THE OPTIMAL SCALE OF LV DISTRIBUTION NETWORK OPERATION

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BRIEF INTRODUCTION, OBJECTIVES AND CHALLENGES

This study's main purpose is to define geographic areas for a new tender to award municipal concessions for the operation of the low voltage (LV) electricity distribution network. The aim of that tender is to aggregate the existing 278 municipal concessions into larger, fewer areas. However, currently, in mainland Portugal, almost all of the low voltage electricity distribution network operation is performed by a single agent, responsible for 99.5% of all national delivery points. The remaining portion is carried out by 10 very small size operators.

A secondary objective of the present study is to ensure that the LV distribution network operation in the newly defined concession areas do not jeopardize economic efficiency, enables an effective performance of the system and is financially neutral relative to the current situation.

As another secondary objective, the study also aims to ensure territorial cohesion, the concessions' sustainability and the principle of harmonized tariffs, which consists, broadly, in fostering homogeneity in terms of costs and economic efficiency between territorial areas.

These goals pose a number of challenges, considering the current framework for the LV network operation. Therefore, and in order to meet the objectives set out above, a first challenge concerns the rescaling of the entire LV distribution network operation.

Given that the LV distribution network operation is a natural monopoly, the present study aims to find the minimum concession size (in terms of number of customers) that ensures that the rescaling of LV electricity distribution network activity will not compromise economic efficiency and will not result in a cost increase for consumers.

In this context, minimum concession size should be interpreted as the value below which economies of scale can still be achieved. It should not be viewed as the maximum efficient size.

After determining this optimal concession size, the study then seeks to define the geographic area for each concession. For this task, the main challenge is to ensure homogeneity between areas, both in terms of geographic proximity, economic efficiency and of unit cost levels.

BENCHMARKING EXERCISE TO FIND MINIMUM CONCESSION SIZE

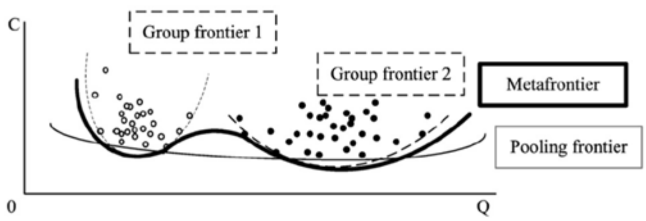
The following steps supported the assessment of the optimal minimum concession size:

1. Analysis of scientific literature;
2. Benchmarking analysis of the performance of DSOs from several countries, split in terms of size:
    a. Micro, small and medium DSOs, including 6 Portuguese cooperatives (very small operators);
    b. DSOs similar to EDP Distribuição in terms of size (this benchmarking had already been performed for the purposes of setting electricity tariffs in 2018).

In what concerns scientific literature, twenty one papers were analyzed. The vast majority conclude that the electricity distribution activity presents increasing returns to scale. Only three conclude that there is no evidence of returns to scale. The papers that assume that the optimal size is less than 150 thousand customers have few or no companies with a size of more than 500 000 clients: results are potentially skewed by the sample consisting of a large number of small companies.

The literature allows us to assume increasing returns to scale up to a certain size (several support the merging of small DSOs to achieve an increase in scale gains (Kumbhakar et al., 2015, Sareamoinen et al., 2017, Orea and Jamasb, Agrell and Brea-Solís, 2017). However, it is not clear which is/are the optimal dimensions.

Figure 1– Optimal size and activity level



Source: Huang et al, 2010.

Therefore, benchmarking was a critical analysis.

Since it was based on data collected from European DSOs, the following paragraphs include a more detailed description and the main conclusions of step 2.a.

Determining the geographic delimitation for the new concession areas stems from identifying the relation between DSOs' size and cost level/performance. Among a number of available alternatives, this process can be developed through a comparative analysis of several DSOs in terms of their performance (benchmarking analysis).

