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A simplified geo-cluster definition for energy system planning in Europe

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Abstract

The past decade has seen the development of new means of production and distribution as well as more efficient appliances and materials that limit consumption. The variety of technical solutions has increased dramatically making decision more complex when it comes to energy systems implementation. This paper presents the ongoing research on the development of geo-clusters for energy system planning in Europe. The geo-clusters have been defined following a heterogeneous set of parameters such as climate, building typologies, socio-economic indicators. Overall, 16 different parameters have been taken into account resulting in the creation of 116 geo-clusters within Europe. The outcome of this study is the design of two tools that help the user in the geo-cluster exploration. Those geo-clusters along with a technologies' library will ease solutions' selection by referring to successful implementation within the same geo-cluster.

Keywords: Geo-cluster, energy planning, Europe

1. Introduction

Currently, cities are changing their mode of production by gradually integrating renewable energy systems, new distribution networks along with a more holistic view of the field. However, this new vision does not go without challenges. The ever growing variety of production systems has led to a more complex energy planning at district to city level [1]. Energy system design are highly sensitive to geographical constraints because technologies have gained in complexity [2]. Indeed, in contrary to simple systems that can be implemented everywhere, energy planner must now be aware of technologies' specificities for a relevant use. Many argue that this shift in the energy system paradigm can only be achieved with the consideration of geospatial dimension [3]–[5]. Thus, before considering the implementation of new systems, a good knowledge of the location main characteristics is essential.

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On this matter, the extended amount of data can help in the definition of geo-cluster with common characteristics. Public data are believed to play a central role in economic growth and are currently part of the EU 2020 development strategy [6]. In the context of building structure and energy systems, the concept of geo-cluster is highly relevant because it defines trans-national virtual regions with strong similarities [7].

On the geo-cluster definition related to energy systems, one recurrent framework is leading the field: GE2O. GE2O is a European funded under the FP7-NMP framework [8]. The objective is the creation of geo-clusters that define similarities across EU regions by combining various parameters such as Climate, building typology, socio-economic, regulation, financial incentive [7]. Calvert et al. created mapping through geographically explicit indicators such as environmental, technical and social constraint and potential benefits for the implementation of renewable energy sources[2]. Fatiguso et al. applies geo-cluster using climatic data, simulation of solar radiation and wind exposure, mapping of typologies, materials, construction techniques and historic-architectural values for a simple site retrofitting [9].

The present study aims to define geo-clusters based on heterogeneous parameters related to energy consumption and production. Building typologies, environmental conditions and economic considerations will thus be used for the creation of sub-continental regions in Europe reflecting strong similarities of localised systems behaviour. Such framework is believed to help in the decision-making when selecting technologies that must be applied for a more efficient district energy production, distribution and consumption. Indeed, the selection of retrofitting solutions and energy system implementations at a specific location will be strengthened by an already successful implementation within the same geo-cluster. The advantage of the new approach compared to the ones presented above is it simplicity. Indeed, geo-clusters defined by Calvert et al. [2] are based on more finely defined GIS. This result in a intensive and complex data collection, using remote sensing and/or survey. The new approach is meant for a pre selection of technologies and is not intended to choose for the user. In that prospect, there are no need for finely defined GIS since the data collection is resources-consuming (time, money and people). Additionally, the GE2O project focuses on 2 particular technologies which are thermal insulation and solar cooling while the tool presented in this paper is meant for the implementation of cutting-edge technologies for district heating and cooling.

2. Methodology

In the literature, there is an overall consensus toward the parameters that must be considered for the creation of geo-clusters in an energy system efficiency context [7], [10]. They follow Pizzi et al. suggestions [11]:

- Climate characteristics;
- Environmental context and culture;
- Technological characteristics;
- Construction typologies.

This section presents the methodology that has been applied to collect the most relevant parameters as well as the creation of the geo-clusters regarding the parameters.

