THE RELATION BETWEEN ENERGY CONSUMPTION AND DEVELOPED LAND; A MODEL FOR THE METROPOLITAN AREA OF BARCELONA

Jorge **CERDA**, Yraida **ROMANO**, Claudia **PEREZ**, Josep **ROCA**
Centre of Land Policy and Valuations, CA1, Polytechnic University of Catalonia
Av. Diagonal 649, 08034 Barcelona, Spain
jorge.francisco.cerda@upc.edu; yraida.romano@upc.edu; claudia.perez@upc.edu;
josep.roca@upc.edu

Abstract

The study of the developed land and the energy consumption is part of a main project, which objective is the development of a model for the evaluation of the environmental and energy efficiency of the interaction (mobility) and land use structure (called as "territorial functionality"), applied to the metropolitan area of Barcelona. One of the most important points of the main project is the modelling of energy consumption, and developed land produced by the territorial functionality. This paper presents the calibrations results of econometrics models (log-log) for developed land, and electricity consumption. The used information for those models was; built surface by activity (cadastre), coverings of land uses of Catalonia (CREAF), electric consumption by economic activity (CNAE), meteorological variables, and operating time of activities. The analysis was for the 164 municipalities of the metropolitan area of Barcelona. The electric consumption was analyzed in different categories of activities like as residential, industrial, trade, financial services, hotels, transport, education, public lighting, etc. The artificial area was differentiated in three categories; cadastre surface, streets, and developed land without cadastre. Overall, the results show that the extension of developed land depends (with 0.8 R2) mainly from single-family homes, followed by industrial activities, and finally sport activities. The trade activities induce a contraction of developed land, result that is consistent with agglomeration economies. The different models calibrated for energy consumption show a strong dependence (with R2 between 0.5 and 0.9) first with built surface, and second with other variables such as weather condition in the municipality (minimum temperature in summer), and average operating time of the activities (mean work time, shopping time, etc). The integration of the different models shows that the relation between developed land and electric consumption reveals an advantage of low dense compact structures over dense and compact structures.

Keywords: electric consumption, developed land

1.- Introduction

In recent decades, the metropolises of the Southwest Europe have undergone a process of territorial dispersion. The coastal and agricultural lands have been affected by urban expansion [8]. This context required the assessment, monitoring, and prediction of the externalities generated by urban expansion, under a comprehensive approach to the phenomenon. Only this approach can identify the elements that influence the efficiency of the territorial system, to predict the negative impacts of plans or programs, and preventive measures to mitigate them [5].

Environmental policies have influenced transport and urban planning themes on several levels. At the tactical level (specific project) through the assessment of environmental impact, and the incorporation of good environmental practices in the different project stages. At strategic level (metropolitan scale), the strategic environmental assessment ensure environmental consideration in early stages of the plan design. Spite this, the simulation of environmental impacts of transport projects or land use plan, in a systemic approach over a metropolitan scale is not usual.

In the context of modelling environmental and energy efficiency of the territorial functionality of the metropolitan area of Barcelona, one of the problems is to model the consumption of natural soil, and to model the electric consumption by located activities.

A simple point of view of this problem is that there is a direct relation between activities, developed land, and electric consumption. This statement is trivial and not very analytical, in the sense that not all activities have the same need of land and electric consumption for its operation.

Understanding the phenomenon of consumption (electrical and land) as a production process arises from the premise that a specific activity "produces" electricity and land demand. This demand is satisfied in the space where it is generated, transformed into consumption. The production approach generates a series of nonlinear equations [1].

The aim of this study is to quantify the relationship between activity surfaces in the municipalities of the Metropolitan Region of Barcelona, and the developed land and electric consumption that they generate.

The followed sections presented the different calibrated models and the understanding of its results. Finally the both models are integrated to detect the relationships analyzed.

2.- Developed land model

2.1.- Independent variable

The independent variables considered to explain the developed land, was the activities surfaces (registered in the cadastre). Table 1 show the different activities included in the modelling process.

Table 1.- Activities included in the analysis

Activities
Residential buildings
Single family residence
Rural residence
Industry
Offices
Shops
Sports centers
Entertaiment
Hotel and leisure
Health
Cultural and religious
Singular buildings

Font: CPSV-UPC

When performing an exploratory analysis of the built surface information, there was a high correlation between activities. This situation creates a multicollinearity problem to the econometric model. So, to summarize the variables in uncorrelated factor, we apply a factor analysis.