For that purpose, there was the need to obtain a sample of financial and physical information from DSOs that operate exclusively the LV electricity network. Two paths were adopted to gather such sample:

- Collecting data from the six biggest DSOs of very small dimensions that perform their activity in Portuguese municipalities;
- Collecting data about LV DSOs from different European regulators;

This process provided economic and physical data on 38 DSOs:

Table 1– LV DSOs Sample

Country	Number of DSOs	Source
Portugal (small DSOs)	6	Annual Reports
Belgium	8	National Regulator: CREG – Commission for Electricity and Gas Regulation
Spain	16	National Regulator: CNMC – Comisión Nacional de los Mercados y La Competencia
Finland	4	National Regulator: Energiavirasto – Energy Authority
Netherlands	4	National Regulator: ACM – Authority for Consumers & Markets

In order to avoid complex comparability issues regarding reported information about non-current assets, such as asset value, amortization policies and asset remuneration, the values of non-current assets that are used to measure the cost associated with remuneration and investment return have been purged from the total costs. In addition, all the costs considered in the analysis were adjusted to offset purchasing power parity effects.

Thus, the benchmarking analysis focused on operational costs. This option has advantages and drawbacks. While it allows a greater comparability of the data provided by the different DSOs, this type of analysis does not incorporate the scale gains relative to investments in non-current assets as well as the effects of the possible replacement of shared infrastructures with new infrastructure, due to the rescaling of the activity. It also does not take into account the scale effects in investment cost levels.

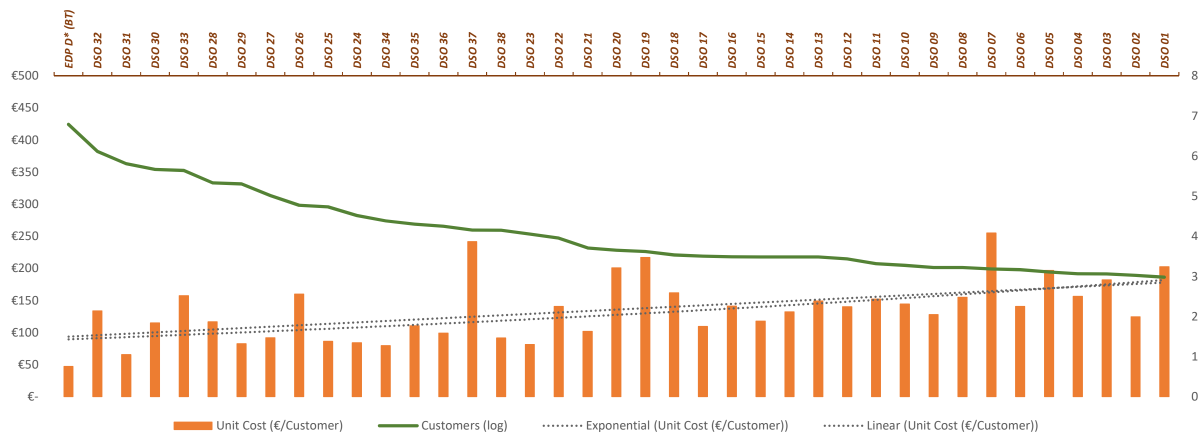
Table 2– Benchmarking Analysis Procedures

Stage	
1	Identify similar sized groups through a cluster analysis applied to number of customers.
2	Evaluate unit cost levels prevailing in each cluster – relation between size and cost level.
3	Identify, in each cluster, the operator with the lowest operational unit cost.
4	Evaluate the theoretical cost impact in the LV distribution network activity considering as reference the DSO with lowest unit costs identified in step 3.

Figure 2 and Figure 3 show the link between DSO's size and the average operational costs, demonstrating that it is not possible to infer any marked relation between size and unit costs due to the lack of a cost level response to DSOs' size changes.

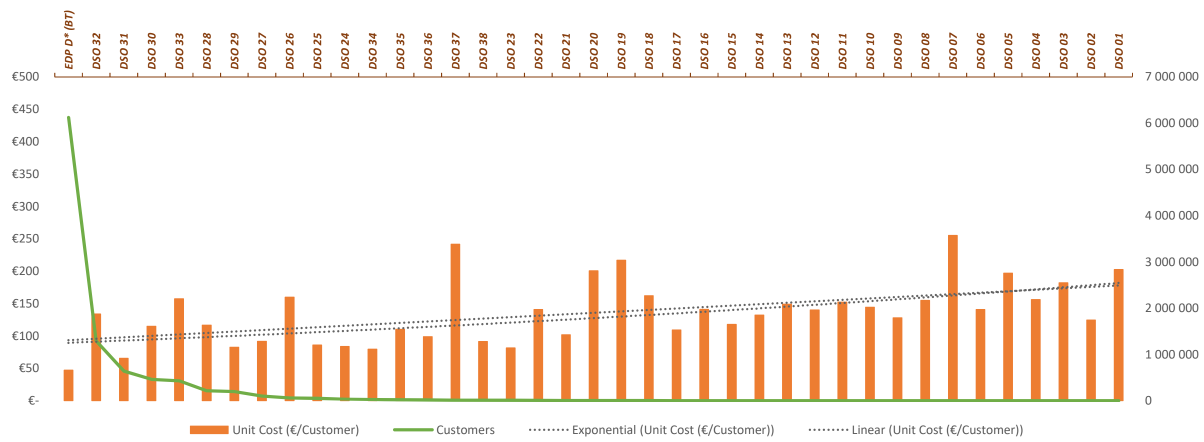
However, despite the lack of evidence of a significant relation between size and unit costs, the figures below do show a slight indication of a negative relation, which would mean that an increase in size would lead to lower unit costs.

