

A Downscaled Population Density Map of the EU from Commune Data and Land Cover Information

Javier Gallego

JRC-Ispra, e-mail: javier.gallego@jrc.it

Abstract

Population data in the European Union are available at the level of the commune. More detailed data are available for some countries, but they are often confidential or difficult to obtain. CORINE Land Cover (CLC) provides georeferenced land cover information with a medium resolution (minimum mapping unit: 25 ha). This paper describes several approaches followed to combine commune population data with CLC to produce a EU-wide grid with 1 ha resolution of downscaled population density. An iterative algorithm was first developed to estimate coefficients of a simple multiplicative model. In a further stage the information provided by the point survey LUCAS (Land Use/Cover Area frame Survey) has been integrated through a logit regression to improve the coefficients of the model. Some examples of application are presented: an attempt of automatic definition of urban agglomerations and the estimation of the population living less than 10 km from the coast.

This work is a complement to the initiative of the “European Forum for Geostatistics”, an initiative of a group of National Statistical Institutes, that propose a population density grid with 1 km² resolution with a bottom-up approach, i.e. produced from individual census data, that are aggregated to respect confidentiality. The top-down method presented in this paper is obviously less accurate, but provides a way to fill the EU population gridded map for countries that do not apply the bottom-up approach.

Keywords: Dasymeric mapping, population density, CORINE Land Cover

1 The European forum for Geostatistics.

A group of National Statistical Institutes of European countries, supported by Eurostat, launched a few years ago the “Grid Club Initiative”, now called “European Forum for Geostatistics” (<http://www.efgs.ssb.no/>). Scandinavian countries are particularly active in this group, as well as the Netherlands, Austria, Switzerland and Slovenia. The mid-term target is providing socio-economic data in a harmonized geographic system based on regular grids, that can be efficiently analyzed in a GIS environment. The first topic identified is population density; other topics should be progressively added. The best way to produce gridded maps is collecting georeferenced individual data and counting or aggregating in each cell of the grid. This is what we call the bottom-up approach.

There are two practical limitations to the bottom-up approach:

- Not all countries are willing to apply it.
- Confidentiality rules for individual data may oblige to degrade the results.

2 The top-down approach: downscaling.

Harmonised population density data for the European Union (EU) are available at the level of the commune. Some countries, in particular the countries mentioned above, have more detailed geo-referenced data, but for EU-wide studies the communal level is the most detailed available. This level of spatial resolution may be insufficient in many cases for planning or modelling purposes. There is a need to downscale population density, i.e. to represent it in smaller geographical units. We have used land cover information as proxy variable to achieve this aim. The result of each downscaling procedure presented here is a GIS raster layer with 100 m resolution.

Presented as a poster of the EU population density, the grid looks nearly identical to the population per commune. Differences appear when the data are used to study the spatial link between population and other variables.

This layer has some differences with the Landscan population density grid (Dobson et al., 2000, Bhaduri et al., 2002) and the Gridded population of the world (GPW, CIESIN, 2005): In our case the area covered is smaller but the spatial resolution is finer. Landscan refers to the “ambient population”, a time-weighted average of the number of people in each cell, while our grid locates each person in his/her dwelling.

Among available methods, we can mention the binary method (Langford, 2007), that assigns the whole population to one land cover class (usually urban or artificial land cover); the three-class method attributes some density to agricultural and forest classes. An improved three-class algorithm is proposed by Mennis (2003). The limiting variable method (Mc Cleary, 1984) first assigns densities by simple areal weighting and then modifies them by putting thresholds to each land cover class and redistributing the excess to the other classes. Eicher and Brewer (2001) find that the limiting variable method gives better results than the binary and the three-class method. Other methods (Flowerdew and Green, 1989, Yuan et al, 1997) use a regression model. Coefficients are applied later to adjust the total population assigned to each administrative unit (commune) to the known population.

Some authors have produced more precise downscaled population density layers using streets and roads networks in a small area, such as a county (Xie, 1995). This approach might be interesting at EU level with the help of navigation databases.