2.1. Parameters definition

The first step in the definition of geo-clusters is the selection of parameters that are closely related to energy systems. Building energy simulation programs such as EnergyPlus, Design Builder or TRNSYS are used by engineers to model both energy consumption and HVAC. Across the years, those software have shown reliability and performance. The study of the input parameters used in building simulation software shows that building typologies and environmental conditions are the most influencing constraints when it comes to energy consumption.

Within an energy system, environmental conditions are most often limited to weather conditions. Moreover, the creation of regional clusters requires data on a geographically fine scale. Therefore, a Network Common Data Form (NetCDF) data file containing gridded data for daily mean temperature from 1950-01-01 to 2016-08-31 has been used [12]. NetCDF is a format that supports the creation, access, and sharing of array-oriented scientific data [13]. The dataset used covers the following area: 25N-75N x 40W-75E (extended Europe) with a 0.5 degree regular lat-lon grid. From those data, two typical seasonal mean temperatures have been calculated for each single point of the grid by averaging on the period 1950-2015 giving the geo-cluster parameters (GCP) 1 and 2 in Table 1. The study has shown that in Europe, the hot season runs usually from the 21 of April until the 26 of October, the rest of the year being the cold season.

Another parameter with great influence on energy consumption is the building typology itself. Therefore, the different building typologies found in Europe have been investigated. The TABULA project looked at the residential building stocks of 13 European countries and aimed at creating a building portfolio providing typical building characteristics such as the floor area, envelope or heating systems [14].

The web tool presents characteristics such as reference floor area, the overall U-value (a thermal resistance index) or energy consumption of several building types, namely, single family house, terraced house, multifamily house and apartment block. From this rigorous example of building classification, some parameters have been selected for the geo-cluster definition (GCP3 to GCP8 in Table 1).

A good overview of the building stock is needed as well. This will help to better catch the repartition of the different building types within a region. Therefore, GCP9 and GCP10 have been considered.

Finally, European countries' socio-economic status is broad. Therefore, it is relevant to introduced socio-economic parameters within the geo-clusters in order to fully understand the current state of their building stock and the extent of feasibility of certain solutions. Projects such as ECODISTR-ICT, ODYSSEUS or URB-Grade have acknowledged the importance of energy prices within the key performance indicators they addressed [15]–[17]. Indeed, economical savings for consumers and providers is one of the main objective for the implementation of new systems. Therefore several socio-economic factors (GCP11 to 16) have been taken into account.

Table 1Geo-cluster parameters

GCP	Description	GCP	Description
GCP1	Hot season mean temperature (°C) [12]	GCP9	Residential building stock (%) [18]
GCP2	Cold season mean temperature (°C) [12]	GCP10	Single family stock (% of residential) [18]
GCP3	Residential building energy use (KWh/m2) [18]	GCP11	Energy use (kg of oil equivalent per capita) [19]
GCP4	Non-residential building energy use (kWh/m2) [18]	GCP12	Gas prices for domestic consumers (€/kWh ex. VAT) [20]
GCP5	Single family unit U-value [21]	GCP13	Gas prices for industrial consumers (€/kWh ex. VAT) [20]
GCP6	Multiple family unit U-value [21]	GCP14	Electricity prices for domestic consumers (€/kWh ex. VAT) [20]
GCP7	Single family unit floor area (m2) [22]	GCP15	Electricity prices for industrial consumers (€/kWh ex. VAT) [20]
GCP8	Multiple family unit floor area (m2) [22]	GCP16	Share of renewable energy in gross final energy consumption (%)[20], [23]

Those parameters are believed to give an insight on the energy market of each country in term of energy production, costs and consumption. Because they are based on their recognized influence on heating and cooling systems, such approach could be applied not only in Europe but in other parts of the world. The relevance of certain GCP only relies on their heterogeneity on the region studied.

Note that some data were missing for particular combinations parameter/country which may interfere in fully mapping Europe.