Figure 2– Relation between Unit Costs and Dimension (log(customers))



Source: ERSE, EDP Distribuição and sources cited on Table 1.

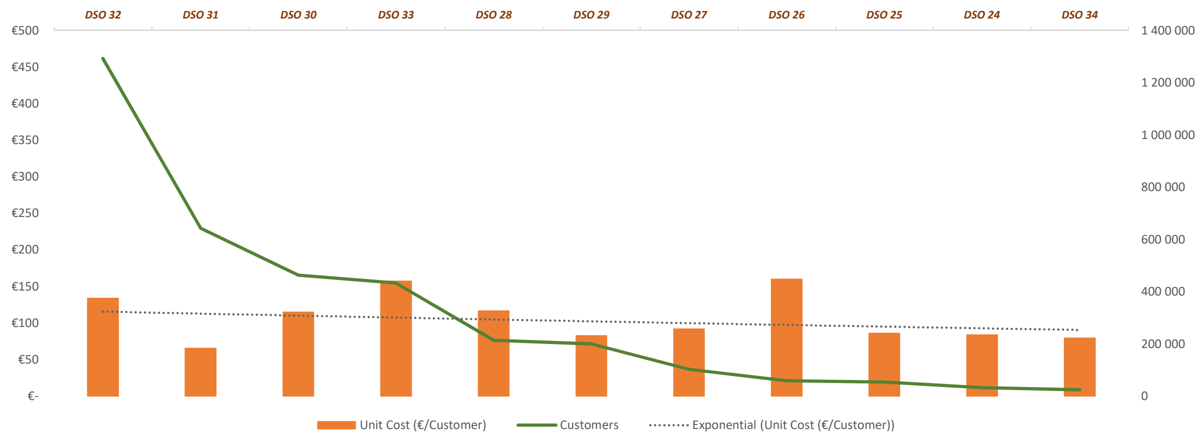
Figure 3– Relation between Unit Costs and Dimension (Number of Customers)



Source: ERSE, EDP Distribuição and sources cited on Table 1.

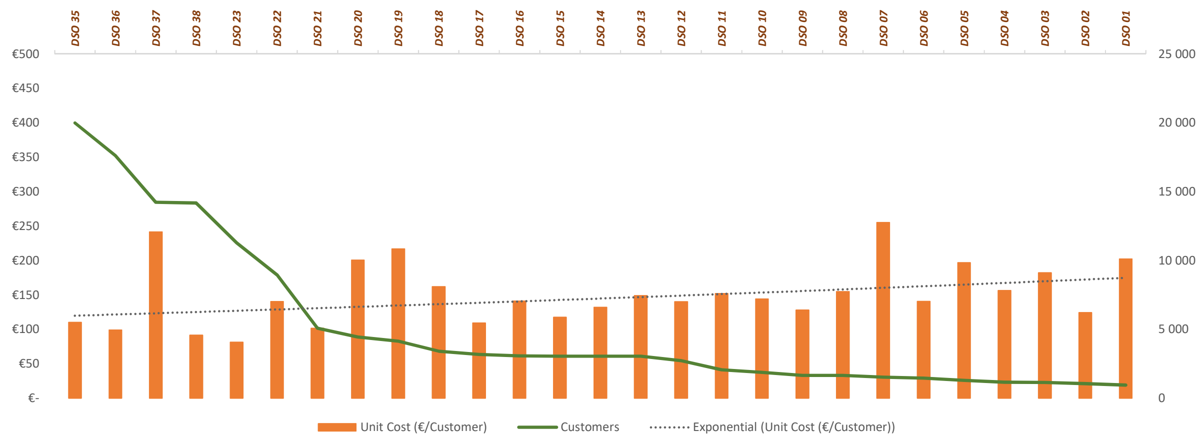
To further deepen the analysis and try and find a connection between unit costs and size, the sample was split in two subsets, above and under 20 000 customers. However, it was not possible to draw any conclusion regarding the relation between dimension and unit costs.