One possible approach is based on the EM algorithm (Dempster, 1977). We discuss below the application of this algorithm. An alternative is provided by the method, summarised below, applied by Gallego and Peedell (2001). This method has been assessed by Thielen et al (2006), that find the obtained density map gives realistic population figures to the areas flooded in Germany in the flood events of 1999 and 2002, but find, by comparing data with the population of the 5-digit postal codes, that the population in non-urban land cover classes is generally over-estimated.

The International Committee on Aviation Environmental Protection has used the grid presented here to assess the impact of noise around airports (Vinkx and Visée, 2008). The Directorate General Regional Development (DG REGIO) of the European Commission (EC) has used it to compute indicators of accessibility to services in rural areas (Dijkstra and Poelman, 2008). A different approach to the problem, mainly for application at national or sub-national level, is designing the census enumeration areas optimizing its compatibility with different applications, to minimize the need of downscaling procedures (Martin, 1998). Langford (2007) fairly claims that complex areal interpolation methods to produce dasymmetric population maps is a major obstacle for the use of such methods by many users. The target of this paper is presenting a ready-to-use grid to overcome this difficulty.

3 Data

Several layers of information are combined for this exercise: Commune data (population and geographic boundaries), a land cover map, and a point survey:

3.1 Commune data.

The area covered by the study includes the EU (excluding for the moment some peripheral islands and overseas territories), Croatia, Liechtenstein, San Marino and Monaco. Altogether an area around 4.3 Million km² with more than 480 Million inhabitants.

Population data from the 2001 census are available in principle for each commune of the study area, although Eurostat had to sort out some code problems to match the population data with the geographic boundaries of the communes of the SABLE GIS layer (<http://www.megrin.org/SABLE/Sable.html>), © Eurogeographics).

The number of communes in the study area is slightly above 114.000. The average area of a commune is about 36 km², The average area per country ranges from less than 15 km² in Slovakia, Czech Republic and France to more than 1500 km² in Sweden.

3.2 CORINE Land Cover 2000

The map we have used is CORINE Land Cover 2000 (CLC), produced by photo-interpretation of Landsat ETM+ satellite images (panchromatic + multispectral resampled with a resolution of 12.5 m.) with common rules in most countries in Central and Western Europe (CEC-EEA, 1993, JRC-EEA, 2005, Perdigão and Annoni, 1997). The nomenclature of CLC has 44 classes. The minimum mapping unit of CLC is 25 ha; smaller units are included in the dominant land cover type around or grouped in an area coded as heterogeneous. We have used a raster version of CLC with a pixel size of 1 ha. The class “heterogeneous” is important due to the relatively coarse scale of CLC. A raster version with cells of 1 ha has been used in projection Lambert Azimuthal Equal Area with the parameters recommended for Europe by the INSPIRE initiative (Annoni et al., 2001). For the disaggregation procedures the 44 CLC classes have been regrouped into a relatively small number. Several recoding criteria have been tested; at the moment we use a grouping into 9 classes (Table 1).

<i>Grouped class</i>	<i>CLC classes</i>
Urban dense	1.1.1
Urban discontinuous	1.1.2
Other urban - infrastructure	1.2.1, 1.3.3, 1.4
Artificial non residential	1.2.2-1.2.4, 1.3.1, 1.3.2
Agricultural	2.1, 2.2, 2.3
Heterogeneous	2.4.1 - 2.4.3
Forest and agroforestry	2.4.4, 3.1
Natural vegetation	3.2, 3.3
Open spaces and water	3.4, 4, 5

Table 1: CLC grouping criterion currently used for population density grids

For a large number of communes CLC2000 does not report any urban area. In most cases this is because the communes do not contain any urban area larger than 25 ha, threshold size for CLC2000. This happens for 29% of the communes, that correspond

to 16.6% of the total area and 2.9% of the total population. These communes require a specific consideration when CLC2000 data are combined with population data.