The procedure arise 5 main factors. Communalities denote a high percentage of extraction of the components, which was ratified in cumulative explained percentage of the total variance (73.35%). Table 2 show the structure of the main factors extracted from the original variables.

Table 2.- Correlations between main factor and original variables

	Main factors				
Original variables	**F1**	**F2**	**F3**	**F4**	**F5**
Prop. Residential buildings	**,890**	,238	-,078	,028	-,142
Prop. Single family residence	**-,808**	**,412**	,118	-,126	,012
Prop. Rural residence	**-,389**	-,148	-,169	**,605**	,151
Prop. Industry	-,126	**-,912**	,039	,026	,069
Prop. Offices	**,580**	**-,488**	**,332**	-,065	,005
Prop. Shops	**,864**	,073	-,170	-,105	-,007
Prop. Sports centers	**-,479**	**,546**	,287	-,071	-,041
Prop. Entertaiment	,085	,131	-,295	,185	**,830**
Prop. Hotel and leisure	,069	,118	**-,597**	**-,592**	,117
Prop. Health	**,557**	**,381**	,252	,116	,241
Prop. Cultural and religious	**,511**	**,397**	,149	**,374**	-,110
Prop. Singular buildings	,068	-,071	**,657**	**-,368**	**,441**

Font: CPSV-UPC

From Table 2 can be interpreting each component as follows:

- Factor 1 (29.2% variance).- The positive value of this factor is associated with high proportions of flats, shops, offices, and health care and religious culture. While a negative value is associated with high proportion of single-family, and sports uses. That is why this factor can be called ***Density***.
- Factor 2 (16.3% variance).- The positive value of this factor is associated with a mean proportions of single-family, and sports activities. While it's negative value is strongly associated with a high proportion of industrial, office and associated activities. That is why this polarized factor can be called ***Periphery***.
- Factor 3 (10.3% variance) .- The positive value of this factor is associated with high proportions of singular buildings. While a negative value is associated with a high proportion of leisure and hotel uses. That is why this polarized factor can be called ***Singular-leisure***.
- Factor 4 (8.9% variance) .- The positive value of this factor is associated with a high proportion of rural housing. While a negative value is associated with high proportion of leisure and hotel uses. That is why this polarized factor can be called ***Rural housing-leisure***.
- Factor 5 (8.5% variance) .- The positive value of this factor is associated with high proportion of spectacle and singular buildings, so this factor can be called ***Entertainment and singular***.

2.2.- Depend variable

The dependent variable in this case was the developed land (or artificialised area). This information arises from an analysis and critical evaluation of different sources of available information of land-use coverage. The analyzed sources were

- Corine Land Cover (CLC): (Coordination of Information on the Environment) Land Cover
- EURMET project
- The land cover map of Catalonia: Centre for Ecological Research and Forestry Applications (CREAF)

A comparative analysis [6] concluded that CREAF database is the most suitable for analysis of land consumption, since the levels of disaggregation ensure accurate. However, to define the coverage artificialised soil used was necessary to perform a process of homogenization between the databases of three years, because each one of them was carried out with different resolution.

The next step was to differentiate the developed land, overlaying the cadastral map. Thus the CREAF developed land was divided into three categories which are; developed land in cadastral areas, developed land between cadastral areas (understood as street or flow space) and developed land without cadastral association.

Table 3.- Developed land by categories for the Metropolitan Region of Barcelona

	Year		
Developed land	**1990**	**2000**	**2006**
RMB (Km2)	537,43	641,06	751,75
% developed land in cadastral areas	68	66	63
% developed land between cadastral areas	24	23	23
% developed land out of cadastral areas	8	11	14

Font: CPSV-UPC

Table 3 shows results, whose values are consistent, because the traditional percentage used for residential projects is 30% of streets surface, percentage that is very close to the obtained results for different years.

2.3.- Model structure

The phenomenon of the natural soil consumption can be seen, in reverse, as a "production" of artificial soil (developed land). As a production approach, the general structure of this type of model is the production function of Cobb-Douglas, which is perhaps the most widely used in economics, based their popularity in fulfilling the basic properties that considered desirable (it is the neoclassical production function par excellence) [2].

In general, the production function is a model that is used to analyze the relationship between the inputs used in the production process and the final product, further describes the rate at which inputs are transformed into products (output). It is also assumed that the function is continuous and unambiguous, those the first and second derivatives exist and are continuous.

