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 build-ing 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.

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 Con-sortium.

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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).

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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 reduc-tions 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 spa-tial 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 vir-tual 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 analy-sis is a mathematical procedure to identify natural groupings of objects, in such a way that the characteristics of objects belong-ing 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 recogni-tion, 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 qualitative than quantitative in nature (Tutmez, Tercan, Kaymak, & Lloyd, 2009). On the other hand, soft approaches like fuzzy comput-ing have desirable characteristic features for spatial data analysis (Wong, Aminzadeh, & Nikravesh, 2001). The soft computing based algorithms are developed on the ground of less restrictive assump-tions, and are flexible in appraising non-linearity and non-constant variable structures.

Therefore many fuzzy computing based methods have been used for spatial estimation in geo-environmental problems (Amini, Afyuni, Fathianpour, Khademi, & Fluehler, 2005). The fuzzy approach obtains the means to combine numerical data and linguistic statements and satisfies a more transparent representation of the system under study (Sousa & Kaymak, 2002). It is utilized to handle uncertainties and imprecision involved in the analysis of real world data.

Tutmez et al. (Tutmez, Kaymak, Tercan, & Lloyd, 2012) defined a new local estimation model by partitioning a heterogeneous study area into relatively homogeneous subareas and appraising the spatial structure within them separately employing the extended fuzzy clustering algorithm, proposed by Kaymak and Setnes (Kaymak & Setnes, 2002), and combining it with least squares estimation for local analysis of environmental data. In these researches they have stated that the fuzzy clustering based local analysis method could be used as a conventional modelling tool for evaluating spatial rela-tionship between geo-environmental variables.

2.1. Geocluster methodology for science, technology and innovation correlations

In this study, an approach of cluster analysis has been introduced to correlate and integrate available EU data within GIS, in order to map a geospatial framework enhancing the benefits of an inte-grated EU vision. In a clustering method for energy efficiency buildings to considering the geographical aspect, it means to:(1) investigate the main important and innovative technologies currently available or under development, (2) classify them into macro-families and (3) then individuate the main parameters for each technology that could explain its own potential in energy efficiency in a given geographical area. Once the technologies are clearly identified, the step further foresees the identification of the possible correlations of their indicators with other important layers, such as regulations, financial incentives, building typology, that could affect and influence their functionality and potential regarding the energy efficiency. For example, the promulgation of a building energy code needs an accurate estimation of potential energy savings to ensure that its implementation can achieve the goal set. Generally, the estimation is carried out using the mean value averaged from sample buildings as a representative for the whole sector. However, the actual data of building energy perfor-mance may not be described by a single normal distribution. A geoclustering analysis could estimate the potential energy savings in buildings by comparing the different building sector technolo-gies with the parameters that could have an effect on the market and with the geographically identified regulations. Geoclustering analysis itself cannot be reduced to one specific algorithm. The appropriate geoclustering set of algorithms depends on the indi-vidual data set and intended use of the results because it is not an automatic task, but an iterative process of knowledge discovery or interactive multi-objective optimization that involves trial and error.

Relational strategies in statistical data analysis can be strongly powered by spatial data analysis based on the geographic and spatial characteristics of any kind of information. Inference methods and clustering can be strictly connected and usefully joined to spatial analysis for mapping, data matching and topologies analysis (Mussio & Dante, 2007).

The geoclustering analysis could be considered as a way for displaying cluster results into maps, supported by geographic analysis and geographic relationship. At the same time clustering methods are widely applied in processes such as image interpretation, image feature extraction, image matching, and object recognition and reconstruction techniques.

Thus, geoclustering offers wide possibilities of application: as a multivariate analysis task it can be used to analyse complex scenario characterized by multiple variable. Moreover, it has been used in marketing research and for Competitiveness in the EU – Challenge for the V4 Countries (Cooke, Urange, & Extebarria, 1998; Delić, 2006) , as well as in medicine research, health and disease analysis.

Lately, there has been an increasing amount of efforts to produce and collect science and technology data, while recently these data are being progressively accurately structured within spatial infor-mation infrastructures. Geomatics as a science is already largely contributing to urban planning of big cities around globe, tackling some of the most urgent problems like urban sprawl and energy efficiency. Those cities that fail to adapt to the trend of embracing the use of geospatial information will have great difficulties ensur-ing a healthy environment and efficient infrastructures for their citizens in the future (Grun, 2013).

The semantic web adds another machine readable layer onto existing web pages, ensuring standardization, readability, and self-documentation of internet sources of information (Yu, 2011).

An innovation system consists of discrete units and the structural relationships occurring between these units and it is organized to produce and utilize science and technology for the individual and collective betterment of society. There is a wide variety of concepts used to denote this innovation system, including, national systems of innovations (Freeman, 1995; Nelson, 1993), regional systems of innovations (Cooke, Urange, & Extebarria, 1997; Cooke et al., 1998), industrial (Marshall, 1920) or technological dis-tricts (Antonelli, 1994), learning regions (Florida, 1995; Lundvall & Johnson, 1994), industrial atmosphere (Marshall, 1919), clus-ters (Porter, 1990), the French filière approach (Raikes, Jensen, & Ponte, 2000), etc. This literature emphasizes the importance of the institutional setting of norms, routines, etc. that provide an organizational-support infrastructure for economic competitive-ness, the importance of informal networks grounded in trust as well as more formal organizations and mechanisms for sustaining this trust in reducing transaction costs among organizations, and the importance of institutional and organizational learning (Cooke et al., 1998). In addition, this literature highlights in the role of geo-graphical proximity as a facilitator for the rapid dissemination of tacit knowledge and other externalities.

The ongoing fusion of research on innovation systems and organizational networks, and the need for methodological clarity as well as theoretical circumspection in applying these ideas outline a clear direction for methodological enhancement (Kwakkel, Carley, Chase, & Cunningham, 2012).

Similarly, the use of a variety of alternative geo-visualizations can help in defining a region more conscientious, by cross-comparing administrative boundaries, the spatial concentration of firms and other organizations, the geospatial character of social and economic networks, etc.

As remarked by Kwakkel et al. (2012) the rapid rise of new data sources comes three mains challenges: (i) assessing the quality of the data, (ii) necessity for integration of sources in order to extract useful information and (iii) need for data to be supplemented with a range of geographic information, including territorial units and coordinates.

Current approaches for researching European geographies are: the Nomenclature for Territorial Unit for Statistics, or NUTS regions and Eurostat (ESRI) the main resource for European regions. Commercial sources of this data include those provided by ESRI

(Hazewinkel, 1994). These latest data sources and NUTS nomenclature have been included in the GeoCluster Mapping Tool.

3. Geocluster methodology

The proposed Geocluster concept is based on the possibility to locate similarities across enlarged EU by correlating single or multiple parameters and indicators organized in homogeneous layers and sub-layers. The different layers can be analysed using a single descriptor, to identify for instance geographical areas which share similarities in climatic conditions or financial incentives, or they can be analysed based on several layers and their corresponding descriptors for more complex investigations.

