Land use changes in the Douro Valley and carbon emissions

Introduction

Deforestation for economic development and urbanisation or urban sprawl as a result of human population growth is a common feature of land-use change and is an important source of increased atmospheric CO_2. At the global level, carbon emissions from burning fossil fuels are two to three times higher than carbon sequestration by land systems, mainly forests and woody vegetation.

The work presented herein focuses on the identification of carbon balance shifts due to land use changes in a group of municipalities located in the Douro River Valley in northern Portugal, where the dominance of vineyards and forestry uses over urban occupation is the norm. However, when urban sprawl occurs through the replacement of forested areas by urban uses, the ability to sequester carbon dioxide is reduced while its production rates increase. A thorough study (Lourenço et al., 2008) of land uses evolution between 1990 and 2000 shows that urban uses have been growing near Vila Real as well as vineyard plantations. Forest fires and a complex topography are major causes for the growth of abandonment, which make these areas more prone to erosion and desertification.

The Douro Valley

Following an urbanization trend supported by migration of population from rural areas that has been in place for over 400 years – since the 16th century to Lisbon and later on, since the 18th century to the coastal areas – (Lourenço, 2004), Portugal underwent significant urban development in the period between 1990 and 2000, particularly for coastal urban areas located in and in between the metropolitan areas of Lisbon and Porto.

Urban development has not been homogenous throughout the country and the duality between coastal versus interior urban growth is clearly identifiable. This disparity is not due to an imbalanced distribution of plans and/or programmes for territorial development but rather due to the lack of critical mass essential to secure and sustain the desired level of urban growth and development. Cases in point, the regions of Trás-os-Montes and Alto Douro, located in the interior north-eastern part of the country, are extensively covered by many types of urban development plans and have yet to demonstrate a level of growth that can compete with the far more successful coastal regions.

For the past two decades, the Douro River Valley was subject to a set of diverse projects and specific territorial development programmes, comprising both the Douro and Alto Trás-os-Montes NUTs. As they were implemented, they shared common purposes: to mobilize local growth potential and resources towards social and economical development, job creation and improvements to the quality of life of the population, thus taking a rather exemplary character regarding the nature and the content of regional development policies implemented in Portugal during the same period. Consequently, a considerable level of investments was channelled to the region – several millions of Euros –, along with renewed tools and models of intervention that addressed development objectives and strategies through more than eleven programmes financed by the European Union. As a result, a new inter-sectoral approach has progressively emerged from strategies centred in increasing agricultural production and productivity and in the improvement of the life conditions of the rural populations. This approach has been complemented with investments in infrastructure and agricultural interventions. The goals have been to streamline the undertaking of initiative capacity and management, the attracting and holding of qualified human resources and the promotion of historic, cultural and natural heritage as well as tourism. Simultaneously, several incentive systems were made available to the region's private agents and investors, which carried special benefits in sectors like vineyard farming and wine-making, tourism, food industry, services and local commerce.

The relative improvement of the quality of life of the populations, the reinforcement and the extension of water supply infrastructure coverage, the social equipment network and the partial modernization of the economical and social tissue are visible results and evidence of the positive impact brought by the incentives and associated investments. In fact, agriculture and tourism are the dominant economic activities, where the Douro Region is second only to Porto (Lourenço, 2004). Notwithstanding, according to some specific economic indicators, the overall contribution to the development of this region is declining or at the very least, fails to meet expectations given the magnitude of policy incentives.

Given their transitional location between the coastal and interior regions of northern Portugal, the municipalities of Alijó, Mesão Frio, Murça, Peso da Régua, Sabrosa, Santa Marta de Penaguião and Vila Real were selected (see Figure 1).

Figure 1 – Case study municipalities
(Adapted from Danko and Lourenço, 2008)

In terms of urban development, it appears to follow some logic of accessibility improvement and not necessarily the availability of land development policies. Such is the case for other regions in Europe, namely Holland (Priemus, 2004). Vila Real certainly benefited from the improvements to its transportation infrastructure systems, namely the construction of the IP4 (*Itinerário Principal*, main road itinerary) that promoted the consolidation of the urban front and the creation of new urban areas through the swift conversion of rural land uses into urban ones. Neighbouring municipalities have also benefited from this infrastructure improvement.