The traditional econometric structure for this model, considering a single factor of production, is showing in the following equation

$$Yi = \beta_0 * X^{\alpha} * e^{\mu i} \qquad (1)$$

Where

Y : production
X : inputs of the production process
β_0: is a value that is determined in part by the units of measurement of the variables (Y, X) and partly by the efficiency of the production process. Represent the transformation factor of the inputs into outputs (production factor).
α : is variation (percentage) in production by a unit variation (percentage) in the amount of input, commonly known as elasticity.
μi : random error

By using the Cobb-Douglas function in the developed land model, it is necessary to conceptualize all of the components of the equation, to achieve consistency with the phenomenon analyzed. Finally, the model used in this study is

$$A_i = e^{(\beta o + \sum_k \beta k * Fki)} * Ti^{\alpha} * e^{\mu i} \qquad (2)$$

Where

Ai : developed land produced in the municipality i

Ti : total activity surface in the municipality i

Fki : main factor k (1-5) from de municipality i

β_0: constant

β_k: regression coefficient of the main factor k

α : elasticity.

μi : random error

The transformation factor of the original model was changed to a more complex term (no longer constant) that reflects the different structures of activities represented by the main factors. Thus, the term $e^{(\beta o + \sum \ \beta k * Fk)}$ should be interpreted as the production factor of developed land (natural soil consumption) by a unit built surface area. Well βk coefficients represent the effect of each main factor in the production factor.

Finally, linearization of equation 2 generates a log-mixed model, linear in parameters, whose calibration can be performed by ordinary least squares (OLS). The model was calibrated using SPSS program (stepwise) with a sample of 164 municipalities, with information from 2001.

2.4.- Results

Table 4 shows the results of the OLS calibration.

Table 4.- Calibrated parameter of the developed land model

Variables	Coeff.	Coeff. Stand.	t (student)	Sig.
Constant	-13,473		-31,912	,000
Ln (total built surface)	1,058	1,290	33,888	,000
Density factor	-,527	-,487	-12,808	,000
Adjust R square	**,910**			

Font: CPSV-UPC

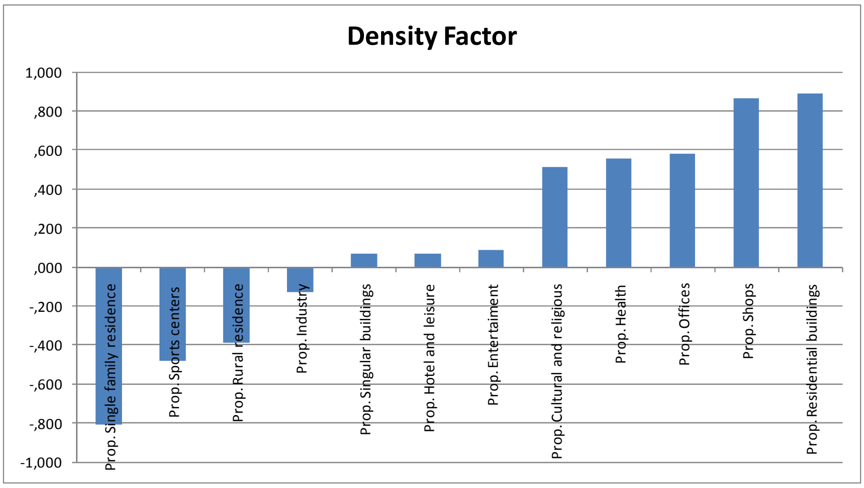
The table shows that not all of the main factors were included into the final model. In general, the coefficients show a high statistical significance.

The calibrated model fit is significantly higher (91%), but for log-mixed or log-log models is necessary to make a post-analysis to calculate the predicted values for the original variable, and then assess the explanation of model. This has not yet been done, so the results should be analyzed with caution.

The standardized coefficients show the high participation (highest absolute value) that has the variable Ln(total activity surface) (alpha) in explaining the developed land.

Regarding the alpha coefficient, the value indicates that a variation of 1% of the activity surface in the municipality causes a variation of 1.058% from the developed land, which indicates indirectly the need of access space by the activity surfaces.

