Mapping the Economic Value of Vegetation Carbon Sink and Stock in the Municipality of Cuenca (Spain)

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Methods

For the project I built an initial multi-source file geodatabase as shown in Table 1.

Data	Resolution/Scale	Description
Spanish Forest Inventory 2 (1996)	1:50000	txt/dbf tables + shapefile for Cuenca province
Spanish Forest Inventory 3 (2007)	-	mdb/xls tables with inventory data
Spanish Forest Map (MFE50 2007)	1:50000	Shapefile for Cuenca province associated to SFI 3
Spain Land Use (SIOSE 2014)	1:25000	Land use and land cover file geodatabase for Cuenca province
DEM (MDT25)	25 m	11 ESRI ASCII files to cover the Municipality of Cuenca
Boundaries	-	Shapefile with Municipalities in the Province of Cuenca
Temperature	-	xls/json files with time series of data for 5 different stations across and near the Municipality.

Table 1. Data sources considered for the analysis. Date of retrieval: May 2020

To start with, the area of study (Cuenca municipality, Cuenca province, Spain) was extracted from the boundaries layer by selecting it and exporting it as a separate feature class. The DEM was prepared by mosaicking all 11 files and clipping based on the municipality borderline. It was then reclassified into 3 different altitudinal sectors (800-1100 m, 1100-1500 m and 1500-1900 m) from which final economic value statistics were checked against. The temperature series were averaged in 5-year intervals to check evolution in different places in and around the Municipality with which I will create some graphs on the final maps. The SIOSE 2014 was also clipped to the area of study and features filtered to the same major starting constraints used for the Forestry Inventories, which are conifers, broadleaf or mixed forests where the canopy cover fraction (CCF) is equal or greater than 10%. This way, areas per altitudinal sector were extracted for final comparison purposes, as no stem volumes or tree species details are integrated in this database. All spatial data was projected to the same coordinate system ETRS_1989_UTM_Zone_30N.

Both provincial forestry maps were clipped too to the study area and by combining different tools – actually different procedures for each inventory as they present data differently–, two vegetation feature classes (one per inventory: SFI2_Vegetation and SFI3_Vegetation) were extracted with the 7 main tree species in terms of surface covered, and with CCF>=10% (Table 2).

SFI code	Species name	Type	*BEF*[1] (t/m^3)	R^2	*CF*[3]
21	*Pinus sylvestris*	Conifer	0.62	0.272	0.509
24	*Pinus halepensis*	Conifer	0.74	0.309	0.499
25	*Pinus nigra*	Conifer	0.64	0.244	0.509
26	*Pinus pinaster*	Conifer	0.55	0.284	0.511

44	*Quercus faginea*	Broadleaf	1.11	0.462	0.475
45	*Quercus ilex*	Broadleaf	1.28	0.529	0.480
937	*Juniperus spp*	Conifer	0.62	0.314	0.475

1 – BEF (Biomass Expansion Factor): a measure of how much crown volume (branches + foliage) compared to stem volume.
2 – Root:shoot ratio: a measure of how much belowground dry mass compared to that of aboveground vegetation.
3 – CF (Carbon Fraction): mean concentration of carbon in a dry weight sample of wood. Normally ~0.5.

Table 2. Major forest species considered in the analysis, with Spain-specific coefficients for estimating carbon sink and stock amounts (Montero et al. 2005, Ruiz Peinado et al. 2011).

Afterwards, I combined GIS and mathematical equations and coefficients taken from different sources (see Table 2 and Table 3) to estimate for each inventory and per species the following attributes: stem volume (m^3), net biomass –including both aboveground and belowground vegetation– (t), carbon stock (t C) and carbon sink (t C/yr). With the help of two lookup tables from forest inventory data, this was an automated process created with model builder. I also built a spreadsheet with the corresponding formulae to back-up results obtained through GIS.

