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Spatial analysis of the wood pellet production for energy in Europe

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ABSTRACT

The distribution of the wood pellet plants in Europe was analysed using a geo-statistical kernel based approach, in order to identify and define cluster-regions with high concentration of pellet production capacity. For that, a database with the location of pellet plants, as well as its capacity, was constructed, identifying 378 pellet plants with annual capacities over 1000 t, and an aggregated production of 11.5 million t. The geo-statistical methods facilitated the analysis of the plants with regards to their market position at global and local level.

At a European level, four main production areas were identified, defined as: "*Central Europe*" (Bavaria, Austria, and neighbouring areas of France, Switzerland and Italy), "*Scandinavia*", "*Finland*", and the "*Baltic*". These areas concentrated over 50% of the pellet production, although presented different characteristics regarding market establishment and development, their role in the global pellet trade and their raw material availability. The paper provides with methodological tools to identify and characterise the main pellet production areas in Europe that can have further economic and policy applications.
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1. Introduction

In recent years, pellets have become an important fuel in heat and power production across Europe. Pellets are considered to be a competitive fuel option since the higher fuel density translates in a reduction in the transportation and storage costs, and this advantage can be used in areas where cost efficient supply is a challenge due to storing and long transportation distances. In addition, they present lower moisture content in comparison with unprocessed biomass higher effective heating value and uniform shape, and a clear burning and reduction of ashes. Finally, they are easy to be transported and stored and can be obtained from different feedstocks being therefore adaptable to different locations with alternative raw materials for biomass [1].

These advantages have led to an increase in pellet trade, as domestic markets have increased the use of high quality pellets resulting in a rise in the demand that often is fulfilled through imports [2–4]. Investment subsidies and other national incentives have been the driving forces for the development of domestic pellet markets, as pellets heating systems are considered an essential component of European plans to reduce GHG emissions and are targeted by incentive programs in countries such as Germany, Norway, Sweden or Austria [3]. Similarly, in Denmark (one of the forerunners in wood pellet use), large scale pellet combustion became an issue in order to meet the renewable energy targets by 2020 set by the European Union [5].

However, the supply of raw material, the availability of skilled manpower, the capacity to adapt to new technological challenges, a sufficient demand of a product from local markets, and the presence of investors, are also requirements that should be fulfilled to successfully establish a new transformation industry such as the pellet production. The presence of the these factors, together with the possibility to capture investment subsidies and the capacity to consolidate a growing market by ensuring the supply of pellets, could explain the potential aggregation of pellet transformation industries in pellet production cores. The uneven spatial distribution of economic activities of diverse nature has been studied and verified for a long time (e.g. Refs. [6,7]). By identifying and measuring the agglomeration patterns of an economic activity, such as the pellet production, not only would be possible to provide a description of the actual situation of the pellet production sector in Europe, but to establish the framework for future analysis about the pulling forces causing that agglomeration.

In this context, the aim of this paper is to define the pellet supply areas in Europe based on extensive data on the location and production capacity of the pellet plants. To do that, the paper investigates the application of a geostatistical approach based in

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kernel methods in order to define, if possible, core areas from the pattern of geographical concentration of the pellet production at various spatial levels in order to better describe those areas and its possible applications for market analysis.

2. Material and methods

2.1. Inventory of pellet capacity

An inventory of capacity was performed for the countries analysed, including the capacity and location of the pellets plants. The inventory aimed to be exhaustive. The location of the plants was based on different accounts of pellet producers, complemented and updated by using the companies' homepages and the companies' official financial reports. The accounts included the databases of pellet plants for Sweden [8], Finland [9], Austria and Germany [10] and the rest of Europe [11,12]. Additional sources of information were based on existing scientific literature, company's financial summaries, and companies' homepages. The collection of information involved in some cases direct contacts with pellet producers and pellet associations in some of the countries studied. The location of the pellet plants was geo-referred, using their precise location or the closest urban centre, the last when the precise location of the plant was not available.

Only pellet plants with capacities over 1000 t a^{-1} were included in the database in order to facilitate the data collection. In case that the pellet plant capacity was not available, but there was information about the location of the pellet plant and data on the company suggesting a significant pellet production, then an average value was attributed to the plant in order to minimise any potential bias in the definition of the areas.