Figure 1.- Correlations between original variables and the Density factor



Font: CPSV-UPC

The density factor gets a negative coefficient. As shown in figure 1, high density activities (residence in buildings, shops, offices, etc.) "holds" the developed land, while the factor has a positive value. A negative value (predominance of single-family housing, rural housing, sports centres, and industries) increases the production factor of developed land.

3.- Electric consumption models

A review of the modelling of electric consumption concluded that there are few studies that address electric consumption at a city scale, with spatial and temporal dimensions. The main studies are of buildings energy simulations, considering environmental conditions and construction materials [7][9].

The few studies with neighbourhoods or city scale [3] can be classified in three categories, by their approach of understanding the problem:

- Bottom-up approach: where is simulated (and calibrated) consumption by types of building, and then extrapolate this behaviour to the city.
- Top-down approach: information is total consumption of the city, and calculated the consumption factors by the different types of buildings.
- Mixed approach: where previous approaches are integrate.

Either approach required a morphology model, in addition to the location of buildings. Therefore, this study applies a top-down approach, considering activities and not buildings scale.

3.1.- Independent variable

The independent variables considered to explain the electric consumption, also was the activity surfaces (registered in the cadastre).

Other variable was included in these models, like weather conditions, and time use behaviour in the different activities. The weather conditions were obtained from the meteorological office of Catalonia, and refer to temperature and air humidity.

The time use by activities was obtained from transport metropolitan authority (ATM), and specifically from the household travel survey of 2001. The methodology applies a trip chain and a time geography approach to processing and to analyze the household travel surveys. The results are average time use by people, by different activities (work, study, shop, social, personal, leisure, etc), in different municipalities.

3.2.- Depend variable

The available information is the annual electricity consumption of municipalities of the RMB, by three years (2005, 2007 and 2008), provided by Endesa Electricity Distribution Company Ltd. Only for 2005 the annual consumption is differentiated by activity.

3.3.- Model structure

Under the same approach of consumption-production applied in the developed land analysis, the final structure for the electric consumption models is presented below:

$$C_{i,j} = e^{(\beta o + \sum_k \beta k * Vk,i,j)} * S_{i,j}^{\alpha i} \qquad (3)$$

Where

Ci,j : electric consumption by activity i in the municipality j

Si,j : built surface (m2) by activity i in the municipality j

Vk,i,j : weather variable or functional variable k, by activity i in the municipality j

β_0: constant

β_k: coefficient for weather or functional variable

αi : electric consumption elasticity by activity i

3.4.- Results

Table 5 shows the values of built surface and annual electric consumption for the RMB (2005, calibration year), by the main modelled activities [4].

Table 5.- Comparison between built surface and electric consumption by activity, RMB 2005

Activity	Annual electric consuption (Kwh 2005)	%	Built surface (m2 2005)	%
Industry	7.030.724.574	**38,0**	57.126.766	14,2
Residence	5.792.747.971	31,3	257.597.812	**64,2**
Shops	2.159.251.967	11,7	23.469.345	5,9
Transport and comunication	764.144.468	4,1	21.190.966	5,3
Health	666.538.743	3,6	3.500.726	0,9
Hotels	426.138.862	2,3	4.843.349	1,2
Personal services	415.165.810	2,2	22.553.418	5,6
Public administration	218.896.512	1,2	1.399.358	0,3
Financial services	217.414.542	1,2	1.504.748	0,4
Education	101.702.346	0,5	7.909.588	2,0
Public lighting system	705.920.396	3,8		
Total	**18.498.646.190**	**100,0**	**401.096.076**	**100,0**

Font: CPSV-UPC

From the table we can see the dissimilarity between the percentages of the various activities both on the built surface as in electric consumption. For example, the residential activity accounts the 64% of built surface, but produced only 31% of the electric consumption. The industrial surface arise 14%, and produced the 38% of electric consumption. Something similar happens in Retail activities. This result indicates the variability of the electric consumption rates by activity, which supports the objective of this work.

Table 6 shows the results of the OLS calibration.