3.3 LUCAS point data

The LUCAS-2001 sample has a two-stage systematic design (Delincé, 2001, Bettio et al, 2002). Primary Sampling units (PSU) are selected with a systematic grid of 18 km without any stratification. Each PSU is a cluster of 10 points following a 5x2 rectangular pattern with a 300 m step. To be consistent with the ground work definitions, we can conceive the “point” as a circle of 3 m diameter. LUCAS-2001 only covers the EU15, i.e. the 15 countries that were member states in 2001.

LUCAS has a double nomenclature, i.e. each point has a land cover code (57 classes) and a land use code (14 classes). For this work the land use code has been used, focusing in particular on the class “residential”. 2245 LUCAS points were residential (2.4% of the total sample). Therefore LUCAS estimates the area with residential use in EU15 to be around 75,000 km².

4 Methods

The general simplifying assumption is that the population density can be expressed as:

$$Y_{cm} = U_{ch} W_m \quad (1)$$

Where Y_{cm} is the density for land cover type c in commune m , the coefficient U_{ch} depends on the land cover class and stratum h . Three strata are defined grouping higher and lower density communes, as well as a stratum for communes without urban area in CLC. W_m is a factor that ensures that the total of the grid in each commune matches the known population. If the coefficients U_{ch} are known, we have

$$\begin{aligned} X_m &= \sum_c S_{cm} Y_{cm} & X_m &= \sum_c S_{cm} U_{ch} W_m \quad \Rightarrow \\ W_m &= \frac{X_m}{\sum_c S_{cm} U_{ch}} & Y_{cm} &= U_c \frac{X_m}{\sum_c S_{cm} U_{ch}} \quad (2) \end{aligned}$$

Where X_m is the population in commune m and S_{cm} is the area of land cover type c .

4.1 Iterative estimation of coefficients with regional and commune data

The first version of the grid estimated U_{ch} with an iterative method that was described in Gallego and Peedell (2001). The scheme was:

- Pretend that we only know the data for larger regions.
- Disaggregate regional data with CLC using an initial set of coefficients.
- Compute the population attributed to each commune in the the previous step.
- Compute a disagreement indicator with the known population per commune.

$$\delta_r = \sum_{m \in r} |X_m^* - X_m| \quad \delta = \sum_m |X_m^* - X_m| \quad (3)$$

- Modify the coefficients trying to reduce the disagreement and start again.

4.2 Application of the EM algorithm

Flowerdew et al (1991) apply the EM algorithm (Dempster, 1977) to estimate disaggregation coefficients. The algorithm assumes a probabilistic model; we follow the suggestion of Flowerdew et al. (1991): the population X_{mc} has a Poisson

distribution with parameter $\mu_{mc} = U_c S_{cm}$; all distributions for different m and c are assumed to be independent. It can be argued that the parameter does not take into account the average population density of the commune and would give for example the same density to an agricultural area in a peri-urban commune or in a remote unpopulated region. However the E step of the algorithm corrects this undesired effect. Each iteration of this algorithm has two steps: the E step (expectation) and the M step (maximum likelihood). For the t^{th} iteration the E step gives an estimate of the population in land cover class c for the commune m from the disaggregation coefficients obtained in the previous M step:

$$\hat{X}_{mc}^{(t)} = \frac{U_c^{(t-1)} S_{cm} X_m}{\sum_c U_c^{(t-1)} S_{cm}} \quad (4)$$

This step ensures that the total population attributed to each land cover class c inside a commune equals the known population of the commune. In the M step we estimate the values of U_c that give maximum likelihood to the $\hat{X}_{mc}^{(t)}$ from the previous E step.

$$p(X_{mc} = \hat{X}_{mc}^{(t)}) = \frac{e^{-\mu_{mc}} \mu_{mc}^{\hat{X}_{mc}^{(t)}}}{(\hat{X}_{mc}^{(t)})!} \quad \text{with likelihood is } L(U) = \prod_{cm} \frac{e^{-\mu_{mc}} \mu_{mc}^{\hat{X}_{mc}^{(t)}}}{(\hat{X}_{mc}^{(t)})!} \quad (5)$$