Land use changes and carbon balance

Changes in agricultural policies, demographic trends and globalisation trade are drivers of land use changes in Europe. Since carbon dioxide (CO_2) sources and sinks over terrestrial masses are intimately related to the types of soil and vegetation, changes in land cover and related uses are sure to bring more or less significant shifts in carbon stock change (Schulp et al., 2008; Shao et al., 2008, Houghton, 2007). Under the Kyoto Protocol and despite the uncertainty related to the estimates of carbon storage shifts due to land use changes, countries are required to report these and are given the possibility to partially offset their carbon emissions by implementing beneficial measures regarding land cover and uses.

Urban sprawl is a consequence of urban population growth into rural areas, thus replacing agricultural and forestry with other uses more susceptible to affect carbon cycling processes. Urban land transformation studies conducted in mainland USA point out to a reduction in the capacity for carbon fixation by as much as 1.6 % of pre-urban conditions (Imhoff et al., 2004). The rate of urban sprawl in north-central Indiana in a study (Shao et al., 2008) for the Midwestern USA between 1940 and 1998 showed that the overall effects of land-use changes have led to the region becoming an increasing source of CO_2 in the past half-century. It was concluded that forestation of marginal agricultural land, improved soil/crop management practices, and use of renewable energy could lead to a 67% reduction of the gap between CO_2 emissions and carbon sequestration.

Using emission factor (EF) data reported for each EU State, Schulp et al. (2008) devised a methodology capable of assessing the effects of agricultural, forest and natural land use changes on carbon sequestration. The work was carried under different scenarios defined according to level of globalisation and government intervention (Figure 2), for a period of 30 years into the future (2000-2030).

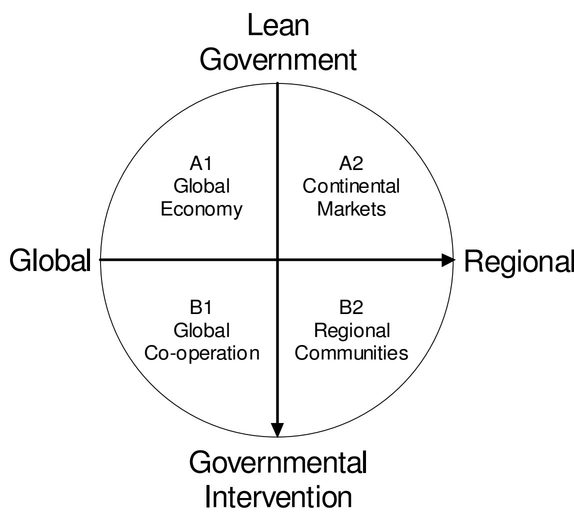

Figure 2 – Guiding axes and scenarios
(Adapted from IPCC, 2000; Schulp et al., 2008)

As defined, the scenarios for EU States cover the wide range of possibilities regarding macro-economic policies and their potential consequences in terms of land uses. Overall, the results show that, depending on scenario, there are clear differences in terms of spatial distribution of carbon sources and sinks, as well as in their size. Nevertheless and except for scenario A2, the results indicate a net increase of carbon sequestration due to a decrease in cropland area, ranging from 90 to 111 $TgC.year^{-1}$ by 2030.

For North-eastern Portugal (Figure 3), the region consistently meets the 400 to 800 $tonC.km^{-2}$ sink class. The differences between scenarios are not discernible perhaps because the region is not expected to undergo significant land use changes at the selected resolution. However, as Shao et al. (2008) and others emphasize, changes in atmospheric carbon are global in scope and effect despite, as these and other studies have demonstrated, their local and spatially confined origins. Though there are no universal solutions, there are strategic approaches that can be derived from commonalities such as urban land growth and deforestation processes.