Table 6.- Calibrated parameter of the electric consumption model

	Electric consumption models										
Variables	**Residence**	**Public administration**	**Shops**	**Education**	**Financial services**	**Hotels**	**Industry**	**Health**	**Personal services**	**Transport and comunication**	**Public lighting system**
Constant	1,207	-7,763	2,718	4,489	6,221	3,335	-5,965	7,722	-7,698	-8,388	10,496
Ln (residence surface)	1,001										
Ln (Public administration surface)		,764									
Ln (Shops surface)			,921								
Ln (Education surface)				,847							
Ln (Financial services surface)					,868						
Ln (Hotels surface)						,377					
Ln (Industry surface)							1,138				
Ln (Health surface)								,793			
Ln (Personal services surface)									1,200		
Ln (Transport and comunication surface)										,514	
Summer minimum temperature	,106		,161			,477			,427		
Summer average temperature		,686					,346			,814	
Average working time							,158				
Average time of personal engagement					,164						
Ln(Total developed land)											1,326
% developed land between cadastral areas											10,454
Adjust R square	**,909**	**,531**	**,725**	**,696**	**,773**	**,448**	**,638**	**,705**	**,543**	**,511**	**,546**

Font: CPSV-UPC

The table shows the results variables that are significant for each electric consumption model. The models have a higher fit level, but also for log-mixed is necessary to make a post-analysis to calculate the predicted values for the original variable, and then assess the explanation of model.

The standardized coefficients analysis (no presented in table) show the high participation (highest absolute value) of the surface by activity (alpha) in explaining the annual electric consumption.

The weather variables obtain positive coefficient in the model that was included. These mean that the elevation of the temperature induced mayor electricity consumption, especially in summer situation, perhaps associated with the air conditioning of places where the activities are developed.

Only two functional variables were included in the models, the working time for the industry model, and the personal engagement time for the financial activities.

Table 7 show the elasticity value (alpha) for the different activities, and the associated percentage of electric consumption and built surface.

Table 7.- Comparison of elasticity and surface/consumption participation of activities

Activity	% of electric consumtion	% of built surface	Elasticity (alpha)
Industry	**38,0**	14,2	**1,14**
Residence	31,3	**64,2**	**1,00**
Shops	11,7	5,9	0,92
Transport and comunication	4,1	5,3	0,51
Health	3,6	0,9	0,79
Hotels	2,3	1,2	0,38
Personal services	2,2	5,6	**1,20**
Public administration	1,2	0,3	0,76
Financial services	1,2	0,4	0,87
Education	0,5	2,0	0,85

Font: CPSV-UPC

When the elasticity is more than 1, the behaviour of this activity is elastic in terms of the built surface, that mean that a variation of 1% of the built surface arise a mayor percentage variation from the electric consumption (is an activity that amplifies consumption). This is the case of the residential and industrial activities, which represent around the 80% of the built surface (69% of the total electric consumption). Personal service is also an elastic activity, which behaviour is no clear.

Activities with elasticity's less than 1, has an inelastic behaviour in terms of built surface that mean that these activities "holds" the electric consumption. This is the case of hotels and transport and communications. Activities with values under, but near 1, are shops, health, public administration, financial services, and education.

Perhaps one explanation of the elastic or inelastic behaviour respond to the intensity of the daily utilization of the activity, so hotels and transport has a lower utilization like as shops, health, services, etc., and also lower than industry and residence activities.

4.- Model integration

With the calibrated models (land and electric consumption), we proceeded to integrate them in functional terms, in order to construct a procedure for calculating electric consumption, based on a developed land value.

The developed land production model is

$$A_i = e^{(-13{,}473-0{,}527*DFi)} * Ti^{1{,}058} \qquad (4)$$

Where

Ai : developed land produced in the municipality i

Ti : total activity surface in the municipality i

DFi : density factor of municipality i

From this model, was obtained a built surface model, by a mathematical process. The obtained model is

$$T_i = e^{(12{,}734+0{,}498*DFi)} * Ai^{0{,}945} \qquad (5)$$

With this equation, whose independent variables are the developed land and density factor (in municipality i), was built the following procedure for calculating the electric consumption by municipality:

Step 1.- With the developed land and DF, was calculated the total activity surface for a municipality.

Step 2.- The total activity surface was distributed with the activity proportion included in the DF, to obtain built surface by activity.