2.2. Geo-cluster definition

Geo-clusters are generated using a MATLAB program that takes as inputs both excel files with gridded dataset and the NetCDF file of mean daily temperatures. Therefore, tables of size 232x101 are created for each parameter where the columns correspond to the longitude (40W-75E) and rows the latitude (25N-75N) with a 0.5 degree regular difference. Each cell contains the GCP value with empty cell assigned to non-existing data.

Once the parameters are selected, geo-clusters must be defined according to some criteria. The definition of those criteria will influence the meaning of the cluster. To avoid the creation of too many clusters, it has been decided that each set of data for each parameter would be divided in quartiles. Therefore, for each parameter, 4 groups of equal importance in size will be defined. The combination of all the parameters divided in 4 groups each leads to the creation of 116 different clusters.

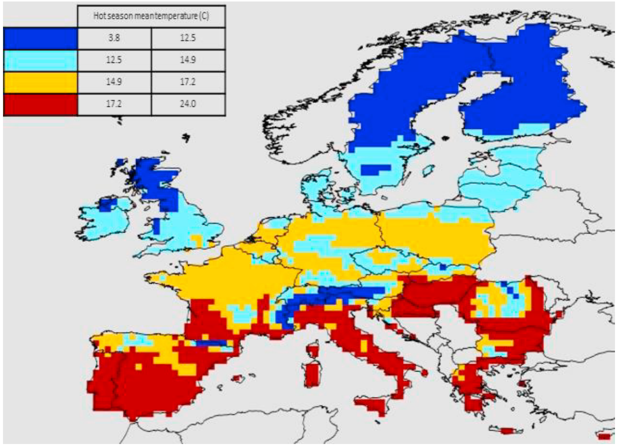

Fig. 1. Hot season mean temperature clusters

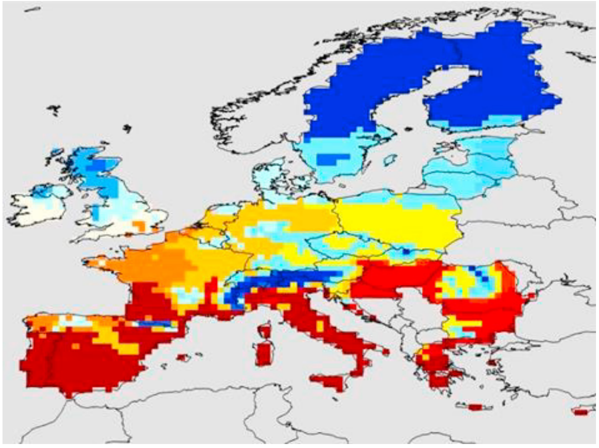

Fig. 2. Environmental condition clusters

3. Results

Each parameter divided in quartiles can be seen as layers which, combined together, change the mapping of the geo-clusters. For instance, the Figure 1 shows the clusters defined by the hot season mean temperature while Figure 2 shows the combination of the cold season mean temperature parameter with the hot season mean temperature. The combination of the two parameter results in the creation of 13.