For the purpose of maximization we can use the log-likelihood and disregard the denominator, since it is seen as the set of data and therefore constant.

$$\log(L(U)) = B + \sum_{cm} [\hat{X}_{mc}^{(t)} \log(U_c S_{cm}) - U_c S_{cm}] \quad (6)$$

That can be decomposed in separate terms, one for each c . Thus the maximum is reached maximizing separately for each c ; this is obtained for

$$U_c^{(t)} = \frac{\sum_m \hat{X}_m^{(t)} \log(S_{cm})}{\sum_m S_{cm}} \quad (7)$$

4.3 Simple parameter estimation with LUCAS-2001 data

Overlaying the approx 96,000 point of the LUCAS sample on the CLC map, we get a contingency table crossing CLC classes with fine scale land cover types (Gallego and Bamps, 2008). In particular we can estimate the proportion of each CLC class that has residential use. CLC classes were clustered on the basis of the proportion of residential use to get the simplified nomenclature in 9 classes reported in Table 1. For the non-urban classes, the % of residential area is used as a proxy of the population density. For urban classes a subjective expert-based choice was made.

<i>Land cover class</i>	LUCAS points			suggested coefficients
	residential	total	% resid.	
Urban dense	60	132	45.4	2000
Urban discontinuous	1085	2609	41.6	500
Other urban	72	748	9.6	150
Artificial non residential	2	241	0.8	0
Agricultural	576	31956	1.8	30
Heterogeneous	272	9492	2.9	50
Forest and agroforestry	142	30826	0.5	8
Natural vegetation	19	13339	0.14	2
Open spaces and water	15	7087	0.21	0
Total	2243	96430	2.3	

Table 2: Proportion of residential area in CLC classes using LUCAS 2001

4.4 Application of logit regression

We can expect that the same non-urban CLC class (e.g. “agriculture”) has more dense population in areas with higher average density, i.e. the commune coefficients W_m are higher for communes with higher average density D_m but W_m does not grow linearly with the average population density. Let us consider the next question: If we select a point at random and he have some information about this point (CLC class= LC_i , commune, altitude, etc.), which is the probability that this point has a residential land use?. A usual way of modelling this type of probabilities is the logit regression:

$$\text{logit}(p_{cm}) = \log(p_{cm}/(1-p_{cm})) = \alpha + \sum_c \beta_c J_c + \gamma \log(D_m) + \varepsilon_{cm} \quad (8)$$

Where J_c is an indicator function of CLC class c . For non-urban classes, the values of p_{cm} are generally small and the logit function is close to the simple logarithm. The model (8) is similar to a multiplicative model:

$$p_{cm} = \exp(\alpha + \beta_c + \varepsilon_{cm}) \times D_m^\gamma \quad (9)$$

A value $\gamma=0$ would suggest that the population density in a point depends only on the CLC class and not on the average density of the commune. A value $\gamma=1$ would correspond to a population density in each CLC class that would be proportional to the average density of the commune.

The model is adjusted separately for different types of communes (strata). The stratification used for the iterative method reported above has been tested, but a better fit was obtained with a slightly different definition of strata:

- Stratum a: Communes in which the CLC class “urban dense” is present.
- Stratum b: Communes with some CLC artificial area, but no “urban dense”.
- Stratum c: Communes without any CLC artificial area.

The explanation can be that the absence of the “urban dense” class in CLC usually indicates that the urban nucleus (or nuclei) of the commune does not reach the CLC size threshold (25 ha), but it still exists: it has been integrated in a “heterogeneous” polygon or in another dominant class (agricultural, forest...). Therefore the probability that a LUCAS point, that appears to be agricultural or forest in CLC, falls in residential areas is increased. Communes without any artificial area reported in CLC are also a separate type. Table 3 shows the parameters obtained for the logit regression (8). We can make several comments on this table:

- For communes without any artificial area, the residential density for a given CLC class strongly depends on the average population density of the commune ($\gamma=0.67$). The dependence is much smaller, but still significant ($\gamma=0.23$, $\gamma=0.18$) for communes with CLC artificial areas.
- The central columns of table 3 provide information on communes in which the class “urban dense” is absent, but there is some other artificial area. If we take as a reference the residential density in the class “urban discontinuous”, for the same type of commune, the residential density is approximately 34 times lower for the CLC class “agricultural”, 19 times lower for CLC “heterogeneous”, and more than 160 times lower for CLC “forest”. For communes with some “urban dense” class these ratios become around 65, 34, and 175. This suggests that the ratios estimated in section 4 might have been underestimated. The ratios for the other classes (artificial, natural vegetation) are based on a small number of residential; points and are consequently weaker.

- These ratios are valid for CLC and cannot be directly extended to other land cover maps, especially if they have a different spatial resolution, although the same methodology can be applied.
- The residential density (proportion of the territory with residential use) is a proxy for population density, but both densities are not exactly proportional: the average residential surface per inhabitant may be larger in agricultural or forest areas than in urban areas, even if we consider “urban discontinuous”. It has to be also taken into account that LUCAS points are coded as residential if they fall on secondary houses, where people are generally not censused.

Communes	without CLC artificial		With CLC artificial		With dense urban	
	Logit param.	$\exp(\beta_c)$	Logit param.	$\exp(\beta_c)$	Logit param.	$\exp(\beta_c)$
α	-9.2	1.0 e-4	-7.3	6.4 e-4	-7.9	3.5 e-4
γ	0.67		0.23		0.18	
β : Urban disc.			5.9	354.4	6.7	799.5
β : Other artificial			3.8	42.7	4.5	91.9
β : Agricultural	2.8	17.3	2.4	10.5	2.5	12.4
β : Heterogeneous	3.6	36.8	2.9	18.2	3.2	23.8
β : Forest	0.2	1.3	0.8	2.2	1.5	4.6

Table 3: Parameters obtained for the Logit model.

More than 94% of the communes do not have any pixel of the CLC class “urban dense” ($S_{urbandense,m} = 0$). For these communes the density per class is computed as

$p_{cm} = \lambda_m \exp(\alpha + \beta_c) \times D_m^\gamma$ with the constraint.

$$X_m = \sum_{c=2}^8 S_{cm} \lambda_m \exp(\alpha + \beta_c) D_m^\gamma \quad \Rightarrow \quad \lambda_m = \frac{X_m}{\sum_{c=2}^8 S_{cm} \exp(\alpha + \beta_c) D_m^\gamma} \quad (10)$$

For the communes in which the CLC class “urban dense” is present we need a different strategy, since the approach described above does not attribute any specific density to the CLC urban dense class. We first attribute a population density Y'_{cm} for the other land cover classes ($c \geq 2$, i.e. excluding urban dense) by simply averaging the densities Y_{cm} for the same land cover class c in neighbouring communes without urban dense class. The remaining population of the commune $X'_{1m} = X_m - \sum_{c>1} Y'_{cm} S_{cm}$ is attributed to the class “urban dense with a density $Y'_{1m} = X'_{1m} / S_{1m}$. This provisional computation attributes in some cases an unrealistic value for the density Y'_{1m} compared with the density Y'_{2m} attributed to the class $c=2$ “urban discontinuous” (notice that the procedure computes a value of Y'_{2m} even if the class $c=2$ does not exist in the commune m). We have introduced the empirical rule that the density Y'_{1m} should be between 4 and 10 times higher than Y'_{2m} .

5 Validation in 5 countries

The performance of the disaggregation procedures presented above have been compared with the help of reference data provided by five countries as 1 km

resolution grids in national cartographic coordinates. They have been obtained by aggregation of individual dwellings (bottom-up). We have compared the reference data with the next dasymetric maps with 1 ha resolution:

- Communes: the average population density of each commune is attributed to the whole commune in a uniform way.
- CLC-Iterative: disaggregation with the method presented in 4.1.
- CLC-EM: EM algorithm as reported in 4.2.
- CLC-LUCAS Simple: disaggregation with the method presented in 4.3.
- CLC-LUCAS logit: disaggregation with the method presented in 4.4.