Purpose	Equation	Description
Total Tree Biomass	W_t (t/ha) = SV(m^3/ha) BEF(t/m^3) (1 + R)	Total tree biomass (living biomass) including the above-ground vegetation and roots. *SV* is the stem volume taken from forestry inventories
Carbon Stock	CS_t (t C / ha) = W_t CF	Total carbon stock is living biomass times a tree-specific carbon factor (normally about 0.5)
Carbon Sink (Pine)	CS_i (t C/ha/yr) = $5.565 W_t^{\,0.157}$	NPP[1] formula for pine
Carbon Sink (Quercus)	CS_i (t C/ha/yr) = 9.2	NPP formula for economic forests
Carbon Sink (Juniperus)	CS_i (t C/ha/yr) = $0.208\, W_t + 1.836$	NPP formula for other wooden forest species

1 – NPP: Net Primary Productivity is a measure of how much carbon a tree can absorb from the atmosphere.

Table 3. Formulae for amount estimates of carbon stock and sink (Montero et al. 2005, Shuhong Deng et al. 2011).

Because any given polygon in each one of the two vegetation layers can hold more than one species, I extracted from SFI2_Vegetation 7+7 rasters with the carbon stock and sink estimates per species, respectively, and added every set of 7 rasters with cell statistics to obtain the total amounts of carbon stock and sink for the forest species. I did the same with SFI3_Vegetation. All rasters were created as 25 m pixel resolution to match that of the DEM.

Finally, I multiplied all four previous rasters by a constant raster I created with the price of carbon tax in Spain for the current year 2020 (*15* €/t CO_2, World Bank Group 2020), yielding rasters SFI2_EV_Forest_CSink, SFI2_EV_Forest_CStock, SFI3_EV_Forest_CSink and SFI3_EV_Forest_CStock. Then, I simple added the resulting rasters in pairs to get the total economic value (carbon sink plus carbon stock) per inventory (**SFI2_EV_Forest_Total** and **SFI3_EV_Forest_Total**).

To test the loss or gain of economic value against altitude, I obtained mean values of the previous two rasters against the reclassified 3-zone DEM (obtaining tables **ZonalSt_SFI2EV_DEM** and **ZonalSt_SFI3EV_DEM**).

Results

The overall results are summarized in Table 4. I estimated the material amount of forest carbon stock and sink from the Spanish Forestry Inventory 1996 to be approximately slightly over 2 million tons of carbon -2.081 and 2.074 respectively-, whereas for the Spanish Forestry Inventory 2007 to be approximately 2.371 million tons and 1.945 million tons of carbon respectively. The similar figures obtained in each inventory for sink and carbon sequestration agree well with other studies, being the sink amount usually lower than the stock amount.

	SFI2 – 1996	SFI3 – 2007
Estimated Total Forest Carbon Stock (t)	2,081,347.47	2,371,387.32
Estimated Total Forest Carbon Sink (t)	2,074,838.16	1,945,991.82
Total Economic Value of Forest Carbon Stock (€)	31,220,211.99	35,570,809.82
Total Economic Value of Forest Carbon Sink (€)	31,122,572.46	29,189,877.25
Total Economic Value Combined (€)	**62,342,784.45**	**64,760,687.06**

Table 4. Total material amount estimates (metric tons) and equivalent economic values per inventory. The total value combined per inventory is the addition of the carbon stock and sink economic values.

The corresponding economic values for SFI2 are 31,220,211.99 € and 31,122,572.46 € for forest carbon stock and sink respectively, whereas for SFI3 the total economic values are 35,570,809.82 € and 29,189,877.25 € for forest carbon stock and sink respectively. This yields a total economic value of the tree species considered of 62,342,784.45 € and 64,760,687.06 € respectively for SFI2 and SFI3. Figure 1 charts these values.