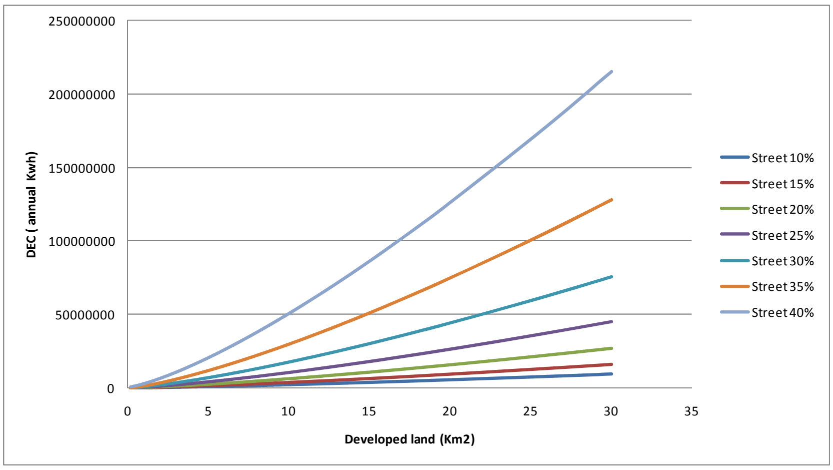
Step 3.- With the different built surfaces by activity (and the weather and functional variables), were calculated the different electric consumption (by activity). The sum of this consumption is called Indirect Electric Consumption (**IEC**).

Step 4.- On the other hand, with the developed land was calculated the electric consumption by the public lighting system, called Direct Electric Consumption (**DEC**).

4.1.- Results

Figure 2 shows the relationship between DEC (consumption of electric lighting) and the developed area, for different percentages of street.

Figure 2.- Relation between DEC and developed area

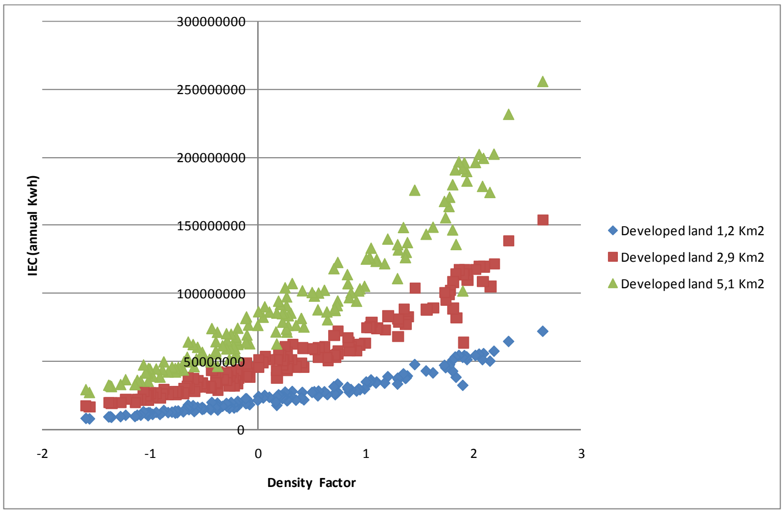


Font: CPSV-UPC

As shown in the figure, the effect produced in the DEC by the developed land is increasing. The growth rate is directly related to the % of streets surface. For values less than 20% of the streets, growth and magnitude of the DEC are relatively similar. Above this percentage, the slope of the curve increases significantly with the percentage, which is amplified even more for large municipal developed areas.

Figure 3 shows the relationship between IEC and DF value, by different developed areas categories.

Figure 3.- Relation between IEC and DF



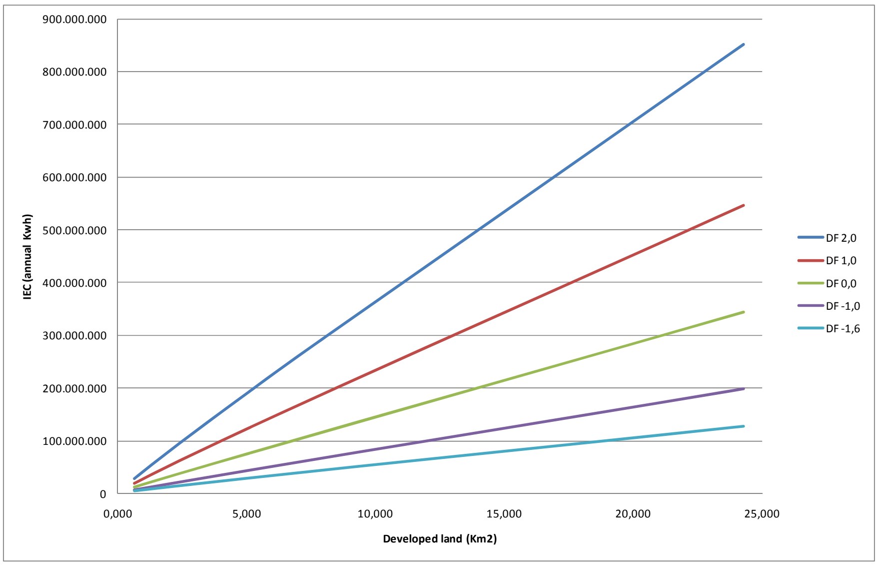
Font: CPSV-UPC

Remembering the structure of the DMF, positive value are arise when the municipality has high proportion of residence in buildings, shops, offices, health, cultural, etc. (dense structure). The negative value is associated to high proportion of single family residence, sports centres, rural housing, and industry.

