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Geomapping methodology for the GeoCluster Mapping Tool to assess deployment potential of technologies for energy efficiency in buildings

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ABSTRACT

Energy efficiency in buildings will play a major role in responding to EU climate change and energy-saving policies, if sustainable actions are to be trigged at large scale involving EU, all Member States and their regional and local authorities.

The objective of this paper is to explain the Geocluster methodology developed within the European "GE2O" project aimed at developing a general framework for the assessment of the effectiveness of building technologies for energy efficiency. The research aimed to locate similarities across the EU countries by combining parameters and indicators structures in homogeneous layers and sub-layers (i.e. building technology, context, policies and regulations, climatic conditions, social aspects) in order to develop a repository to be used as source of data for a dynamic geo-database web service. The assessment has been performed on two selected technologies, thermal insulation for envelope retrofitting and solar cooling, respectively, for two pilot areas: Benelux and Mediterranean arc. The final goal was to create an Open Source geo-portal named GeoCluster Mapping Tool, based on international standards in the GIS domain, which implements the methodology developed and becomes a decision-making tool for private or public parties.

1. Introduction

In the last 20 years, the European Union (EU) has been successful in decoupling greenhouse gas (GHG) emissions from economic growth. While GHG emissions in the 28 countries of EU fell by 17% over the period 1990–2011, the overall economy grew by 45% (Kyoto, 2013). This development is to a considerable extent due to a gradual improvement in the carbon intensity of the EU's energy mix, including higher shares of renewable energy, and to a decreasing energy intensity of the EU economy, thanks to energy efficiency (EE) measures taken across the economy. In parallel to these developments, the EU has made significant progress towards the creation of internal energy markets in electricity and gas (Commission Communication; Directive 2009/72/EC). At the same time, the Climate and Energy package adopted in 2009 (Directive 2009/28/EC, 2009) and the Commission's Green Paper (European Commission, 2013) on a 2030 framework for climate and energy policies highlighted this trend providing a comprehensive overview of the climate and energy objectives and policies applicable in a 2020 perspective.

Since recently, the European Council has been addressing energy policies in a more holistic way: firstly in February 2011, when it stated for example that "safe, secure, sustainable and affordable energy contributing to European competitiveness remain a priority for Europe" (CSWD); and again in May 2013 emphasizing the importance of the internal energy market and in particular stating that the EU's energy policy "must ensure security of supply for households and companies at affordable and competitive prices and costs, in a safe and sustainable manner"(European Commission, 2013).

Abbreviations: EU, European Union; GHG, greenhouse gas; EE, energy efficiency; EEB, energy efficiency in building; GE2O, Geoclustering to deploy the potential of Energy Efficient building across EU; PA, public authorities; GIS, Geographical Information Systems; NUTS, Nomenclature for Territorial Unit for Statistics; PoC, Proof of Concept; CSPF, Cooling Seasonal Performance Factor; OGC, Open Geospatial Consortium.

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Nomenclature

V_{ins} volume of thermal insulation material to be added to the opaque construction element to reach the U_{value} target at NUTS (1, 2, 3) levels (m^3)
λ thermal conductivity of the insulation material used for envelope retrofitting ($W\,m^{-1}\,{}^{\circ}C^{-1}$)
U_{exist} average U-value of the opaque construction element before retrofitting ($W\,m^{-12}\,{}^{\circ}C^{-1}$)
U_{target} average U-value of the opaque construction element after retrofitting (target) ($W\,m^{-12}\,{}^{\circ}C^{-1}$)
$n_{dwelling}$ number of typical residential buildings at NUTS (1, 2, 3) levels
A_i area of opaque construction element calculated for a typical residential building (m^2)

In particular energy efficiency in buildings (EEBs) and the reductions of their energy consumptions is one of the main EU priorities for the energy policies.

The building sector, in fact, accounts for approximately 30% of the energy consumption in most countries (Janda, 1999; Perez-Lombard, Ortiz, & Pout, 2008). This rate is expected to continue to increase globally, owing to the growth in population together with increasing demand for building services and comfort levels. In this respect many countries have launched policies to promote EEBs, and Member States' efforts are effectively supported by a series of measures at the EU level, including the regulation of CO_2 emissions from transports, the Energy Performance of Buildings Directive, the Energy Efficiency Directive, the Renewable Energy Directive, the F-gas regulation and the eco-design framework setting minimum energy efficiency standards for a range of domestic and industrial appliances (International Energy Agency, 2008). Energy Performance of Buildings Directive (EPBD) has been also revised in 2010 in order to facilitate Member States in applying minimum energy performance requirements in building sector, but delays in implementation are a risk, which could seriously impact the extent to which the EU takes full advantage of the cost-effective savings potential in the buildings sector (equivalent to 65 Mtoe by 2020).