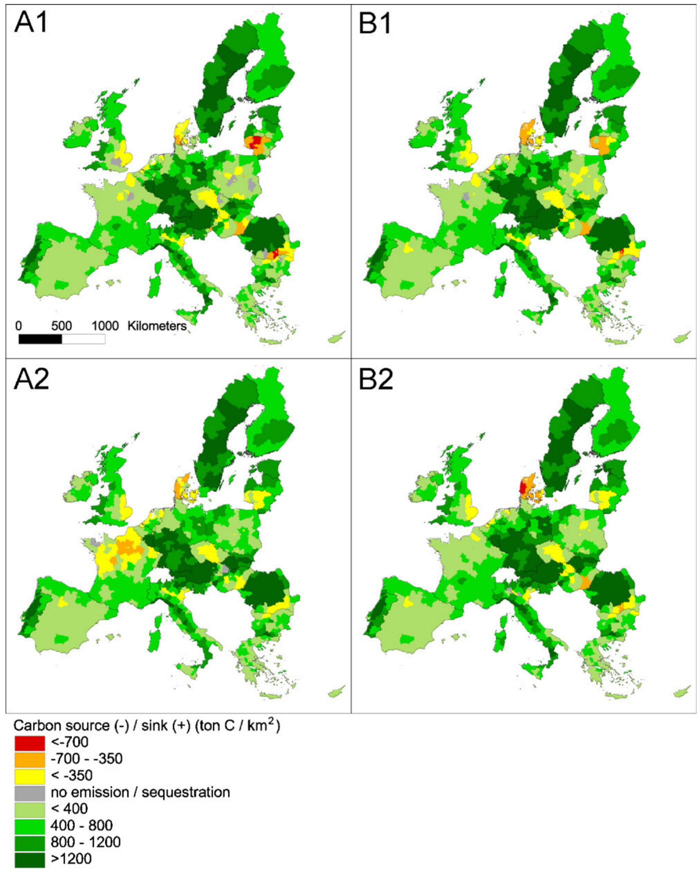

Figure 3 – Projected carbon emissions and sequestration for 2030 (Adapted from Schulp et al., 2008)

Methodological Framework)

The results described and discussed below concern a two-part study devoted to assess (1) land use changes, and (2) carbon balance shifts originated by those changes, for selected municipalities in North-eastern Portugal.

Land use changes

The following is a brief synthesis of work already published. Therefore, the reader is referred to Lourenço et al. (2008) for further details.

A series of parameters was calculated in order to identify and quantify the processes that originated the land occupation changes (Lourenço et al., 2008). The methodology was based on the analytical method described by Pontius (2002) and Pontius Jr. et al. (2004) for land use changes, who recommend the collection of cartographic data for two discrete moments in time followed by the quantification and recording of said changes in a tabular format or 'transitional matrixes', so that the most significant changes can be readily identified.

The years of 1990 and 2000 were selected for the analysis. Land uses were identified using a database of digital information built using a combination of satellite and cartographic images that were treated, validated and ultimately used to create thematic maps according to desired parameters. Data were quantified for each year and tabulated in a matrix following the steps described in Lourenço et al. (2008). Overall results show that although the most significant, urban uses generally occur in a small percentage of the total area under scrutiny (Figure 4).