As shown in the figure, the DMF produced a non linear increasing behaviour of the IEC. This behaviour is intensified by the size of the developed area, mainly in the positive value of DF (dense structure).

Another approach of the same relation is presented in figure 4, who show the relationship between IEC and developed area, by different DF categories.

Figure 4.- relation between IEC and developed area



Font: CPSV-UPC

The figure shows that the size of the developed land produced a linear increasing effect over the IEC. The slope of the curve increases proportionally with the value of the DF (from low to high density structure).

Well, both approaches show the same effects, dense activity and large developed area produced high IEC, low dens activities and small developed areas produced low IEC. But is important to know where dimension (size of developed land or density of activities) is more important in terms to produced (or reduced) electric consumption. For that, we make a sensibility analysis of the parameters included in the calculation process. This parameters are; developed land area, DF (associated to an activity proportion profile), weather conditions, and time by activities.

The parameters for developed area and DF can be managed by policy and planning tools. The weather parameters can not be managed, but allows the integration of environmental effects (climate changes). The time parameters are mainly productivity factors of each economics activity, but also can be managed by policies.

The sensibility analysis varied each parameter value in a certain percentage (normally +/- 10%, keeping constant the other parameters), and evaluate de variation (in terms of percentage) of the output variable. Table 8 shows the result of this analysis.

Table 8.- Sensibility analysis for parameters in the procedure

	Value		Direct electric consumption		Indirect electric consumption		Total electric consumption	
Parámeters	Base	Variation (+/-10%)	Annual Kwh	% variation	Annual Kwh	% variation	Annual Kwh	% variation
Base			**1.455.523**		**85.560.758**		**87.016.281**	
Developed land (Km2)	2,93	3,23	1.651.603	**13,5**	92.964.536	**8,7**	94.616.139	**8,7**
		2,64	1.265.740	**-13,0**	78.090.417	**-8,7**	79.356.157	**-8,8**
Density Factor	1,50	1,65	1.455.523	0,0	90.031.187	**5,2**	91.486.710	**5,1**
		1,35	1.455.523	0,0	82.895.277	**-3,1**	84.350.800	**-3,1**
% Street	0,22	0,24	1.826.007	**25,5**	85.560.758	0,0	87.386.765	**0,4**
		0,20	1.160.207	**-20,3**	85.560.758	0,0	86.720.966	**-0,3**
Summer minimun temperature	16,5	18,1	1.455.523	0,0	100.308.083	**17,2**	101.763.606	**16,9**
		14,82	1.455.523	0,0	77.063.169	**-9,9**	78.518.692	**-9,8**
Summer average temperature	21,6	23,8	1.455.523	0,0	128.346.329	**50,0**	129.801.851	**49,2**
		19,44	1.455.523	0,0	67.984.422	**-20,5**	69.439.944	**-20,2**
Average time of personal engagement	1,6	1,8	1.455.523	0,0	85.570.592	0,0	87.026.115	0,0
		1,46	1.455.523	0,0	85.551.182	0,0	87.006.705	0,0
Average working time	7,0	7,7	1.455.523	0,0	86.857.599	**1,5**	88.313.122	**1,5**
		6,32	1.455.523	0,0	84.400.145	**-1,4**	85.855.667	**-1,3**

Font: CPSV-UPC

As shown in the table, the base or reference situation is a municipality with 1,93 Km2 of developed land, a DF of 1,5 (dense structure of activities), 22% of streets surface, with a summer temperature minimum of 16,5ºC and mean of 21,6ºC, 1,6hrs for personal engagement, and 7hrs for working. The most of these values are mean values from municipalities of the RMB.