The definition of the term correlation, by Encyclopaedia Mathematics (Hazewinkel, 1994), makes immediate the logic connection between the energy efficiency aim of this project and the use of correlation methodology. In fact the term correlation in statistics describe a dependence between random variables not necessarily expressed by a rigorous functional relationship. Unlike functional dependence, a correlation is, as a rule, considered when one of the random variables depends not only on the other (given) one, but also on several random factors. The dependence between two random events is manifested in the fact that the conditional probability of one of them, given the occurrence of the other, differs from the unconditional probability. Similarly, the influence of one random variable on another is characterized by the conditional distributions of one of them, given fixed values of the other. In probability theory and statistics, correlation is always used to include a standardizing factor in such a way that correlations have values between −1 and+1, and the term cross-correlation is used for referring to the cor-relation (*X*, *Y*) between two random variables *X* and *Y*, while the "correlation" of a random vector *X* is considered to be the correla-tion matrix (matrix of correlations) between the scalar elements of *X*.

In statistics, dependence refers to any statistical relationship between two random variables or two sets of data. Correlation refers to any of a broad class of statistical relationships involving dependence. Correlations are useful because they can indicate a predictive relationship that can be exploited in practice. However, statistical dependence is not sufficient to demonstrate the presence of such a causal relationship, correlation does not imply causation.

Formally, dependence refers to any situation in which random variables do not satisfy a mathematical condition of probabilistic independence.

3.1. From methodology to 3D model structure

The biggest effort that has been made within GE2O is to identify a set of variables able to influence the energy efficient dimension to address policies and deploy market potential, and to describe the dependence between random variables not necessarily expressed by a rigorous functional relationship. Consequently, the data model defined for the GeoCluster Mapping Tool was based on a 3D corre-lation matrix, defined by XYZ layers due to the huge heterogeneity of the EU data available on EE: numerical values range, attributes, statements, units, limits, targets, in function of the sphere of inter-est.

For this reason and in order to comprehend the correlation between the three axes, the structure has been represented into the following schemes.

Fig. 1 represents the 3D matrix exemplification, Fig. 2 provides the definitions of the three main families' layers, also so-called axes, in which the structure is subdivided and Fig. 3 declines the real layers considered for the Proof of Concept (PoC) of the GeoCluster Mapping Tool.

In particular, the *X*-axis includes, from a theoretical point of view, all the key technologies relevant to EE. Each technology has been then characterized by a set of properties (parameters and performance indicators), placed on *Y*-axis. So it is possible to virtually place on the *XY* plane each technology that can be identified and described for its real characteristics. However, a certain number of these (e.g. thermo hygrometric properties, costs, range of application, etc.) depend on another set of data that has a strong geographical and context relevance (climate conditions, socio-economics data, building typologies). Moreover, considering the specific aim of the Geoclustering approach, i.e. to identify the potential for application of EE technologies, it has been observed that other non-technological data – such as financial incentives, regulations, cultural aspects to name a few – play a significant role in the application of a technology. All these geo-referenced data are virtually placed on the *Z*-axis and identified as geo-descriptors, i.e. context indicators that do not depend on a single technology. Therefore, the 3D matrix makes the correlation structure more dynamic.

Every technology (X layer) have its own intrinsic parameters and/or performance indicators (Y), specifically defined for that technology. The correlation between XY is in fact the one that occurs between each key technology and its *Y* indicators. This correlation can be defined by the methods for numeric objects. In this case it is possible to have two kinds of limits:

- there is a min and max values and all other values are interpolated in this range (fuzzy correlation methods applied);
- there are no values of the object, but it is simply assigned as existing or non-existing (binary correlation methods applied).

Technologies are acknowledged to have important implications for sustainability (Kranzberger, 1997; Mulder, Ferrer, & van Lente, 2011) and fields associated with the EE. In order to cluster and analyse the main and possible correlations of EE technologies related to the building sector, the research methodology assumed to consider a non-exhaustive list of energy-efficient technologies and to classify the technological layers ($X - i$ layers), into four main categories and their respective applications. In particular, 28 energy efficient technologies were identified and analysed (Table 1); a few of them represent existing market solutions, some others are not widely spread. Innovative solutions that are at their early stage of market development were not considered.

From the whole X layers, only two – thermal insulation (X.1 layer) and solar cooling (X.2 layer) – were specifically investi-gated during the development of the GeoCluster Mapping Tool, respectively, for two pilot clusters: Mediterranean arc and Western Central and Northern Europe with a focus on Benelux. Through these pilots it was possible to carry out a detailed analysis of possible technologies and options for definition of similarities and quantitative comparisons performing Life Cycle Costs (LCC) methodology which permit to assess economic feasibility and potentials for the EE technologies development into the market (Hernandez & Kenny, 2010; Kapsalakia, Leal, & Santamouris, 2012; Sesana & Salvalai, 2013). However, LCA and other life cycle-based methods offer a well-defined basis, which needs to be coupled and/or integrated with inputs from other domains of knowledge, considered in the project as *Z* layers.

Moreover, beside the fact that these two technologies were explicitly chosen for the PoC of the GeoCluster Mapping Tool at the beginning of the research, the other important reasons that can explain this assumptions are summarized as follows:

- one technology is related to building envelope, the other one to energy systems;