With regard to overall progress in the EU in terms of energy savings, the economic crisis has fully demonstrated the strong correlation between energy consumption and economic and social networks and their influence on innovation (Brass, Galaskiewicz, Greve, & Tsai, 2004; Jackson, 2008).

This paper explores how defining a methodology to structure these multidisciplinary and heterogeneous data sources, so that they can be used to deploy innovation for EE in EU building sector. The aim of the study presented was in fact to structure, correlate and cluster available EU data, in order to build a common reference framework for the assessment of the deployment potential of EE technologies in buildings across EU. The research was carried out by an interdisciplinary team within an EU-funded FP7 project "Geoclustering to deploy the potential of Energy Efficient building across EU – GE2O". The main objectives was to address policies of public authorities (PA) towards EE and support professionals or stakeholders to identify market potential of building technologies throughout the creation of the GeoCluster Mapping Tool based on international standards in the Geographical Information Systems (GIS) domain.

Considering geospatial information, there is a huge number of data available and for a variety of sectors (economy, society, policies, EE, technologies). However, these are not in any manner homogeneous, so there data require the possibility to visualized and analysed as high dimensional geo-reference data (Penn, 2005; Uhlenküken, Schmidt, & Streit, 2000).

Some of these problems, often related with the explanation of complex spatial phenomena, require an extensive exploratory data analysis based on the search of unknown patterns and spatial relationship without a priori hypotheses. This kind of analysis is generally achieved through clustering, defined as the unsupervised classification of patterns into groups (Jain, Murty, & Flynn, 1999). The concept of Geoclusters is highly relevant, being virtual trans-national areas where strong similarities are found (i.e. climate, culture and behaviour, construction typologies, economy, energy price and policies, etc.). From this perspective, a novel Geoclusters methodology for data correlations has been developed, considered a potentially useful technique when the main goal is to search to patterns in spatial data and to correlate heterogeneous information, in this case related to EE.

The outline of the paper is as follows. Section 2 provides an overview on geospatial clustering analysis and outlines the Geocluster methodology, its structure and data. In Section 3, a practical application of the presented methodology to two predefined technologies – thermal insulation and solar cooling – is described with correlation results. Section 4 presents outcomes of the research: correlation results from the Geocluster methodology and the GIS platform, which implement these results, the GeoCluster Mapping Tool.

Finally Sections 5 and 6 respectively conclude the paper with discussion on the presented work and remarks for policies implications.

2. Methodology and data: an overview on clustering

Cluster analysis or clustering is the task of grouping a set of parameters in such a way that objects in the same group "(called cluster)" are more similar, to each other than to those in other groups (clusters). Clustering of numerical data is used as the basis for many classification and modelling algorithms. Cluster analysis is a mathematical procedure to identify natural groupings of objects, in such a way that the characteristics of objects belonging to the same cluster are very similar while the characteristics of objects in different cluster are quite distinct, producing thus a concise representation of the dataset behaviour.

Cluster analysis has long played an important role in a wide variety of fields, including biology, statistics, pattern recognition, information retrieval, machine learning, and data mining (Petcharat, Chungpaibulpatana, & Rakkwamsuk, 2012). In the field of energy, cluster analysis has been applied to classify energy performance of buildings instead of equal frequency rating methods (which define energy classes based on the frequency distribution of buildings and by considering an equal number of buildings for each class) (Gaitani, Lehmann, Santamouris, Mihalakakou, & Patargias, 2010); while similar techniques have been used in the development of energy codes and standards.

Moreover, a clustering technique can be used to classify climate, meteorological data (Andersson, Carroll, & Martin, 1985; Oliver, 1991; Fovell & Mei-Ying, 1993; Wiedenhofer, Lenzen, & Steinberger, 2013), to find patterns of characteristic averages for modelling renewable energy systems (Calvert, Pearce, & Mabee, 2013; Gomez-Munoz & Porta-Gandara, 2002; Hackl & Harvey, 2013; Hadley & Jarnagin, 1993; Michalena & Hills, 2012) and policies for energy efficiency (Cannemi, García-Melón, Aragonés-Beltrán, & Gómez-Navarro, 2014; Luethi & Praessler, 2011; Mans, Alkemade, van der Valk, & Hekkert, 2008; Suetterlin, Brunner, & Siegrist, 2011).

In recent geo-environmental analyses, spatial statistical methods were advanced based on probability and classical statistics. On one hand, many spatial datasets have high levels of uncertainty, and in some cases, analyses depend on 'soft' data, which may be more