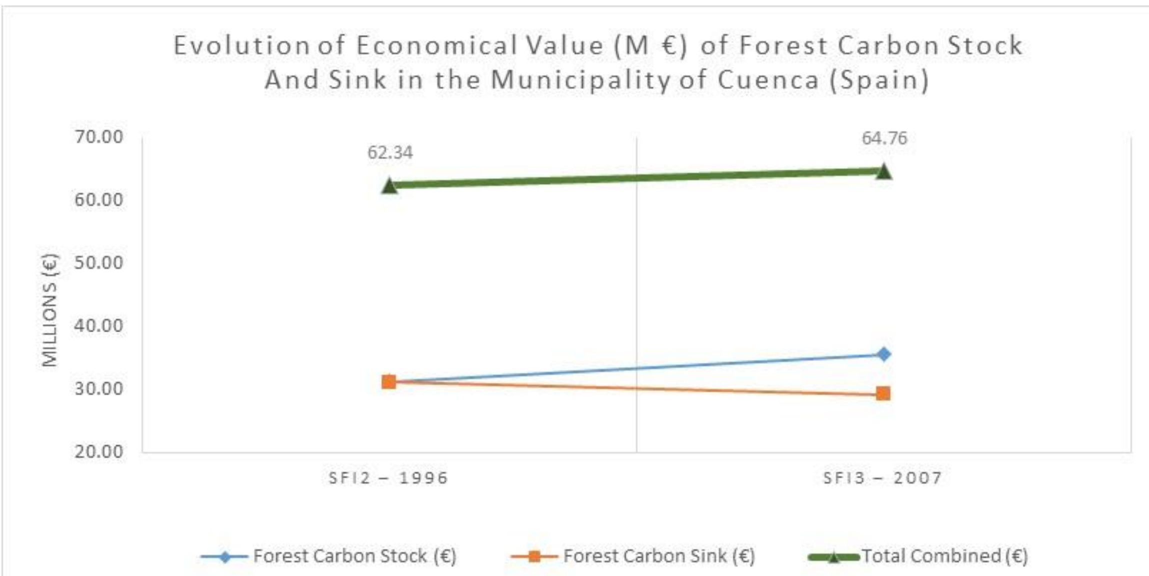

Figure 1. Evolution in time between inventories of economic value for carbon stock and sink. The total economic value combined is represented as the thicker green line.

The mean economic values compared to the altitudinal sectors created with the DEM are shown in Table 5. There is a similar loss of mean economic value in all three sectors between inventories of about 16%, being the lowest sector 1 the one with the largest loss (18.92%).

	***Mean Economic Value* (€)**		
	SFI2 1996	SFI3 2007	Diff (%)
Sector 1 (800-1100 m)	29,331,676.73	23,783,055.62	-18.92%
Sector 2 (1100-1500 m)	36,421,523.20	31,219,260.68	-14.28%
Sector 3 (1500-1900 m)	33,147,313.60	27,454,840.69	-17.17%

Table 5. Comparison of mean economic value in euros per altitudinal sector.

Analogously, the forestry areas were also compared to the altitudinal sectors, with the addition of a third period, i.e. SIOSE 2014 (Table 6). While between Forest inventories there is a 38% increase of charted forestry area in the lowest altitude interval (800 – 1100 m), the other two sectors remain similar, with slight increases of 8.18% and 5.38% for sector 2 (1100 – 1500 m) and sector 3 (1500 – 1900 m) respectively. The values obtained for SIOSE 2014 are 8,709.75 ha, 47,623.06 ha and 17,589.56 ha respectively. For graphical comparison see Figure 2.

		***Forest Area* (ha)**			
	Sector Area	SFI2 1996	SFI3 2007	Diff (%)	SIOSE 2014
Sector 1 (800-1100 m)	23,219.81	7,276.44	10,040.75	+37.99 %	8,709.75
Sector 2 (1100-1500 m)	49,831.36	44,581.81	48,227.56	+8.18 %	47,623.06
Sector 3 (1500-1900 m)	18,047.19	16,426.69	17,311.13	+5.38 %	17,589.56
Total area (ha)	**91,098.37**	**68,284.94**	**75,579.44**		**73,922.38**

Table 6. Comparison of forestry areas for the tree species considered in hectares per altitudinal sector. Difference percentage is only between SFI2 and SFI3.