Figure 4- Relation between Unit Costs and Dimension (>20 000 customers)



Source: ERSE and sources cited on Table 1.

Figure 5- Relation between Unit Costs and Dimension (<20 000 customers)



Source: ERSE and sources cited on Table 1

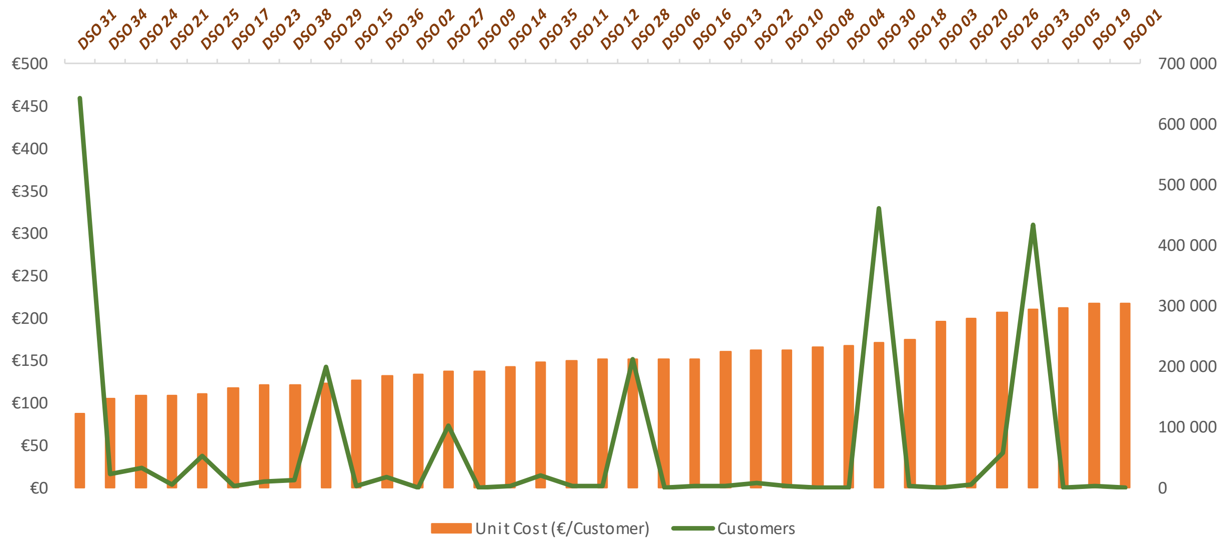
The chosen method to assess if there is any relation between size and unit costs was a cluster analysis to identify homogenous groups. Cluster analysis can be split in two main types of methods[1] (Everitt et al, 2011): hierarchical methods or partitioning (non-hierarchical) methods. The chosen option was the K-

[1] Everitt, S.B.; Landau, S.; Leese, M.M. e Stahl, D., 2011, "*Cluster Analysis", John Wiley & sons, Ltd,* 10.1002/9780470977811.ch8.

means algorithm (an optimization clustering method) due to the sample characteristics (small size) and because this method is widely applied given the stability of the solutions that it presents.

The figure below shows the sample grouped in 3 clusters, determined based on unit cost. Four outlier observations were removed from the initial sample, by applying Tukey's fences. However, the resulting clusters do not show a relation between customers and unit costs.

Figure 6– Relation between Unit Costs and Dimension (clusters based on unit costs)



Source: ERSE and sources cited on Table 1

Cost Impact

The following table shows financial and operational data of the DSOs considered in the sample, including EDP Distribuição. Additionally, the table also groups companies in terms of size (number of clients). The size of EDP Distribuição and another DSO (with 1.3 million clients) stand out in the sample, albeit with significantly different unit costs between the two. In the remaining groups there is also a wide range of unit costs, both intra and inter group. Thus, there is no evidence of a specific cost level in a specific group, but rather of a much higher cost level of most DSOs when compared with EDP Distribuição.