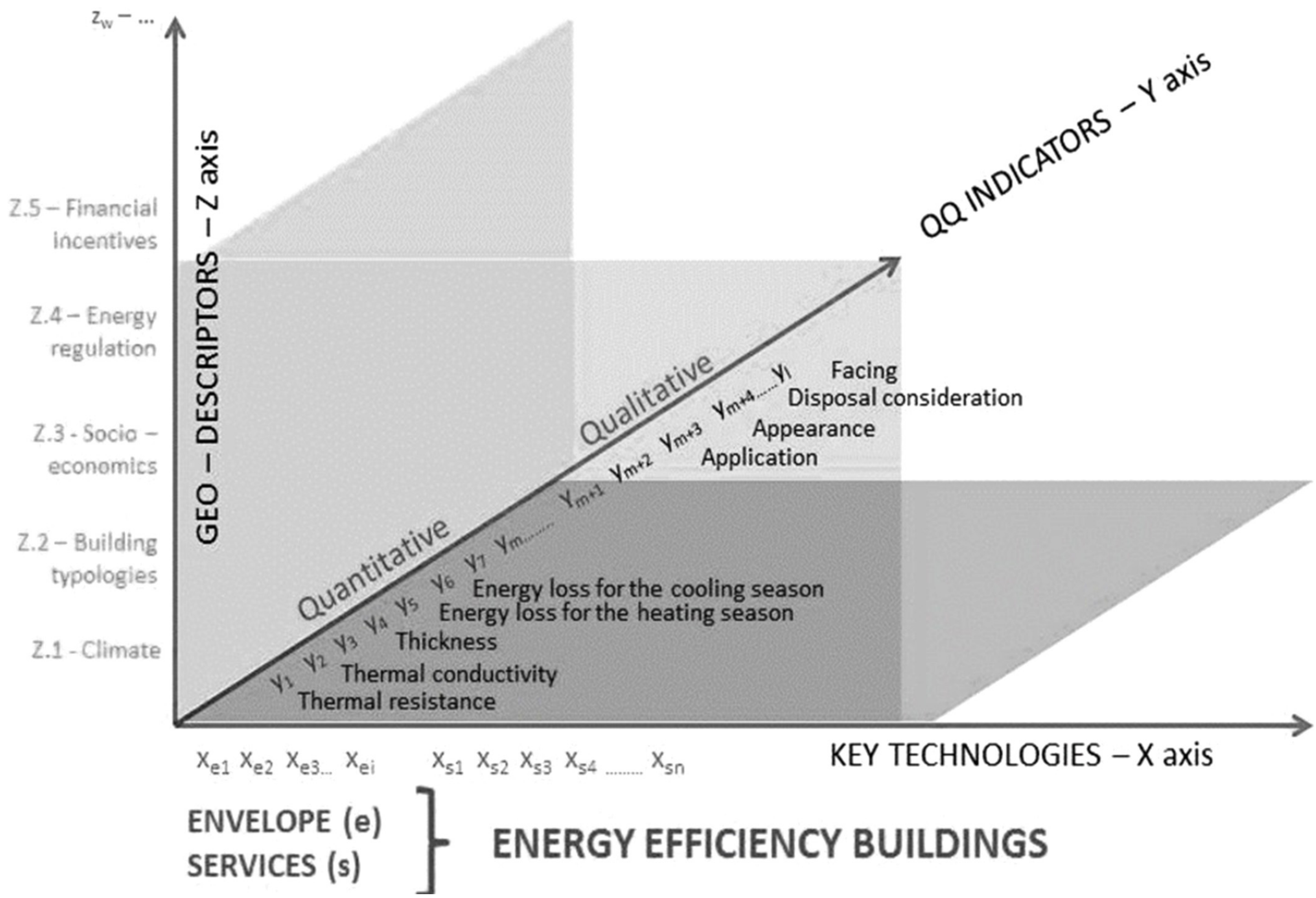

Fig. 1. 3D matrix exemplification of the Geocluster methodology.

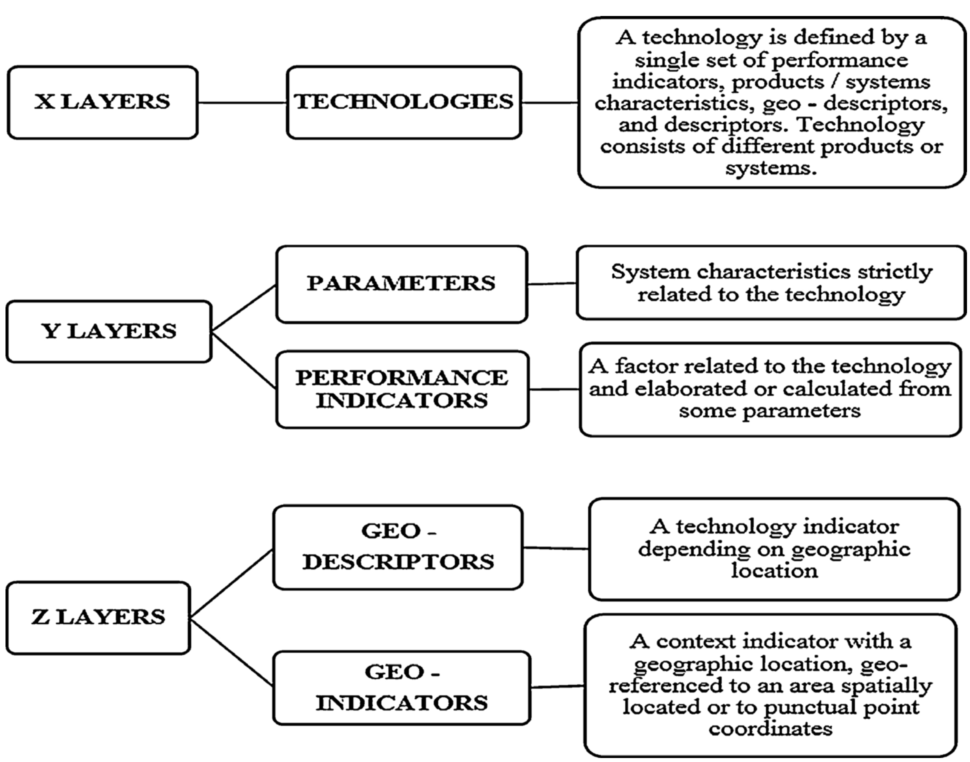

Fig. 2. Structure definition of the three layers (axis) of the Geocluster methodology.

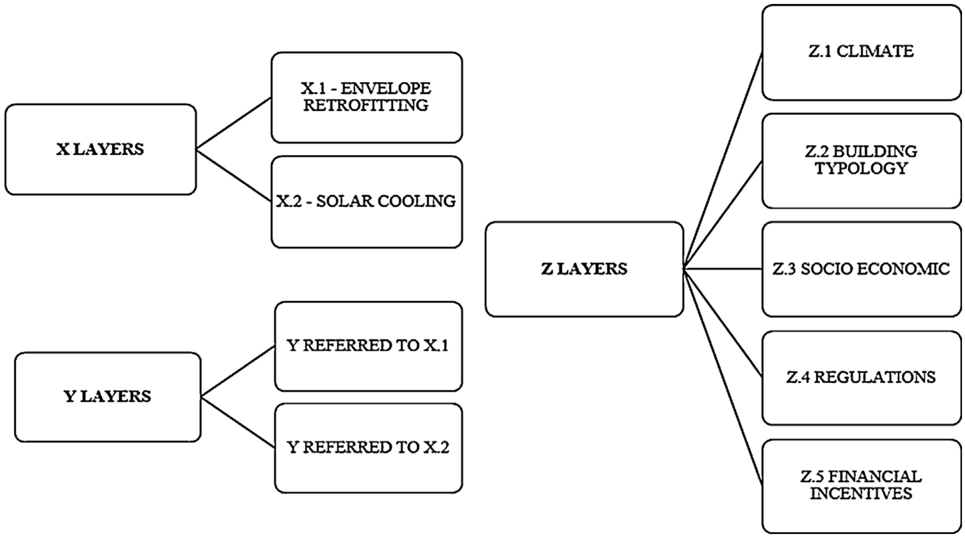

Fig. 3. Structure of the layers considered for the Geomapping Tool.

Table 1
List of EE technologies analysed in GE2O project (X layers).