These 5 maps were produced as raster grids in the INSPIRE-recommended Lambert-Azimuthal projection with 1 ha resolution, then projected to national coordinates and generalized to 1 km² with the same cell boundaries of the reference grid.

The disagreement indicator was computed as:

$$\Delta_m = \sum_j |Y_{j,m} - Y_{j,ref}| \quad (2)$$

The values obtained for the disagreement (Table 4) indicates that disaggregation with the help of CLC significantly reduces the disagreement with reference data, but is far from eliminating it. The improvement changes very little from one disaggregation procedure to another, except in the case of the Netherlands. The introduction of LUCAS data through a logit regression improves the results, but only slightly. The reasons for this low sensitivity to the choice of the method still need to be investigated more in depth, but the main explanation seems to be the heterogeneity of population density for areas in the same commune and same land cover type in CLC.

<i>Dasymetric map</i>	Austria	Denmark	Finland	Sweden	Netherlands
Communes (homogeneous)	8.96	6.08	6.79	12.48	18.72
CLC-iterative	4.55	4.07	5.44	8.05	7.13
CLC-LUCAS simple	4.39	3.97	5.06	8.09	9.03
CLC-LUCAS logit	4.35	3.95	5.03	8.07	7.08
CLC EM	4.50	3.98	5.12	8.08	9.29

Table 4: disagreement of different dasymetric maps with reference data in 5 countries

6 Discussion and further work.

The downscaled population density map of EU27+ that we have presented in this paper is a significant improvement compared with the homogeneous representation of the density in each commune (choropleth map). The degree of improvement thanks to the information provided by CLC varies from country to country; it is more consistent in Austria and the Netherlands than in the Scandinavian countries.

The data set had a large number of downloads from the EEA data service, and presumably a large number of applications will appear in the next years.

Future work includes several chapters:

- Filling some gaps, in particular Norway and Switzerland.
- Collaborating with the European Forum for Statistics to produce hybrid maps with bottom-up data where it is available and top-down for the rest.
- Updating the map to 2006 and studying the changes 2001-2006. At the moment Eurostat is working to make compatible the tabular population data of communes with the geographic information of the commune boundaries.

- Developing applications, for example by combining the population data with Natura 2000 sites.
- Further improvement of the methods, in particular to correct the over-estimation that still seems to appear in some non-urban areas. Additional data layers can be useful for this purpose: night-time light emissions (Briggs et al., 2007) and a soil sealing map that is being produced by initiative of EEA.

Acknowledgements:

Eurostat provided most of the data for the study. We are particularly grateful to César de Diego, Albrecht Wirthmann, Daniel Rase, Torbiorn Carlquist and Edwin Schaaf. Statistics Austria provided reference data for validation through the “European Population Grid Club” specially Kaminger, Rina Tammisto and Lars Backer. Roger Milego, Oscar Gómez, Stefan Kleeshule and Tomas Soukup, from the European Topic Centre of Terrestrial Environment (ETC/TE) made useful suggestion. Mette Lund managed the distribution of the results through the EEA dataservice.