Table 3– Sample 1 characteristics, comparison with EDP Distribuição (DSO 00)

Firm	Customers	OPEX(10^3 EUR)	Unit Cost (€/Customers)
DSO 00	6 117 803	288 240	47.12 €
DSO 30	462 838	79 481	171.73 €
DSO 29	200 345	24 736	123.47 €
DSO 28	213 668	32 290	151.12 €
DSO 27	102 796	14 106	137.22 €
DSO 26	58 829	12 178	207.01 €
DSO 25	53 543	5 968	111.46 €
DSO 24	32 705	3 549	108.51 €
DSO 23	11 280	1 373	121.68 €
DSO 22	8 945	1 449	161.96 €
DSO 21	5 081	557	109.63 €
DSO 20	4 442	891	200.57 €
DSO 19	4 142	898	216.75 €
DSO 18	3 417	596	174.53 €
DSO 17	3 184	375	117.64 €
DSO 16	3 083	469	152.00 €
DSO 15	3 056	387	126.73 €
DSO 14	3 055	435	142.42 €
DSO 13	3 055	491	160.62 €
DSO 12	2 720	411	151.01 €
DSO 11	2 055	310	150.62 €
DSO 10	1 880	306	162.81 €
DSO 09	1 652	228	137.80 €
DSO 08	1 651	275	166.85 €
DSO 07	1 530	420	274.83 €
DSO 06	1 467	222	151.55 €
DSO 05	1 288	273	212.13 €
DSO 04	1 156	195	168.40 €
DSO 03	1 146	225	196.17 €
DSO 02	1 053	141	134.01 €
DSO 01	955	208	218.00 €
DSO 31	642 547	56 234	87.52 €
DSO 32	1 292 865	231 253	178.87 €
DSO 33	433 081	91 114	210.39 €
DSO 34	24 200	2 570	106.20 €
DSO 35	19 990	2 950	147.56 €
DSO 36	17 619	2 334	132.45 €
DSO 37	14 231	4 598	323.12 €
DSO 38	14 171	1 733	122.26 €

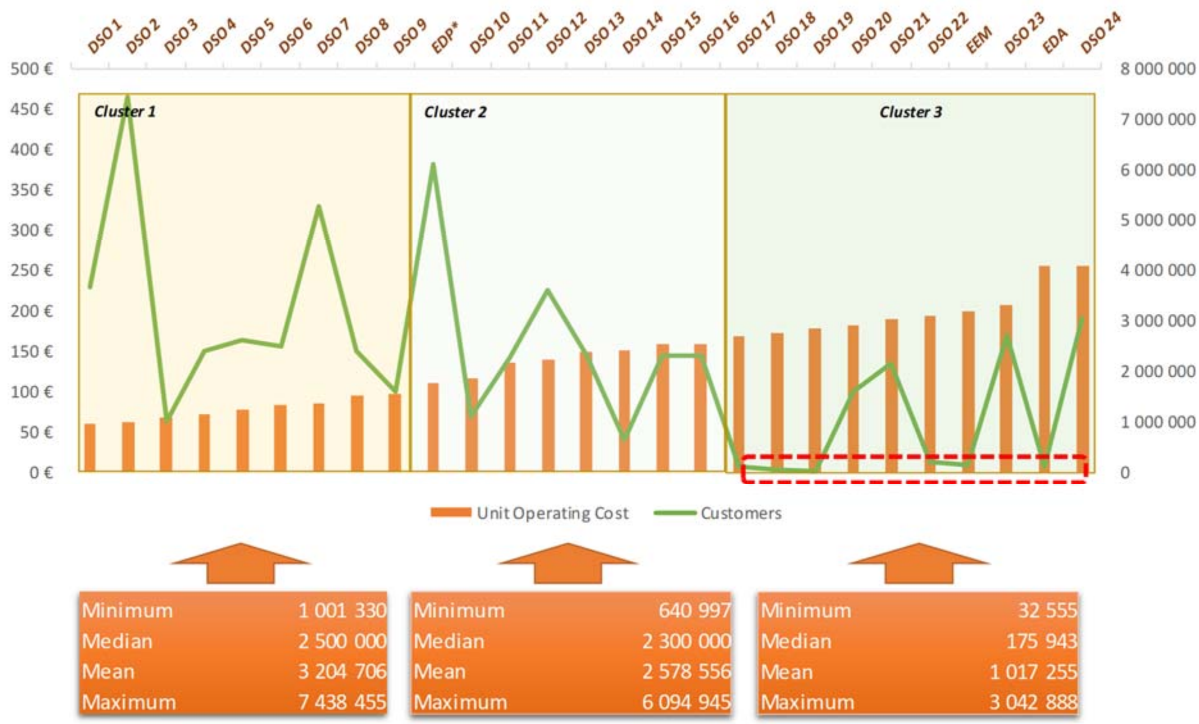
The lowest operating unit costs presented by the different DSOs are 88€ per customer. In 2016, the operating unit cost in Portugal was 47.1€/MWh. If the lowest unit cost in the sample were replicated nationally, it would lead to a cost increase of 247€ million.