Category	Application	Technology
Passive demand reduction	Thermal insulation	Panel, roll Foam Multi layers
	Window and glazing	Double glazing Triple glazing Vacuum glazing
	Building envelope	Mono skin façade systems Double skin façade system Mono and double skin windows systems
	Heat/cool storage	Phase change materials
Active demand reduction	Artificial lighting	Fluorescent lamps Solid state lamps
	Heat recovery ventilation	Air to air heat exchanger Rotary heat exchanger Heat pipe heat exchanger
	Building automation control system	Heating/cooling control Lighting control Ventilation control Blind control
Active generation and storage	Cooling	Evaporative cooling Desiccant cooling Solar absorption cooling
	Heating and DHW	Solar water heaters Ground, air, water source heat pumps High efficiency boilers District heating
	Electricity production systems	PV panels Cogeneration (CHP)

- one technology is mostly favourable to northern countries, the other one to southern countries;
- one technology is very mature, the other one is just emerging;
- thermal insulation is “ready to install”, solar cooling is linked to another technology (solar collector);
- thermal insulation is “easy to design”, solar cooling is quite difficult to design, requiring different skill background;
- overall technologies in a broad sense behave like complex systems, characterized by non-linear relationships, feedback loops, emergent phenomena, and tangled connections among the parts.

Z-axis contains the geo-descriptors which are all the external characteristics and conditions (social, economic, climatic, legislative and so on) that could influence each technologies and they are related to their geographic location considering NUTS3 administrative unit level.

Many geo-descriptors do not have numeric values, in this case the “methods for non-numeric objects” is applied. Since these variables are not represented by any number, some ad hoc “dissimilarity coefficients” were defined in order to quantify (qualitative) differences between non-numerical objects and capable of evidencing common characteristics or differences between two sets of data examined.

Table 2 summarizes the main family of the *Z* layers implemented in the GeoCluster Mapping Tool, while Table 3 shows an example of the complete structure of the geo-descriptor Z.1 “Climate” with the whole list of its sub-layers considered and implemented in the GeoCluster Mapping Tool.

3.2. Three-dimensional structure in the tool

The GeoCluster Mapping Tool has been developed as an Open Source tools based on international standards in the GIS domain (Open Geospatial Consortium – OGC). Ge2O is a public web application available at URL http://www.geocluster.eu/ge2O. The tool have a peer to peer (P2P) approach, it means that (i) the user can download and filter the data in order to create synergies with other GIS platforms, and (ii) the user can update the data in order to keep the system updated (Cuca, Brumana, Oreni, Iannaccone, & Sesana, 2014). Moreover it has been developed to be a user-friendly tool that offers an advanced user experience and graphic appeal to raise the user satisfaction and increase their productivity.

The GeoCluster Mapping Tool is equipped with an online tutorial that is automatically shown at the first access. It appears as a wizard that conducts in nine steps the user in the discovery of the tool components and its functionalities. The tutorial is designed to be interactive intact the user is taken to carry out some actions on the tool during the learning process. When the user completes the

Table 2
Z layers list implemented in the Geomapping Tool.

Code number	Z layers (Geo-descriptors)	Code topic
Z.1	Climate	Z
Z.2	Building typology	BT
Z.3	Socio-Economic aspects	SE
Z.4	Regulations	R
Z.5	Financial incentives	FI

Table 3
Complete structure of the geo-descriptor Z.1 "Climate" with the whole list of its sub-layers implemented in the GeoCluster Mapping Tool.

Z.1 climate	Code	Description	Unit
Z.1.1	HDD	Heating degree days	DD
Z.1.2	CDD	Cooling degree days	DD
Z.1.3	$H_{south,\,45^\circ,\,zone}$	Annual incident energy on a south oriented plane with 45° slope	kW h/m^2 years
Z.1.4	H_0	Annual incident energy on a south oriented vertical surface	kW h/m^2 years
Z.1.5	$T_{air,\,a}$	Average ambient temperature over year	°C
Z.1.6	$T_{air,\,h,\,s}$	Average ambient temperature over heating season	°C
Z.1.7	$T_{air,\,c,\,s}$	Average ambient temperature over cooling season	°C
Z.1.8	$T_{air,\,max}$	Maximum ambient temperature over year	°C
Z.1.9	$T_{gw,\,a}$	Average ground/water temperature over year	°C
Z.1.10	$T_{gw,\,h,\,s}$	Average ground/water temperature over heating season	°C
Z.1.11	$T_{gw,\,c,\,s}$	Average ground/water temperature over cooling season	°C
Z.1.12	$T_{air,\,WB,\,c,\,s}$	Average ambient wet bulb temperature over cooling season	°C
Z.1.13	$T_{air,\,cool,\,day}$	Average ambient temperature during daylight over cooling season	°C
Z.1.14	$G_{south,\,45^\circ}$	Average solar irradiation during daylight over cooling season	W m^{-12}

online tutorial, the Ge2O application will not show this tutorial, but anyway the user, in any time, is able to perform again this tutorial by clicking the "Help button" on the toolbar.

4. Application of Geocluster methodology to two technologies

The application of the Geocluster methodology presented in the previous section is following described throughout: an overview on both X1 and X2 selected technology, from the 28 individuated (Table 1) and the explanation of their respective and possible correlation identified.

4.1. X.1 layer: thermal insulation technology and its correlations

The current building stock of the EU offers a huge potential for improvement of the thermal efficiency of building envelopes. Thermal insulation technology (X.1 layer) of opaque construction elements (wall, roof, floor) is the most relevant and cost effective technology to achieve this objective. Therefore, during the first phase of development of the GeoCluster Mapping Tool, it was decided to give the priority to envelope retrofitting in the existing residential building sector (dwellings and multi-family buildings).

Of course, retrofitting a building envelope cannot just be limited to thermal insulation. Complete façade systems will be considered in a further development of the tool. For envelope retrofitting, it was assumed to adopt a market driven approach to define the most suitable performance indicator. This performance indicator corresponds to the quantity of thermal insulation (expressed in m^3)

Table 4
Opaque area definition of a typical detached house.

	A_i: area (m^2)
Floor	100
Wall	80 (windows and doors excluded)
Roof	100

Table 5
Proposed classification for the performance indicator: volume of thermal insulation material.

Performance indicator	Y.6	$(\text{Vins})_{max}$	0–5% 15–30% 30–50% 50–65% 65–85% 85–100%

needed to improve the thermal efficiency of a building envelope for a given category of residential buildings and at a given territory scale (local, regional, national). It gives an estimate of the potential market associated to the thermal insulation technology in a geo-referenced system.

This performance indicator relies on:

- insulation material properties, namely the thermal conductivity;
- geo-descriptors such as period of construction of existing building stock, insulation levels or regulation instruments.