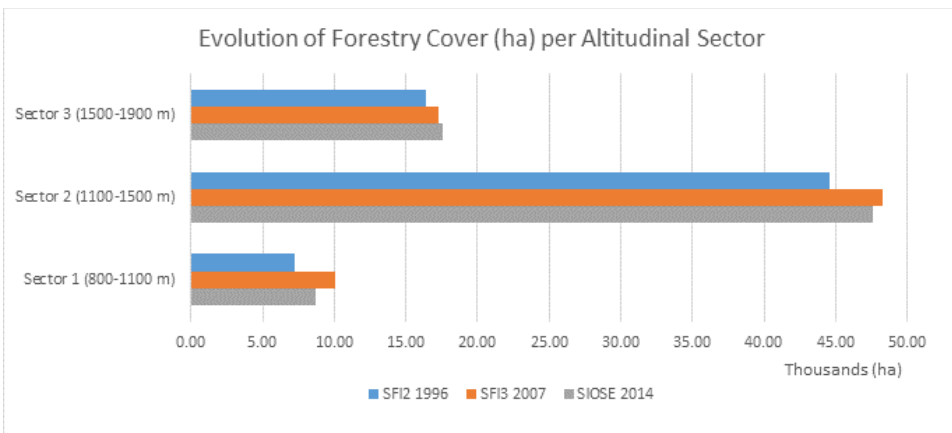

Figure 2. Evolution in time for forestry areas covered in hectares per altitudinal sector.

Discussion

Instead of a decline of economic value over the time period covered as was hypothesized, results showed an increase in economic potential for the municipality due to the higher combined carbon sequestration. This seems reasonable after checking that surfaces and volumes for all the forest species considered grew between SFI2 and SFI3, though at the larger provincial context, I feel overall applicable to the municipality as it contains a good chunk of all the forests in the Serranía de Cuenca –where most trees are in the province–. This growth might be due to reforestation/afforestation plans or the natural growth of vegetation over the years (something that is estimated in the forestry inventories), or both.

However, the fact that carbon sink estimate –and hence its economic value– showed a decrease over inventories seems an artifact of my analysis, and most likely, after analyzing intermediate results, due mainly to an overestimate of the initial surface covered by *Pinus nigra* (which amounts to ~50% of the about 70,000 ha of forestry cover in the municipality) in SFI2. Additionally, not only there were differences in methodologies between SFI2 and SFI3 that prompt you to take overall figures cautiously, but also the spatial data is presented differently and SFI3 were much more spatially detailed: for instance, whereas I extracted and filtered initially 545 plots (records) to consider for the analysis with SFI2, I got more than double plots from the spatial layer for SFI3. All these cumulative effects might explain the loss of mean economic value per altitudinal sector. Taking the more homogenous raw data from inventories instead of the spatial byproducts as starting point for future analysis, though much longer, it may help increase consistency of the methods.

Per altitude interval, the much larger sector 2 (1100-1500 m) holds the most forestry cover and the most accumulated economic value: it turns out that this sector looks like the natural habitat for the abundant *Pinus nigra*, as it rarely seems to exist in altitudes higher than 1500 m.

Overall, nevertheless, this project showed the good economic potential of the municipality for carbon trading and future policies that will help tackle global warming, starting at the local level. The huge forest volumes in the study area leading to over 65 million euros, could greatly increased if a higher carbon tax is finally adopted across the European Union, perhaps a compromise between the countries with lower rates (like 15 €/t CO_2 in Spain) and those with higher rates (~112 €/t CO_2 in Sweden). It would be interesting to check this analysis once the latest SFI4 is released, unfortunately not finished yet for Cuenca province at the time of writing this summary. Despite the increase in average temperature observed through the time series considered for this project (+2.9ºC in Cuenca city over the last 60 years, for example), if significant wildfires or fellings have not occurred since 2007, it might show a growing trend. Although some parts of the municipality were already under special protection before the SFI3 2007, after the creation of the Natural Park of Serranía de Cuenca that same year, about two-thirds of the forest ecosystem of the municipality has potentially a good surviving prospect.

References

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2. Ruiz Peinado R., del Río M. & Montero G., “*New models for estimating the carbon sink capacity of Spanish softwood species*”, Forest Systems 20(1), 176-188, 2011.
3. Shugong Deng et al., “*A GIS-based approach for quantifying and mapping carbon sink and stock values of forest ecosystems*”, Energy Procedia 5, 1535-1545, 2011.
4. World Bank Group, 2020, https://carbonpricingdashboard.worldbank.org/map_data