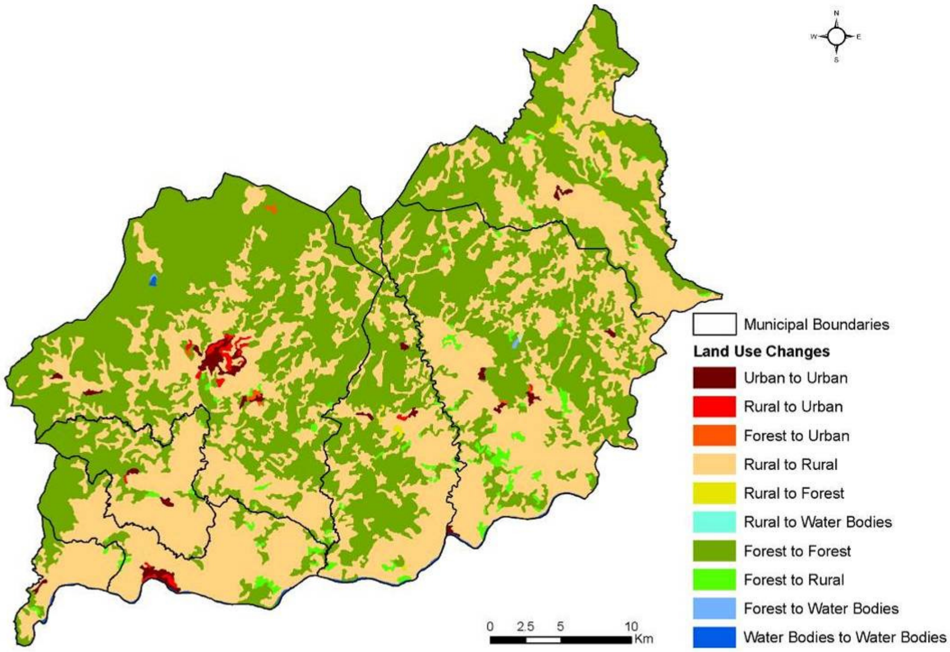

Figure 4 – Land use changes in target areas for 1990-2000

As expected, urban uses have little expression since the Douro region is dominated by agricultural uses, particularly those associated with vineyard farming. While some regions show some development that has been largely associated with rural uses, agricultural or not, other regions have been affected by processes derived from stagnant socio-economic conditions. These are associated to homogeneous land-uses (extensive areas set aside for one single use) and eventually to the abandonment and/or changes to the original land, such that multifunctional capabilities and biodiversity are reduced, potentially causing land and population desertification and aging. As observed, the most significant changes occur when forested areas are taken over by rural land, and conversely, when these are converted to urban land. Table 1 provides a better understanding of the relative significance of these changes.

Land Uses		**Municipality**						
		Alijó	**Mesão Frio**	**Murça**	**Peso da Régua**	**Sabrosa**	**Santa Marta de Penaguião**	**Vila Real**
Total Area	(ha)	29761.9	2665.6	18938.5	9487	15693.7	6930.9	37882
Urban area (%)	1990	0.55	1.07	0.26	1.69	0.5	0.98	1.28
	2000	0.63	1.07	0.26	2.42	0.64	1.12	2.22
	change	0.08	0	0	0.73	0.14	0.14	0.94
Rural area (%)	1990	50.71	72.62	45.97	70.74	46.08	64.12	34.67
	2000	53.17	75.14	46.15	72.38	47.01	64.73	34.45
	change	2.46	2.52	0.18	1.64	0.93	0.61	-0.22
Forest area (%)	1990	48.32	23.37	53.77	26.03	52.63	34.9	63.98
	2000	45.7	20.85	53.59	23.66	51.56	34.15	63.24
	change	-2.62	-2.52	-0.18	-2.37	-1.07	-0.75	-0.74
Wetland area (%)	1990	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	2000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	change	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Water Bodies	1990	0.42	2.94	0	1.54	0.79	0	0.07

(%)	2000	0.5	2.94	0	1.54	0.79	0	0.09
	change	0.08	0	0	0	0	0	0.02

Table 1 – Land use and land use changes in the selected municipalities

Rural uses continue to dominate the landscape, with a tendency to increase in certain municipalities. This is thought to be one of the driving forces behind the loss of forested areas, an observation corroborated by the data obtained for Mesão Frio, Alijó and Peso da Régua, which have seen the most significant increases in rural land use and decreases in forested areas.

As for urban uses, they are most significant for Vila Real. Not surprisingly, given that it consistently displays increasing annual population growth rates of 2-3% (Lourenço et al., 2008), this municipality also underwent the greatest change in urban land, with an increase of approximately 356 ha. Except for Mesão Frio and Murça, the remaining municipalities also exhibit increases in urban uses, albeit more modest ones. Improvements to the accessibility infrastructure are thought to have been the major driving force for Vila Real urban expansion rather than the application of urban and other land-planning policies.

Most changes associated to shifts within agricultural uses refer to an increase in vineyard-occupied areas, accompanied by a decrease in forests and natural vegetation as well as in the percentage of land devoted to annual-permanent crops. Furthermore, a combination of wildfires, complex topography and scant reforestation efforts do not favour the swift and lasting regeneration of the woodland. On the other hand, these and other non-cultivated areas are promoters of biodiversity, offering several habitats possibilities to flora and fauna species.

Carbon balance shifts in the selected municipalities

The second part of the study remains in its preliminary stages as it is part of an on-going effort dedicated to the characterization of the carbon budget within the Douro region. As such, the results presented at this point have been generated through an adaptation of the methodologies described by Shao et al. (2008) and Schulp et al. (2008).

A series of emissions factors (EF) for non-urban uses (Table 2) were obtained from Schulp et al. (2008).

Cropland	Wetlands	Forest
-28.1	-2.0	92.0

Table 2 – Non-urban EF per land use type (tC/km^2/year) for Portugal (Source: Schulp et al., 2008; EF<0: carbon emission; EF>0: carbon sequestration)

According to these parameters, increases in cropland and wetlands and decreases in forested areas mean an increase in carbon emissions. Conversely, carbon sequestration is promoted by reducing cropland and wetland uses and increasing forestry uses.

Carbon emission and sequestration for water bodies have not been considered at this point. Therefore, the corresponding EF was taken as zero.

Urban uses EF were calculated using per capita emissions data published elsewhere (Table 3).