References

- Annoni A., Luzet C., Gubler E., Ihde J. (2001) *Map Projections for Europe*. Report EUR 20120 EN, JRC-Ispra (Italy), 131 pp.
- Bettio M., Delincé J., Bruyas P., Croi W., Eiden G. (2002) Area frame surveys: aim, principals and operational surveys. *Building Agri-environmental indicators, focussing on the European Area frame Survey LUCAS*. EC report EUR 20521, pp. 12-27. <http://agrienv.jrc.it/publications/ECpubs/agri-ind/>
- Bhaduri, B., Bright E., Coleman, Ph., Dobson, J., (2002) LandScan: Locating People is What Matters. *Geoinformatics* 5 (2), 34-37. <http://www.ornl.gov/sci/landscan/>.
- Briggs D.J., Gulliver J., Fecht D., Vienneau D.M. (2007). Dasymeric modelling of small-area population distribution using land cover and light emissions data, *Remote sensing of Environment*, 108, 451-466.
- CEC-EEA (1993) *CORINE Land Cover; technical guide*. Report EUR 12585EN. Office for Publications of the European Communities. Luxembourg,. 144 pp. <http://dataservice.eea.eu.int/dataservice/>
- Center for International Earth Science Information Network (CIESIN), (2005). *Gridded Population of the World (GPW), Version 3*. CIESIN, Columbia University, Palisades, NY. <http://sedac.ciesin.org/plue/gpw>.
- Delincé J. (2001). A European approach to area frame survey. *Proceedings of the Conference on Agricultural and Environmental Statistical Applications in Rome (CAESAR)*, June 5-7, Vol. 2 pp. 463-472 available at <http://www.ec-gis.org/>
- Dempster A.P., Laird N.M., Rubin D.B. (1977) Maximum likelihood from incomplete data via the EM algorithm. *Journal of the Royal Statistical Society B*, 39 1-38.
- Dijkstra L. and Poelman H. (2008) Remote Rural Regions: How proximity to a city influences the performance of rural regions, *Regional Focus* n.1 (2008) EC-DG REGIO.
- Dobson, J.E., Bright, E.A., Coleman, P.R., Durfee, R.C., Worley, B.A. (2000) LandScan: A global population database for estimating populations at risk *Photogrammetric Engineering and Remote Sensing*, 66 (7), pp. 849-857.

- Eicher C., and Brewer, C. (2001) Dasymetric mapping and areal interpolation: implementation and evaluation, *Cartography and Geographic Information Science* 28 125–138
- Flowerdew R., Green M., Kehris E. (1991) Using areal interpolation methods in GIS; *Papers in regional science*, 70 (3) 303-315.
- Gallego J., Peedell S. (2001) Using CORINE Land Cover to map population density. *Towards Agri-environmental indicators*, Topic report 6/2001 EEA, Copenhagen, pp. 92-103. http://reports.eea.eu.int/topic_report_2001_06/en
- Gallego, J. and Bamps, C. (2008) Using CORINE land cover and the point survey LUCAS for area estimation. *International Journal of Applied Earth Observation and Geoinformation*, 10 467-475.
- JRC-EEA (2005) Image2000 and CLC2000; Products and methods; Report EUR 21757 EN. JRC-Ispra.
- Langford M. (2007) Rapid facilitation of dasymetric-based population interpolation by means of raster pixel maps. *Computers, environment and urban systems*, 31 19-32.
- Martin D. (1998) Optimizing census geography: the separation of collection and output geographies, *International Journal of Geographical Information Science*, 12 (7), 673-685.
- McCleary G.F., (1984) Cartography, geography, and the dasymetric method, *Proceedings, 12th Conference of International Cartographic Association*, 1, pp. 599-610. August 6-13, Perth, Australia
- Mennis, J., (2003). Generating surface models of population using dasymetric mapping, *Professional Geographer* 55 (1):31-42.
- Perdigão V., Annoni A., (1997). *Technical and methodological guide for updating CORINE Land Cover data base*. Report EUR 17288 EN. Office for Publications of the European Communities. Luxembourg,. 124 pp
- Thieken A., Müller M., Kleist L., Seifert I., Borst D., and Werner U. (2006), Regionalisation of asset values for risk analyses. *Natural Hazards and Earth System Sciences*, 6 167-178.
- Vinkx K., and Visée, T. (2008) Usefulness of population files for estimation of noise hindrance effects. *ICAO Committee on Aviation Environmental Protection. CAEP/8 Modelling and Database Task Force (MODTF)*. 4th Meeting. Sunnyvale, California, USA, 20 to 22 February 2008
- Xie, Y. (1995). The overlaid network algorithms for areal interpolation problem. *Computers, Environment and Urban Systems*, 19(4) 287-306
- Yuan, Y., Smith, R.M., Limp, W.F. (1997) Remodeling census population with spatial information from Landsat TM imagery, *Computers, Environment and Urban Systems*, 21 (3-4), pp. 245-258