Returns to scale are not the only factor that could explain the different cost levels between the sample and EDP Distribuição. However, since the LV distribution network operation is a natural monopoly, that factor should not be downplayed.

The following step was to perform a benchmarking on the second sample (2.b above), which included DSOs similar to EDP Distribuição in terms of size.

For this sample, results showed some evidence of a relation between size and unit cost levels, such as the existence of size categories with very different cost levels (clusters 1 and 3). The following graph shows sample 2 grouped in three clusters based on unit cost.

Figure 7– Relation between Unit Costs and Dimension (clusters based on unit costs)[2]



Source: ERSE and companies' accounts

Each cluster groups companies that have similar unit costs. The results demonstrate that cluster 3 stands out from the others, in terms of size: operating costs are markedly higher in a group where the DSO median

[2] In parallel with this study, and to test the robustness of the relation between unit operating costs and number of customers, a regression analysis between these two variables was carried out. It included a RESET test to the functional form. For cluster 2, the REST test validates the functional form and the results show a negative and statistically significant relation between number of customers and unit operating costs.

size (in terms of customers) is lower than in the other groups. However, this group also contains a few high cost operators with a large number of customers, which can be an indication that other factors might be relevant in determining cost levels.

According to these results, clusters 1 and 2 do not differ by much, in terms of the relation between size and operating costs. Nevertheless, it should be noted that EDP Distribuição is cluster 2's DSO with the lowest unit cost. Therefore, it represents the starting point from which to assess the impact of changes in size on unit costs.

The smallest DSO in cluster 2 has about 640 thousand customers. In cluster 1, which groups the DSOs with lower unit costs, the smallest DSO has about 1 million customers. Thus, assuming all else is equal, it seems possible to reduce the size of each concession area to about 600 thousand customers without clear indication that it would significantly raise unit costs, or, in other words, that the loss of economies of scale would lead to an increase in unit costs.

Benchmarking Conclusions

The benchmarking exercise performed on micro, small, and medium DSOs, considering 6 Portuguese cooperatives, has indicated that, for these dimensions, the operating unit costs are 2 to 6 times greater relatively to the ones observed in the Portuguese National Electricity System. These conclusions are similar to the ones reached by a Spanish scientific analysis (A. Arcos-Vargas et al., 2017) that compares the costs of the 102 smallest Spanish DSOs (< 65 000 customers) with the 5 biggest (>600 000 customers). That scientific paper highlights that the unit costs of the group of smaller DSOs is 4 times greater than the group of larger DSOs.

When a benchmarking process was applied to a different sample, made of average and large DSOs (which operate in three voltage levels), the cluster analysis enabled the definition of two main groups of DSOs, which differ in terms of operating costs. The first group, with the lower unit costs, can be further split in two clusters (1 and 2), with slightly different cost levels. The second group has contrasting features: smaller DSOs with significantly higher unit costs. The smallest DSO in the first group (clusters 1 and 2) has about 640 thousand customers.

This study thus concludes that 600 thousand customers is the minimum size above which rescaling the lower voltage distribution activity in Portugal would very likely not lead to higher costs or efficiency losses. The Spanish paper mentioned above further supports this conclusion.