Method	1990	2000
1. IPCC Sector 1.A, Fuel Combustion - Sectoral Approach	3.917	5.641
2. IPCC Sector, Total Emissions 1-7, excluding 5 LULUCF*	4.360	6.253

Table 3 – Per capita carbon emissions (tC/inhab), for Portugal (Source: EEA, 2009; LULUCF: Land Use, Land Use Change and Forestry)

Accordingly, two types of urban EF were defined and used for determining municipality-specific EF. Two sets of data were generated and used to determine the extent of the effect of land use changes in the local carbon budget (See Appendix).

In general, there is a decrease in the carbon sequestration versus emissions phenomena. Given the decrease in forested and increase in rural and urban areas, the carbon balance results are not unexpected. However, population density appears to play an important role in terms of how the carbon balance is estimated and the intensity of its variations. Mesão Frio and Peso da Régua yield negative carbon balances. For 2000, emissions surpass sequestration by as much as 73% and 136% (method 1) and 67% and 127% (method 2), respectively. Regardless of EF definition method, both situations can be explained by the high population densities and the increase of the average per capita emissions in the nineties from which the overall EF were derived (Figure 5), since there are no significant increases in urban or rural nor decreases in forested uses.

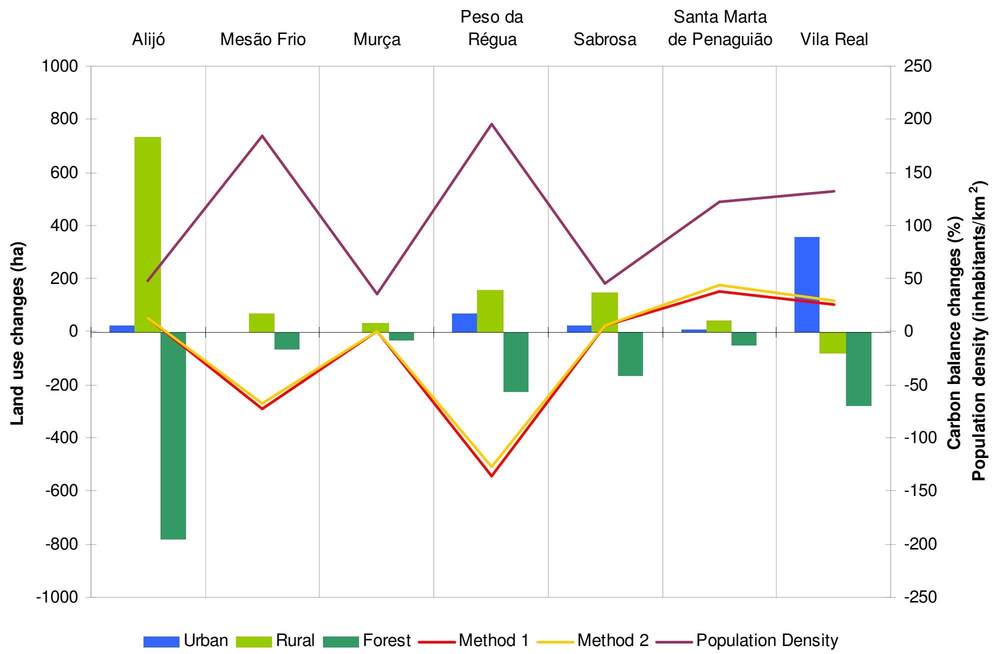

Figure 5 – Land use and carbon balance changes in target areas for 1990-2000

Conversely, Alijó and Vila Real, which exhibit the highest increases in rural and urban uses, respectively, combined with the highest level of deforestation, produced global net results significantly favourable of carbon sequestration. A quick glance at the data shown above suggests the high sensitivity of the EF calculation method to population density over magnitude of land use changes. This is particularly apparent for Alijó, where the loss of forested areas ranked the highest (approximately 780 ha, followed by Vila Real with a loss of approximately 280 ha) but where population density is the third lowest of the group of municipalities. Santa Marta de Penaguião's modest land use changes and relatively high population density indicate a trend of decreasing sequestration capacity, having lost 38% of its positive net gain between 1990 and 2000.

In general (Table 4), both urban EF calculation approaches yielded similar results.