The volume (quantity) of thermal insulation material to be added to the opaque construction element to reach the U_{value} target is calculated at the different administrative NUTS levels (1, 2, 3) according to the following equation:$\text{Vins} = \lambda \times \frac{U_{exist}-U_{target}}{U_{exist}\times U_{target}} \times A_i \times n_{dwelling} = Y.6$ layerwhere the different parameters are detailed below:

- λ: the thermal conductivity of the chosen thermal insulation material (W m^{-1} K^{-1}).
- U_{exist}: thermal conductance of the existing construction type area (wall, roof, floor) (W m^{-1} K^{-1}).
- U_{target}: thermal conductance of the target construction area (wall, roof, floor) (W m^{-1} K^{-1}).
- A_i: construction type area of the reference house (wall, roof, floor) (m^2).
- $n_{dwelling}$: number of dwellings of the geographical zone considered.

The main assumption behind this performance indicator (Y.6 layer = Vins) is based on the hypothesis that the existing building stock, classified according to different periods of construction and at different territory scales, is homogeneous, i.e. it can be represented by a typical reference building.

The European project ASIEPI has defined a set of reference build-ings to give an idea of typical houses build in Europe.

Table 4 gives the definition of the different opaque areas for a typical detached house.

Since the potential market associated to the thermal insula-tion technology is directly influenced by the selected territory scale (local, regional, national), it is impossible to define absolute minimum and maximum values for this performance indicator.

Therefore, the classification proposed in Table 5 is based on the maximum volume of thermal insulation material calculated with the equation previously described at a given NUTS (1, 2, 3) level. Different correlations between the thermal insulation technology and some geo-descriptors (period of construction, insulation levels or regulation instruments) were investigated. These correlations

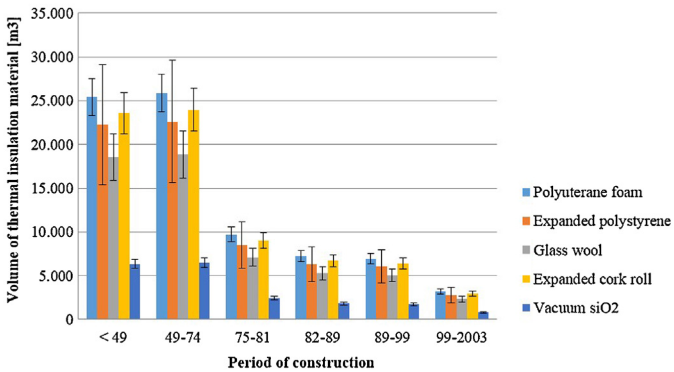

Fig. 4. Potential market for thermal insulation material in Île de France (NUTS 2) for housing sector – breakdown by period of construction.

allow estimating the potential market of thermal insulation material associated to the retrofitting of building envelope in Europe.

In the following figures it is represented only the region Ile de France chosen as an example, but the same analysis has been conducted for the whole European countries.

In Fig. 4, the potential market of thermal insulation materials correlated to various periods of construction at a specified NUTS 2 level and for different thermal insulation materials is identi-fied. This figure shows the quantity (volume) of thermal insulation material that would be necessary to produce, sell and install if all houses of the region Ile de France could be retrofitted and meet the actual *U*-value target for French thermal regulation that are respectively equal to 0.2 $\mathrm{W\,m^{-12}\,K}$ for wall, 0.1 $\mathrm{W\,m^{-12}\,K}$ for roof and 0.3 $\mathrm{W\,m^{-12}\,K}$ for floor. This potential is influenced by the age of construction (sub-layer of Z.2 layer, Building Typology, BT). Old buildings are less insulated than recent buildings. Also the number of building influences this potential. In France, the largest share of existing building stock has been built before 1975 with almost 1/3 previous to 1948.

In Fig. 5, the potential market of thermal insulation materials correlated to different opaque construction elements at a specified NUTS 2 level and for different thermal insulation materials is presented. This potential is more important for roof than for floor. This can be explained by different average thermal insulation levels for floor and roof in dwellings built between 1975 and 1981 and by the fact that *U*-value target for roof (0.1 $\mathrm{W\,m^{-12}\,K}$) in the French thermal regulation is more stringent than for floor (0.3 $\mathrm{W\,m^{-12}\,K}$).

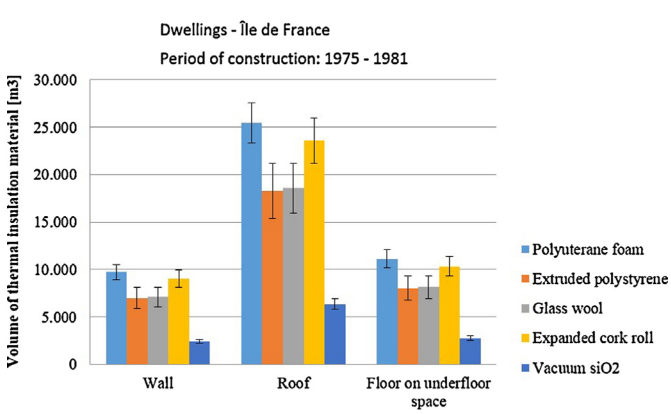

Fig. 5. Potential market for thermal insulation material Île de France for houses built between 75 and 81 – breakdown by type of opaque construction elements.

Table 6
Market segmentation of active solar cooling technologies applied in Europe.

Active cooling systems	Market repartition
Desiccant cooling	11%
Adsorption cooling	15%
Absorption cooling	74%

4.2. X.2 layer: solar cooling technology and its correlations

Solar cooling technologies (X.2 layer) can be classified into passive systems and active systems. Passive systems rely on daily changes in temperature and relative humidity. The technology considered in this project for passive systems is the evaporative cooling. While for active systems, which require refrigeration systems, absorption cooling and adsorption cooling were chosen.

Table 6 gives the market segmentation between active solar cooling technologies. This segmentation comes from recently achieved projects (Climasol Project; IEA; MEDISCO Project; SACE), which validates the project assumptions.

Moreover, it was decided, during the data elaboration, to give the priority to the non-residential building sector (mostly offices and health and care centres) which has the highest needs in terms of space air conditioning.

Being not the main purpose of the paper, definition and analyses for solar cooling performance indicator are here briefly presented and not described in details.

The main indicator for X.2 is the Cooling Seasonal Performance Factor (CSPF) that corresponds at Y.12 performance indicator for active cooling system and at Y.13 performance indicator for the passive cooling systems.

Different correlations between the X.2 layer and some geo-descriptors of Z.1 layer climate were investigated. These correlations allow estimating which European regions are the most favourable to the different technologies of solar cooling.

Fig. 6 shows that active solar cooling when flat plate thermal solar collectors are used is cost effective only in the South part of Europe while when using vacuum tubes (Fig. 7), which offer better thermal performances, active solar cooling can be installed even in less sunny regions.