Because the combination of the 16 different parameters leads to the creation of 116 clusters, a map such as the map above can be confusing. Therefore, a more efficient way to provide results has been investigated. A Matlab program has been developed in order to query the cluster in which a certain location is included. Users is first required to enter the location they want to investigate. Then, the desired combination of parameters must be specified to form the clusters. Once the parameters' selection is done, the program will output a table containing the quartile in which the current location is associated, such as the one shown in Listing 1, as well as a geographical representation of the cluster, such as the one shown in Figure 3.

```
                                     Var1                                              Var2      Var3
_____________________________________________________________________________________  _______   ______

[1]Mean daily temperature during the hot season (21 April to 26 October) (degree C)'    14.866    17.184
[2]Mean daily temperature during the cold season (26 October to 21 April) (degree C)'   6.3068    14.193
[5]Gas prices for domestic consumers (€/kWh ex. VAT)'                                   0.0503    0.0536
[12]Single family unit U-value'                                                        0.99152    1.2953
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Listing 1 Result table

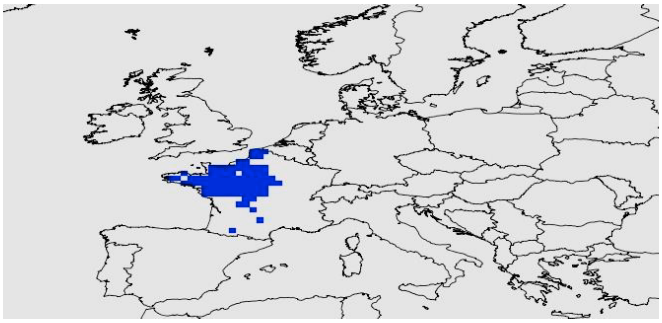

Fig. 3. Geo-cluster mapping

Additionally, another tool has been created with Microsoft Excel in order to conduct more exploratory searches on raw data. Users must first choose the parameters they want to use for the geo-cluster creation. Following the parameter selection, a lon-lat grid appears with the combination code corresponding to each point. At each point, a code can be read that correspond to the quartile of the addressed parameter. The digit must be taken in the same order than the parameters' list. In Microsoft Excel, the geo-cluster exploration is facilitated by the conditional formatting available within the software that highlight the cell with the same value.

Finally, a table is provided with the quartile boundaries for each parameter in order to help better understand the combination values.

4. Discussion

The paper presents a first approach for geo-cluster definition in energy system planning and retrofitting. However, further work is needed in order to come up with a valuable tool. Indeed, the development of more efficient visualisation tool would be needed for a user-friendly experience. GIS software such as ArcGIS, GRASS, MapServer, OpenLayer , QGIS are believed to be resourceful means for the development of web application. In addition to the user-friendly interface, future tasks must focus on the collection of successful use cases of efficient energy system within Europe. Those use cases would help in the creation of a library of technologies and efforts that are known to be efficient. Thus, when querying the possible solutions for improvement, the user can refer to actual technologies that have proven to be relevant within the same geo-cluster. Finally, such tool should not be considered as a final decision maker but rather as a line of thought to the technologies that must be investigated.

Moreover, the study has shown that data quality is important for a significant framework development. In reality, data collection is a tremendous work especially on such specific parameters and at such scale. On that matter, big data are believed to trigger more and more potential for such application. Nevertheless, the field still has to overcome great challenges such as need for policy changes, political uncertainties, lack of appropriate methodologies and metrics to assess valuable returns. Therefore, projects such as EPISCOPE /TABULA [14] that collected extended information for the development of a building typology database are particularly important. Certainly, such projects, supported by valued institutions, will initiate great effort in data collection and trigger a shift in the field.

5. Conclusion

The study aims to create geo-clusters in order to help decision-making for energy system implementation and retrofitting actions. Parameters for the definition of the geo-clusters have first been investigated. They have been selected following their presence in energy simulation software as well as their use in similar approaches found in the literature. In total, 16 parameters regarding climate, building typology and economic context have been considered in the study. They have been taken from EU resources such as EU project and statistical databases. In this approach, all parameters are seen as layers that can be added or removed. The various combination of parameters will therefore change the geo-cluster definition.

Two tools have been developed in the frame of this study. The first one is a Matlab program that allows the query of the geo-clusters' membership of a selected location. The second one is an exploratory version developed using Microsoft Excel that allows the user to go through the gridded data and seek information directly.

Future work includes the creation of a technologies' library that referred to successful implemented sites and the integration of GIS technologies for a user-friendly experience. Nevertheless, because they rely on specific and fine datasets, this type of tools remains limited by the availability and quality of data. Great effort must be done by governmental institutions and the building industry in data collection and dissemination.

Such approach is believed to help in the selection of technologies in a particular location by providing reference cases to the user. In a context where technical solutions are increasingly diverse and complex, it is seen as a preliminary tool that greatly narrows the number of options to the most pertinent ones.

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