Carbon Per land use	Method 1	Method 2
Urban	114% increase	113% increase
Rural	1.90% increase	
Forest	2.57% increase	

Water bodies	0.00% increase.	
Total Sequestration	2.57% decrease	
Total Emissions	28.16% increase	30.15% increase
Carbon Balance	20.22% decrease	22.16% decrease

Table 4 – Overall carbon balance for 1990-2000

Both methods calculated an approximately 30% increase in emissions that, given the dominance of rural and other non-urban uses, were insufficient to overwhelm the carbon sequestration capacity of the target region. In fact, the global 2.57% decrease in sequestration was enough to offset the increase in emissions by as much as 8%.

Nonetheless, it should be noted that the data do not take into account urban sequestration phenomena – brought by urban forests and vegetation – nor did the study consider carbon sequestration processes over water bodies. It is known that in lakes considered in a long term equilibrium with the nutrients they receive, carbon accumulation will be sedimentary which is small relative to in situ primary production, implying most of it is respired either in the water column or at the sediment. It is already well established (Prairie et al., 2009) that for the water column compartment, respiration generally exceeds gross primary production surface. But while the area of aquatic systems is small, they can affect regional carbon balance, representing an active component, especially the fresh water ones, of the global carbon cycle (Cole et al., 2007).

Other non-urban carbon emissions were equally dismissed at this initial stage and are likely to be explored, given the area's propensity for wild fires. Furthermore, given the growing trend in mechanisation of agricultural activities, namely wine-farming, it would interesting to verify the validity of the emission factor for cropland uses, as the trend becomes more visible over time.

Conclusions

The analysis herein presented indicates that in the Douro Valley, the dominance of vineyards and forestry uses over urban occupation accounts for a much higher sequestration than emission of carbon. Albeit general stagnant socio-economic developments in the area, some parts of it show relevant shifts in land-use, be it urban sprawl, deforestation or abandonment. Forest fires and a complex topography are major causes for the growth of abandoned areas which make these areas more prone to erosion and desertification.

Some occurrence of urban sprawl and the replacement of forested areas by urban uses, has determined an overall decrease of 2,6% – from 57566,8 tC in 1990 to 56086,6 tC in 2000 – in carbon sequestration for the area under study. This sets for a somewhat negative trend of increased CO_2 in the atmosphere.

Furthermore, the estimated carbon emissions production has increased, from a level slightly above 21000 tC in 1990, partly due to land-use shifts and in larger proportion to per capita emissions. As the estimated per capita average for Portugal has increased from 1990 to 2000, albeit the reduction in more recent years, the computed emissions in 2000 in the area have risen by 28,2% in a decade, despite the population loss in the sub-region.

This is a preliminary approach at local/sub-regional scale for estimating the carbon balance. Several other approaches, including urban sequestration, aquatic systems, wetlands efflux and adjusted sub-regional per capita emissions, are required in order to be able to put forward an encompassing approach to a detailed and area-specific carbon budget.

Likewise, policy measures such as forestation of marginal agricultural land and re-forestation, among others, may be adopted in order to increase carbon sequestration in the area. The enlarged use of renewable energies in the sub-region and policies towards urban sustainability and energy efficiency, especially in the housing sector and in the built environment, may help lower carbon emissions.