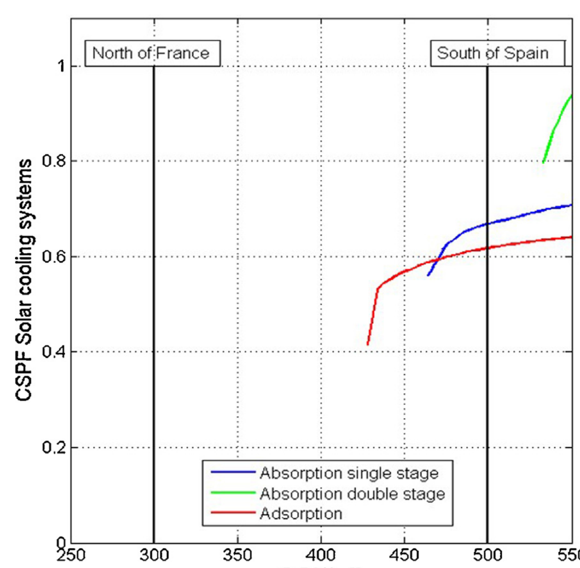

Fig. 6. Active solar cooling – non-residential sector – flat plate collectors – influence of the average solar irradiation over the cooling season (G).

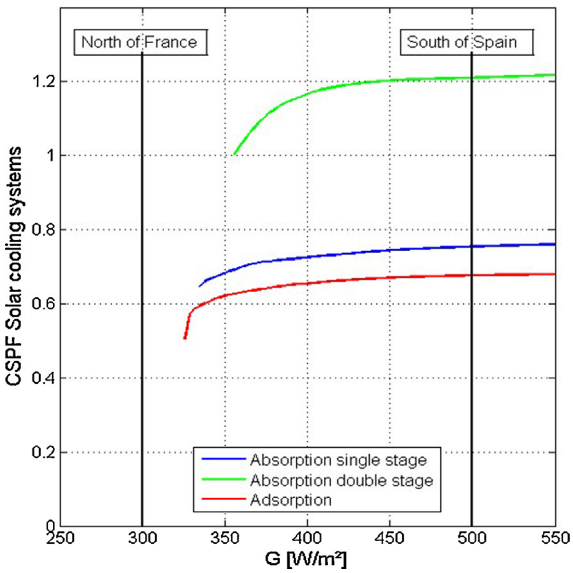

Fig. 7. Active solar cooling – non-residential sector – vacuum tube collectors – influence of the average solar irradiation over the cooling season (G).

Passive solar cooling such as evaporative cooling is not influenced by the irradiation level but by the humidity level as shown in Fig. 8.

Solar cooling technologies, both active and passive, have proved, some during more than ten years, their efficiency and reliability. These technologies use harmless cooling fluids (water generally), and much less primary energy than the conventional systems.

Absorption and adsorption cooling technologies depend on the solar irradiance potential of the site. In configurations using an adsorption chiller or a single effect absorption chiller, the use of selectively coated flat plate collectors is limited to areas with high solar irradiation availability. For other areas and for chillers requiring higher driving temperatures, high efficient collectors are to be implemented, e.g. vacuum tube collectors.

Evaporative cooling technologies work in almost all European climates, not just in hot, dry climates. However, humidity in a region almost always decreases proportionally as the temperature increases. So the cooling power of evaporative systems will be higher as the ambient temperature increases.

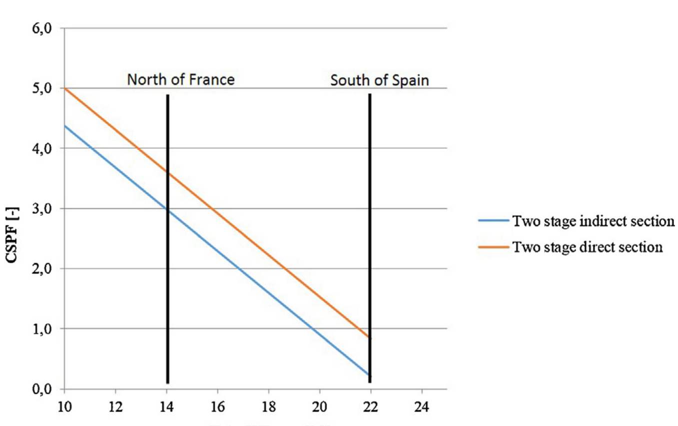

Fig. 8. Passive solar cooling – non-residential sector – influence of the average wet bulb temperature over cooling season ($T_{air,WB,c,s}$).

5. Results and outcomes

Once collected the whole list of data available and collected (X, Y, Z layers) and identified all the possible correlations, they were implemented in a GIS platform, the so-called GeoCluster Mapping Tool, which allows to visualize of all the information gathered on EE throughout maps.

The tool is in fact composed by Geocluster maps, that could be classified into two different levels: the first level map can be defined as thematic map, because it represents a single layer values (i.e. Z.1.3 Annual incident energy on a south oriented plane with 45° slope – Fig. 9); while the second level map illustrates the correlation results, by means of the 3D matrix of the Geocluster methodology, of two or more layers through a correlations map.

This approach allows the access to all the data and their possible correlations and in particular to guarantee an iterative process.

Fig. 10 represents an example of second level map which shows the correlation results of the following geo-descriptors: Z.2 layer – building typology, with the *Y* indicators of the X.1 layer – thermal insulation technology, considering the target of the Z.4 layer – regulation for the refurbishment.

The results of this correlation allow identifying the potential market of thermal insulation materials, i.e. the quantity (volume) of thermal insulation material (in this case polystyrene foam) that would be necessary to produce, sell and install if all houses built between 1961 and 1980 could be retrofitted to meet a *U*-value target of 0.2 $W\,m^{-12}$ K. The maps are not based on fixed geographic regions, but they have to be considered as a multi-dimensional and dynamic results.

Tables 7 and 8 present the whole list of the whole maps currently implemented in the GeoCluster Mapping Tool respectively for the first level and the second level maps.

6. Discussion and conclusions

The overall aim of the project was to apply GIS to development of the GeoCluster Mapping Tool for the assessment of the suitability and potential application of innovative technologies for EEBs throughout correlations maps considering opportunities deriving by a pan-European vision.

Geographic data is broadly handled within GIS, although the use of such systems has tended to focus on land-use or planning, rather than corporate networks and innovation policies. Using the Geocluster methodology presented, the GeoCluster Mapping Tool supports the analysis of deployment of energy policies by private and public parties, at local and global level becoming a decision-making tool.

The review of the whole process highlighted the significance of scale-aware thinking and data modelling techniques; cautions against a purely techno-economic analysis; encourages researchers to consider the implications of potential means by which different EE technologies might be co-located on a single site to increase their potentialities. Moreover, during the data collection and methodology development, a number of barriers and limitations has been encountered, due to scattered knowledge, specific needs, failure modes and bottlenecks, as well as the weakness and threats experienced by running clusters dealing with energy efficiency in the built environment across EU. The main limitation regards data quality, precision and scale; to resolve this issue industry partners, public authorities and academic institutes will need to pool resources and develop knowledge-based network to alleviate the pressures associates with the data intensiveness of geo-information.

