of the chart. The negative values (below the X-axis) represent emissions and the height of the bars the magnitude, whereas the positive values (above X-axis) correspond to sequestration (restoration to forest).

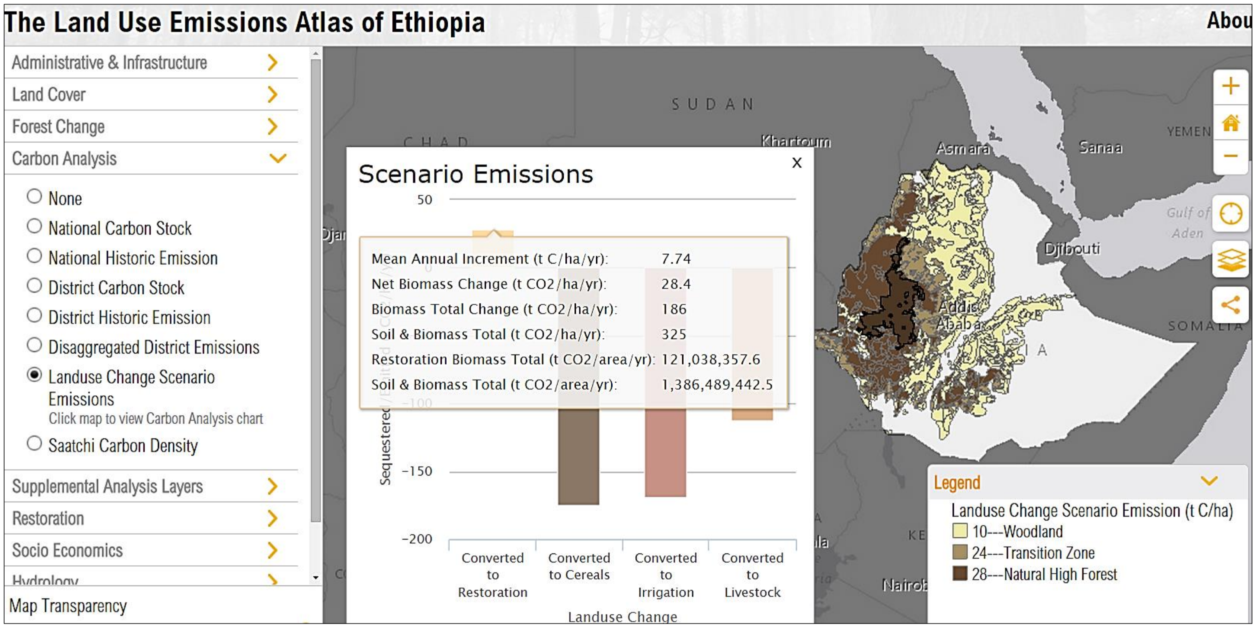

Figure15. An example of map window, the chart, and info window of the Scenario Emissions map

By hovering on the chart bars, a lot more data can be displayed. Explore the information window for the details. The three color gradients represent the three restoration categories indicated in the legend window. The numbers preceding the names are referring to the mean carbon dioxide values of the restoration type per hectare per year (t CO2/ha/year). The region in focus here is also where Ethiopia seeks to restore ca. 15 million hectares as part of the 2014 New York pledge. Hence, it will be the region where significant carbon fluxes can happen due to the policy changes to take place to achieve this target. Therefore the atlas can be instrumental in tracking the changes and emission monitoring from land use changes.

5. DISCUSSION

The discussion here focuses on the main gaps that should be noted with the Atlas and recommendations. Mainly the discussion deals with input data quality and also touches on the IT and website infrastructural requirement for the atlas. The atlas needs to be maintained updates as new data emerges.

5.1. Data Gap Analysis

The atlas does not measure the activities underlying the conversion and/or the current landuse in question. Such activity based emissions is inventory is being developed simultaneously under other strategic climate institutions partnership (SCIP) GHG emissions inventory projects. It should be possible then to bring the outcomes of all projects together to deliver a basic national monitoring, reporting and verification (MRV) system for key sectors.