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Municipality	Population density (km^2)		Land Use	Land use area (km^2)		EF ($tC/km^2/yr$)		Per land use (tC/yr)		Sequestration (tC/yr)		Emissions (tC/yr)		Carbon Balance (tC/yr)	
	Census 1991	Census 2001		1990	2000	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
Alijó	54.86	48.12	urban	1.63	1.88	-214.9	-271.4	-350	-511	13231	12513	-4591	-4958	8640	7555
			rural	150.93	158.24	-28.1	-28.1	-4241	-4446						
			forest	143.82	136.01	92.0	92.0	13231	12513						
			water	1.24	1.49	0.0	0.0	0	0						
Mesão Frio	206.57	184.37	urban	0.28	0.28	-809.1	-1040.0	-230	-296	573	511	-774	-859	-201	-347
			rural	19.36	20.03	-28.1	-28.1	-544	-563						
			forest	6.23	5.56	92.0	92.0	573	511						
			water	0.78	0.78	0.0	0.0	0	0						
Murça	38.92	35.65	urban	0.50	0.50	-152.4	-201.1	-76	-101	9368	9337	-2522	-2556	6846	6781
			rural	87.05	87.39	-28.1	-28.1	-2446	-2456						
			forest	101.83	101.49	92.0	92.0	9368	9337						
			water	0.00	0.00	0.0	0.0	0	0						
Peso da Régua	223.66	195.3	urban	1.60	2.30	-876.1	-1101.7	-1402	-2530	2272	2065	-3287	-4459	-1015	-2394
			rural	67.11	68.66	-28.1	-28.1	-1886	-1929						
			forest	24.70	22.45	92.0	92.0	2272	2065						
			water	1.47	1.47	0.0	0.0	0	0						
Sabrosa	47.65	44.81	urban	0.78	1.00	-186.6	-252.8	-146	-253	7598	7444	-2179	-2327	5420	5118
			rural	72.32	73.78	-28.1	-28.1	-2032	-2073						
			forest	82.59	80.92	92.0	92.0	7598	7444						
			water	1.24	1.24	0.0	0.0	0	0						
Santa Marta de Penaguião	138.92	122.68	urban	0.68	0.78	-544.1	-692.0	-368	-538	2225	2177	-1617	-1799	608	379
			rural	44.44	44.86	-28.1	-28.1	-1249	-1261						
			forest	24.19	23.67	92.0	92.0	2225	2177						
			water	0.00	0.00	0.0	0.0	0	0						
Vila Real	122.78	132.48	urban	4.87	8.42	-480.9	-747.3	-2341	-6290	22298	22038	-6031	-9957	16267	12081
			rural	131.33	130.51	-28.1	-28.1	-3690	-3667						
			forest	242.37	239.55	92.0	92.0	22298	22038						
			water	0.25	0.34	0.0	0.0	0	0						

Table 5 – Carbon balance: fuel combustion, sectoral approach

Municipality	Population density (km^2)		Land Use	Land use area (km^2)		EF ($tC/km^2/yr$)		Per land use (tC/yr)		Sequestration (tC/yr)		Emissions (tC/yr)		Carbon Balance (tC/yr)	
	Census 1991	Census 2001		1990	2000	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
Alijó	54.86	48.12	urban	1.63	1.88	-239.2	-300.9	-390	-567	13231	12513	-4631	-5013	8600	7499
			rural	150.93	158.24	-28.1	-28.1	-4241	-4446						
			forest	143.82	136.01	92.0	92.0	13231	12513						
			water	1.24	1.49	0.0	0.0	0	0						
Mesão Frio	206.57	184.37	urban	0.28	0.28	-900.6	-1152.9	-256	-328	573	511	-800	-891	-227	-379
			rural	19.36	20.03	-28.1	-28.1	-544	-563						
			forest	6.23	5.56	92.0	92.0	573	511						
			water	0.78	0.78	0.0	0.0	0	0						
Murça	38.92	35.65	urban	0.50	0.50	-169.7	-222.9	-85	-111	9368	9337	-2531	-2567	6837	6770
			rural	87.05	87.39	-28.1	-28.1	-2446	-2456						
			forest	101.83	101.49	92.0	92.0	9368	9337						
			water	0.00	0.00	0.0	0.0	0	0						
Peso da Régua	223.66	195.3	urban	1.60	2.30	-975.2	-1221.2	-1560	-2805	2272	2065	-3446	-4734	-1174	-2668
			rural	67.11	68.66	-28.1	-28.1	-1886	-1929						
			forest	24.70	22.45	92.0	92.0	2272	2065						
			water	1.47	1.47	0.0	0.0	0	0						
Sabrosa	47.65	44.81	urban	0.78	1.00	-207.8	-280.2	-163	-281	7598	7444	-2195	-2354	5403	5090
			rural	72.32	73.78	-28.1	-28.1	-2032	-2073						
			forest	82.59	80.92	92.0	92.0	7598	7444						
			water	1.24	1.24	0.0	0.0	0	0						
Santa Marta de Penaguião	138.92	122.68	urban	0.68	0.78	-605.7	-767.1	-410	-596	2225	2177	-1659	-1857	567	320
					44.86	-28.1	-28.1	-1249	-1261						
					23.67	92.0	92.0	2225	2177						
					0.00	0.0	0.0	0	0						
Vila Real	122.78	132.48	urban	4.87	8.42	-535.3	-828.4	-2605	-6972	22298	22038	-6296	-10640	16003	11399
			rural	131.33	130.51	-28.1	-28.1	-3690	-3667						
			forest	242.37	239.55	92.0	92.0	22298	22038						
			water	0.25	0.34	0.0	0.0	0	0						

Table 6 – Carbon balance: total emissions, excluding LULUCF