The validation of the GeoCluster Mapping Tool and its data has been ensured through the engagement of stakeholders in the pilot projects, allowing them to use the instrument during two official

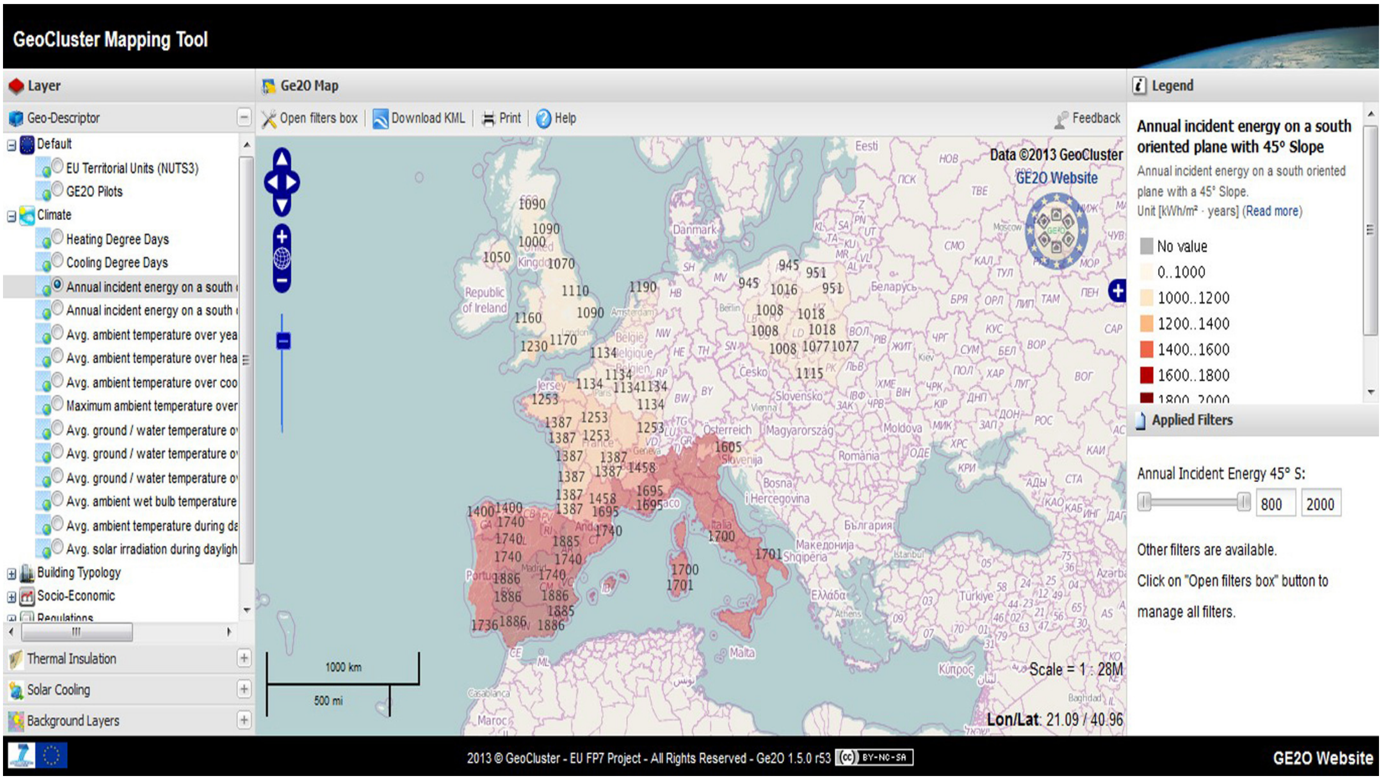

Fig. 9. First level map: Z.1.3 sub-layer – annual incident energy on a south oriented plane with 45° slope.

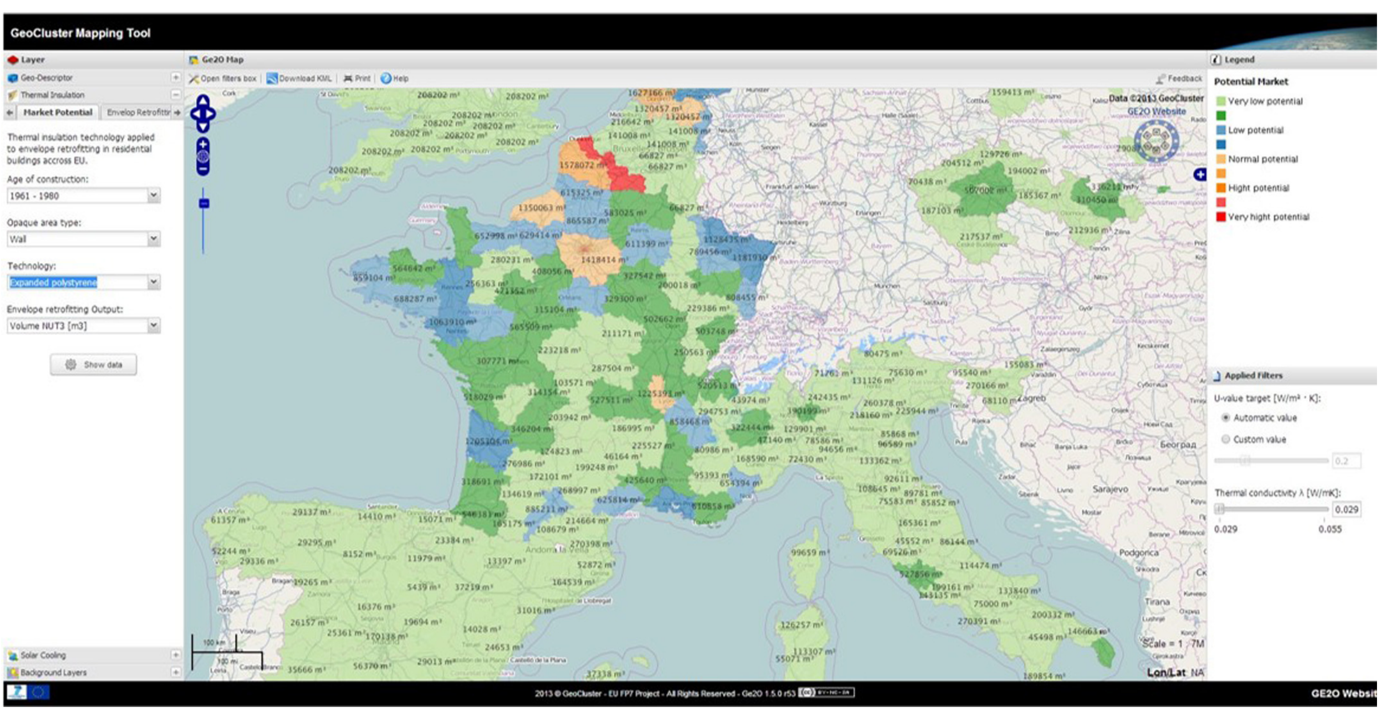

Fig. 10. Second level map for thermal insulation technology: correlation between Z.2 layer – building typology (houses built between 1961 and 1980), with the Y indicators of the X.1 layer – thermal insulation technology (in this case polystyrene foam), considering the target of the Z.4 layer – regulation for the refurbishment (*U*-value target of 0.2 W m^{-1}^{2} K).