The poor spatial and temporal resolution of core input datasets is worth noting limitation in the atlas. Due to the scale at which the input datasets were produced, it was challenging to differentiate among the landcover categories at higher resolution that would be relevant for local level planning. This generalization due to omission and commission errors in landcover classification paused difficulty to come up with exclusively separable mean carbon contents for some landcover classes. This challenge leaves little room for any improvement without acquisition and processing of high resolution data. Moreover, both biomass (Saatchi et al, 2011) and soil carbon data (Harmonized World Soil Database, 2012) used for carbon analysis are of global origin at ca. 1km resolution. All datasets were resampled into 30m resolution for analysis purpose match the best available resolution of University of Maryland GFC dataset. It should be noted that such resampling doesn't improve the quality of the coarse resolution data. We hope in the near future such data on land cover/landuse as well as carbon stock will become available to update the atlas.
Regarding temporal resolution the key input data for the landuse maps obtained from ILRI originates from woody biomass inventory project of 2001/2003 Gregorian Calendar. Hence, it should be noted that the landcover categories, assumed current, might have been altered over this period.
Last but not least, some datasets lack methodological documentation and metadata to fully understand their origins and development processes.
This is a challenge in a sense as it would make it difficult to generate current baseline emissions. The intention is to make projections using the Hansen data to the current year or use the overlapping years (2000/03) as the base layer.
Addis Ababa University Vegetation Atlas uses the term "potential natural vegetation". See the definition about the term on page 7 of Lillesø, J.-P. B et. al, 2011. There is also an ongoing improvements being made to the atlas which can be obtained from the http://www.vegetationmap4africa.org/ site and contacts we have established.

5.2. Carbon Stock Analysis

Differentiation (distinguishing) among certain classes was difficult even after the long refining processes. This might be due to the fact that that the core landuse map input data has very coarse resolution to capture the needed details to separate the relatively small differentiation in carbon content among some landcover classes. It could also be the true nature of those classes being too similar in carbon content due to extreme modification of the natural environment even though the vegetation types are different (e.g. the **intensively cultivate** woodland and grassland in the highland region may just have too similar carbon content due to very strong anthropogenic alteration, even though they naturally would be separable

5.3. Scenario Emissions Analysis

The scenario emissions map focus is on emissions due to land use conversion, particularly in the potential restoration regions of Ethiopia. It does not cover the whole country and does not cover all available landuse categories. This is a region where Ethiopia's claimed 15 million hectare for restoration is situated and hence, where significant differences in carbon fluxes can happen due to the policy changes in the future to achieve this target.

The calculator does not estimate emissions associated with fertilizer use, transportation, industrial processing, enteric fermentation, etc. that would be required for complete GHG accounting for each activity. Additional resources for estimating these sources of emissions can be found in WRI's GHG emissions accounting protocol for Agriculture.
In all cases, we do not estimate emissions due to change in litter, deadwood or harvested wood products carbon pools. If changes in these pools are estimated to be significant by the user, they should also be accounted for separately. Additional guidance on accounting for changes in these pools is available from the IPCC (2006). IPCC default factors are used to minimize the required inputs, however where more detailed local information is available these default data can be overridden.

5.4. None Data Source Capacity Gaps

MEF is a new ministry, just established in 2013. So let's say the skeleton (legal framework) is in place now but flesh has to be put on it to erect a fully functional **institutional** structure. In another hand the ministry has an overarching and urgent mandates such as overseeing the CRGE and MRV implementation. Given this, the ministry will need to catch up very quickly to gain the needed strength and influence at equal level with existing established ministries and agencies. Effective structures have to be in place for smooth lateral and vertical flow of data and information to take place between the ministry and the pillar sectors as identified in the CRGE.
IT and database management capacity is another area that stands out as a gap. MEF moved into a new building near Dembel sub city, Addis Ababa in March 2014. It is still in the process of networking the basic internet and communication facilities. With the strong desire from the ministry to have a national MRV system set, and with its overarching mandate to oversee the whole process of measurement and reporting of GHG emissions, it will definitely require strong and well-functioning IT and database warehouse and management system. This has to be thought about thoroughly to make a sound judgment; if in fact would be better for the ministry to contract an academic institutions and/or private firm to handle this instead.
Technical training on the atlas tools and GIS is still to be provided for the MEF staff that will be identified to utilize, maintain, as well as update the atlas after the project is handed over. Due to MOU delays that resulted in cancellations of trainings and workshops, MEF staff didn't receive adequate training these topics yet. This will seriously affect the knowledge transfer, utilization of the products produced and project sustainability after handover over and should be given a due consideration. Not only the capacity of the existing staff needs to be boosted but, new **man power** at MEF in the thematic areas of landuse analysis, GHG accounting from Landuse changes, and Remote Sensing and GIS is also critical. This may require a recruitment of new expertise in these topics. Last but not list all of the above will have significant **financial** capacity implications. Hence, financing mechanisms has to be secured for the project to be sustained.

6. ENDNOTES

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