The variation of the developed land area parameter (in +/- 10%) produced 1) a symmetric variation of 13,5% of the DEC (public lighting system) 2) a symmetric variation of 8,7% of the IEC, and similar variation in the total electric consumption. The effect is in both type of electric consumption, but because the DEC is a very low part of the total consumption, the main effects is in terms of the IEC.

The variation of the DF parameter produced an asymmetric effect only in the IEC, with a variation of 5,2% and -3,1%, if the value increase or decrease respectively. This asymmetric behaviour is consistent with the non linear relation before indicated.

The variation of the % of street parameter produced an asymmetric effect only in the DEC, with a variation of 25,5% and -20,3%, if the value increase or decrease respectively. Despite this, this variation has no effects in the total consumption.

The variation of the summer minimum temperature parameter produced an asymmetric effect only in the IEC, with a variation of 17,2% and -9,9%, if the value increase or decrease respectively. This asymmetric behaviour (non linear behaviour) has not been analyzed before. The summer average temperature present the same behaviour, but with greater variation percentages, arising a significant variation of 50,0% and -20,5%, if the value increase or decrease respectively

The variation of the personal engagement time parameter don't produced variation in the electric consumption, but the working time parameter produced a symmetric effect only in the IEC, with a variation of 1,5%.

Final remarks

In terms of summarizing the results, the following remarks can be made.

- The management dimension (variables) of the size of the developed land, and the proportion of built activity surfaces (who affect the DF value), produced a differentiated effect in the annual electric consumption, be greater the effects by the size in relation of the effects by the built activity structure. High level of electric consumption is associated with high density activities (residence in buildings, shops, services, etc) and larger size of developed areas. Low level of electric consumption is associated with low density activities and small developed areas.
- The no management dimension of the weather conditions produced the larger effects in the annual electric consumption. In this sense, the present work has not evaluate the synergic effects produced inside the high density developed areas, called the urban heat island (UHI), but is clear that this effects will be increased the effects of this city structure in the electric consumption.

- The dimension of time by activities is lower that the above presented, but significant.

Finally, the results shows that the relation between developed land and electric consumption, reveals an advantage of low dense compact structures over dense and compact structures. This arise two conceptual questions; 1) what is the optimal size of the compact city, and 2) the energy cost to be paid by the city to keep one of its genetic factors, the agglomeration economies.

Acknowledgment

The first author is supported by the "Comisionado para Universidades e Investigación del Departamento de Innovación, Universidades y Empresa de la Generalitat de Cataluña y del Fondo Social Europeo". The study is supported by the Ministerio de Fomento del Gobierno de España.

Reference

[1] Cerda, J. (2010) *Adaptación de un modelo econométrico Cobb-Douglas para modelar la producción de suelo artificializado (antropizado) en la región metropolitana de Barcelona*. Research report [online] http://hdl.handle.net/2117/12005

[2] Gujarati, D. (2003) *Econometría*. Fourth edition, Mc Graw-Hill Interamericana ed.

[3] Heiple,Shem; Sailor,David J. (2008) *Using building energy simulation and geospatial modelling techniques to determine high resolution building sector energy consumption profiles*. Energy Build, 40, 8, 1426-1436

[4] Perez, C. (2010) *Análisis de la distribución espacial del consumo eléctrico: un modelo para la región metropolitana de Barcelona: anàlisis de los coeficientes de correlación de Pearson y la regresión lineal multiple.* Research report [online] http://hdl.handle.net/2117/12272

[5] Rueda, S. (2001) *Modelos de ordenación del territorio más sostenible*. Working paper, Zaragoza.

[6] Romano, Y. (2010) *La evolución del consumo de suelo en la región metropolitana de Barcelona. Metodología de homogenización de datos*. Research report

[7] Sailor,David J.; Lu,Lu. (2008) *A top–down methodology for developing diurnal and seasonal anthropogenic heating profiles for urban areas*. Atmospheric Environmental, 2004, 38, 17, 2737-2748

[8] Travisi, C., Camagni, R. Nijkamp, P. (2006) *Analysis of environmental costs of mobility due to Urban Sprawl – A Modelling Study on Italian Cities*. Tinberger Institute Discussion Paper http://dare.ubvu.vu.nl/bitstream/1871/9836/1/06042pdf

[9] Yamaguchi,Y.; Shimoda,Y.; Mizuno,M. (2007) *Proposal of a modelling approach considering urban form for evaluation of city level energy management*. Energy Build, 39, 5, 580-592.