European workshops organized ad hoc. Their feedback gave some valuable results to identify the different progress tracks for the future development of the tool. The participants were enthusiastic for concept behind the tool and expressed their interest to use the tool once it is operational. In particular to test the tool and prove the relevance of the Geocluster methodology, 11 cases studies have been performed combining:

– different end-user profiles;
– different countries/scopes (national/regional. . .);

Table 7
List of first level maps implemented in the Geomapping Tool.

N.	Topic code	First level map title	Unit
1	C	Heating degree days	–
2	C	Cooling degree days	–
3	C	Annual incident energy on a south oriented plane with a 45° slope	kW h/m^2 years
4	C	Annual incident energy on a south oriented vertical surface	kW h/m^2 years
5	C	Average ambient temperature over year	°C
6	C	Average ambient temperature over heating season	°C
7	C	Average ambient temperature over cooling season	°C
8	C	Maximum ambient temperature over year	°C
9	C	Average ground/water temperature over year	°C
10	C	Average ground/water temperature over heating season	°C
11	C	Average ground/water temperature over cooling season	°C
12	C	Average ambient wet bulb temperature over cooling season	°C
13	C	Average ambient temperature during daylight over cooling season	°C
14	C	Average solar irradiation during daylight over cooling season	W m^{-12}
15	BT	Age of construction (periods: $y < 1900$; $1901 < y < 2000$; $y > 2001$)	Building/km^2
16	BT	Use residential	Building
17	BT	Use residential – single	Building
18	BT	Constructive elements	
19	BT	Constructive elements: *U* value existing – wall	W m^{-12} K
20	BT	Constructive elements: *U* value existing – roof	W m^{-12} K
21	BT	Constructive elements: *U* value existing – floor	W m^{-12} K
22	BT	Constructive elements: *U* value target – wall	W m^{-12} K
23	BT	Constructive elements: *U* value target – roof	W m^{-12} K
24	BT	Constructive elements: *U* value target – floor	W m^{-12} K
25	BT	Heating system: central	Number of HS
26	BT	Heating system: individual	Number of HS
27	SE	Population living in the areas at last census	Number of persons
28	SE	GDP of the area at last census	€ (per inhabitant)
29	SE	GDP in construction	€ (millions)
30	SE	Employment rate	%
31	SE	Employment in construction	Number of persons
32	SE	Labour cost	€ per employee
33	SE	Gas price for household consumers	€/kW h
34	SE	Electricity price for household consumers	€/kW h
35	SE	Disposable income of households	PPS per inhabitant
36	SE	Electricity consumption of households	kW h
37	R	Regulations: link to national energy regulation of DATAHUB	Source BPIE
38	FI	Solar cooling incentives	Yes/No
39	FI	Direct grants for equipment	€
40	FI	Grants for performance	€
41	FI	Tax incentives	%
42	FI	Loans at reduced rates	€
43	FI	Feed-in tariff	€

C, climate; BT, building typology; SE, socio economic; R, regulation; FI, financial incentives.

– the two-predefined technologies (see limitation above);

with the following objectives:

– identification of barriers;
– selected technology potential;
– associated business models;
– readiness for technology innovation, transfer and adoption;
– time to market;
– replication potential.

The general first impression of the testers of the GeoCluster Mapping Tool was positive, the user-friendliness of the tool was appreciated and there was a strong agreement about the relevance and quality of climate data, which is very well valuated by most of participants. Initially the overall approach had to be tested within two pilots cluster namely, Mediterranean Arc and Benelux Cluster; respectively with two technologies: solar cooling and thermal insulation. The limitations due to collection and availability of useful and homogeneous data stress this step of the research and the validation has been done referring mainly to the defined pilot cluster, but also to the whole EU data available in order to extend the vision for the first chance of the GeoCluster Mapping Tool.

However, the SWOT analysis (Table 9) performed on the tool reflects strengths and weaknesses of the current version of the tool (prototype development and PoC) and opportunities and threats for the tool beyond the project duration (future needs and tool potential).

In particular, according to the authors, some current weaknesses could be transformed into strengths in a future version of the GeoCluster Mapping Tool: i.e. considering all the EU countries or implement the technical information and the financial incentives for EE in order to become a more attractive tool for a wider range of users.

Table 8
List of second level maps implemented in the Geomapping Tool.

SECOND LEVEL MAP	TOPIC CODE	TITLE
1	SE + SE	Market potential for new technologies in terms of installation costs
2	SE + C	Market potential for heat saving technologies
3	SE + C	Market potential for heat saving and cooling technologies
4	SE + C	Market potential for solar cooling technology
5	SE + FI	Market potential for new technologies
6	SE + C + FI	Market potential for new products in solar cooling
7	SE + SE	Fuel poverty
8	BT + TI	Potential market for thermal insulation material
9	C + SC	Potential market of solar cooling technologies

C, climate; BT, building typology; SE, socio economic; R, regulation; FI, financial incentives; TI, thermal insulation; SC, solar cooling.

Table 9
SWOT analysis on GeoCluster Mapping Tool.

Strengths (S)	Weaknesses (W)
Present situation	
User-friendly visual tool with intuitive operation – Provision of extensive climate data – Flexibility to develop user's own queries, with adjustable parameter searches – Professional experience and knowledge provided by consortium partners from complementary organizations in a wide range of countries – General agreement on the perceived potential for market development – Errors and corrections completed within project time	Final version is still a prototype – Some EU countries with significant market opportunities are missing – Existing information does not yet reflect the regional/national specificities for some of the layers – Some key indicators are missing, i.e. detailed financial incentives and cost analysis
Future expectations	
– The project proves the importance and usefulness of aggregating technical information across Europe – The tool could be developed and implemented for a wider range of technological and socio-economic variables – Further requirements of potential users could be included	– Great difficulty involved on data management when reflecting a wide range of regional/national realities. – Quality control and independence of the tool (technical rigour)
Opportunities (O)	**Threats (T)**

A new methodology to correlate different layers concerning the promotion and use of different type of technological solutions or building materials for EE across the Europe has been presented. The Geocluster methodology is based on the possibility to locate similarities across enlarged EU by combining single or multiple parameters organized in homogeneous layers and sub-layers. The method allows to map technologies for the building sector in geo-clusters as well as reference indicators to measure the potential impact per cluster, giving also the possibility for policy makers to compare different initiatives and associates benefits.

Although limitations remarked in the previous section, the experience of GE2O project highlighted the potential to combine heterogeneous data, such as technological, socio-economic, political-strategic and climatic, into a unique platform geo-referenced which could support the market development and the definition of strategies for EEBs.

In conclusion, it can be stated that the Geocluster methodology is a powerful approach with which to address these concerns, and can therefore be a powerful lever to remove barriers that prohibit the sustainable development of innovative technologies for EEBs and to deploy a really integrated European Framework.

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