2.2. Geo-statistical methods

The analysis of the location of the pellet factories was based on geospatial kernels. This approach is a non-parametric method for the estimation of the spatial distribution of probabilities of occurrence based on a pool of observed events. For a spatial region, a continuous grid is first created, and the probability of occurrence of a specific event for all the points of the grid is calculated, creating a density function according to the number and distance of the pellet plants.

The kernel function was used in this study to calculate the probability of occurrence of a pellet plant, and the geo-spatial aggregation of pellet capacity in a given area, using:

$$\hat{f}(x) = \frac{1}{nh^2}\sum_{i=1}^{n} K(u_i) \quad (1)$$

$$u_i = \frac{(x - x_i)}{h} \quad (2)$$

where x is the vector of coordinates of a given location, K is the kernel function used, h is the bandwidth radius, which affects the dispersion of the density function and X_i is the vector of coordinates of the i observed pellet plants: therefore $x–X_i$ is the distance between a point where the density function is to be estimated and each of the observed pellet plants used to define the density areas.

The variables used were the Universal Transverse Mercator (UTM) coordinates of the pellet plants, The calculations were based on the spatial statistic package SPlancs [13] adapted for *R* [14] to estimate the probability densities. A quartic kernel function with a fixed bandwidth was applied, considering a method for correcting the border effect based on Diggle [15] and Berman and Diggle [16]. By this means, the factories at the bordering areas are not overrepresented. In addition, the pellet plants were weighted by their production capacity.

The bandwidth radius determines the level of aggregation of the data in the density function, and significantly affects the final outcome [17,18]. Although there is not a broadly accepted methodology to determine the optimal radius, as it also depends of the purpose of the mapping [17,19], a common method is an *ad hoc* choice, referring *h* to a parameter [18]. In this study, the parameter of reference (*h100*) was calculated according to Worton [20] and used to aggregate the probabilities of pellet plant occurrence at local or global level by using different proportions of h100. Therefore, it was used h80, h40 and h20 corresponding to the 80%, 40% and 20% of the h100 value used to define the radius of search.

To analyse the resulting kernel estimations, raster maps with standardised isopleths were created. The isopleths were based on percent volume contours (PVC), in order to compare areas defining a high concentration of pellet production capacity. The PVCs define the volumes under the utilisation distribution, and represent a defined percentage of the total pellet capacity in the smallest possible area. For instance, the isopleths containing the 10th percentile area shows the areas with the highest concentration of pellet production, since it represents the smallest possible area to contain 10% of the pellet capacity in Europe (i.e. the core production area). On the other hand, the 90th percentile area represents the lowest concentration, since it contains almost the total pellet capacity. In this study, we assume that this line defines the supply market for pellet production. The resulting maps were presented using a 150 × 150 grid cells resolution.

Finally, the maps and the calculated PVCs were used to identify and characterise the main pellet production markets in Europe, defined as continuous geographic areas with large shares of pellet capacity. For those areas, additional parameters concerning land uses [21] and population [22] were calculated, as well as main national indicators of pellet trade [23], in order to describe the area with regard to potential raw material supply, potential demand, and current trade.

3. Results

After the inventory of pellet production plants was finalised, 378 pellet plants were identified, capable of producing annually a total of 11.5 million tonnes of pellets (Fig. 1).

Based on the estimation of the radius of reference (h100), equal to 231 km, the spatial distribution of the pellet occurrence probability was estimated using h100 and h80 for defining global agglomerations, and using h40 and h20 for defining local agglomerations (Fig. 2).

Each plant was therefore classified according to the estimation of probability of occurrence for h20 and h80 (Fig. 3), defining a competition index: plants with a high value for h20 are located in an area with a high concentration of pellet capacity at local level, and plants with a high value for h80 are located in areas with high concentration of pellet capacity at European level. The highest value for h20 would correspond to pellet plants with a position of local dominance of the production market (risk of local monopoly), and the highest values for h80 would correspond to global dominance of the production market (risk of global monopoly).

Using this competition index, country averages were calculated with the average values of all the plants. In this case, high country averages for the h20 estimates implied that are few pellet plants but they concentrate most of the local production of pellets (*local dominance*). This would be the cases of Portugal and the Netherlands. On the other hand, countries with high averages for h80 implied that those plants concentrate a large share of the pellet

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