CONSIDERATIONS REGARDING THE GEOGRAPHIC DEFINITION OF CONCESSION AREAS

To reach a proposal for the geographic definition of the new concession areas, the present study relied on the following methodology:

3. Analysis of economic and financial data about the LV distribution network activity in the current concession areas;
4. Definition of a theoretical cost function, in order to allocate non-specific costs and to define each area's efficiency level.
5. Grouping of several areas, considering homogeneity and geographic criteria, through a non-parametric analysis.

As a first step, it was key to know in detail all the costs related with the lower voltage activity in each of the municipal concessions. However, that proved an important challenge as well, since, in mainland Portugal, a single DSO has carried out most of this activity for decades. Therefore, there was no availability of detailed information about costs at the individual concession level, which was necessary to identify the specific characteristics of each concession for this stage of the study.

For that reason, the following task was to analyze the financial information available, leading to the conclusion that a mere 33% of the total operating costs had been allocated by individual concession. Nevertheless, 92% of the distribution activity assets were allocated by individual municipal concession.

Consequently, it was necessary to define a cost and asset allocation procedure and to define a cost function (which variables were determining the cost level), to achieve a full economic depiction of the current concessions.

Thus, the second step comprised the definition of a cost function, which included an extensive scientific literature review, with the aim of identifying potential key factors that determine cost levels (variables), as well as econometric and statistical techniques to validate those factors.

From this exercise, this study identified three main factors: the number of customers, length of distribution lines and transformers (the number of transformers or their capacity in MVA).

The economic literature reports that the electricity distribution activity is related to the following outputs (Hess and Cullmann, 2007; Leme et al, 2014, Altoé et al., 2017, Agrell and Brea- Solis, 2017 and Saastamoinen et al, 2017, among others):

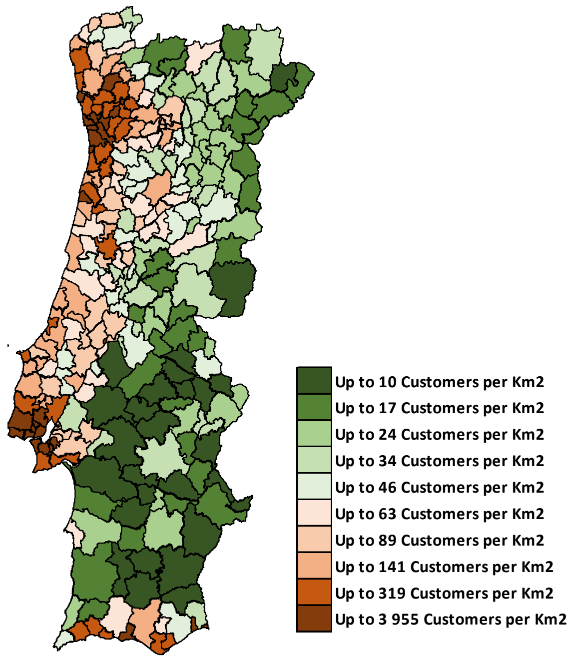
- Number of connection points or customers
- Network Extension
- Transformer Stations
- Distributed Energy

Not all outputs influence the evolution of costs in the same way. It will be important to identify the outputs that have a significant influence on costs, i.e. cost drivers. Clients are the main output in the distribution activity (see Arcos-Vargas et al, 2017). In addition, this variable is the main exogenous factor to the decisions of the distribution operator - the operator can influence, for example, the extension of the network but not the number of clients. The importance of distributed energy is not consensual, and it is even mentioned that it is not the main driver of the activity (see Cossent, 2013 and Saastamoinen et al, 2017). This variable was not considered. In addition to connection points or customers, it remains to evaluate the consideration of the following additional outputs:

- Network Extension;
- Transformer stations (quantity or power).

When assessing a company's cost level and economic performance, scientific literature also supported the need to consider exogenous variables, related with the environment where the activity is performed, which are outside of the operator's control. In this study's context, the most relevant exogenous variable was deemed the inverse of the ratio "number of clients per km^2", because it helps capture and mitigate the cost disadvantage of DSOs located in areas with lower population density.

Figure 8– Costumer density by LV concession areas



Source: ERSE and EDP Distribuição

The econometric analysis[3] carried out for the purposes of this study enabled the validation of a model to assess the efficiency of the LV distribution network operation. Two types of functional models were tested, depending on the intended objectives. Models with the density factor were used to evaluate the performance of the concessions taking into account their constraints, that is, the level of economic efficiency of the concessions (or possible groupings of concessions). Models without the density factor were also applied, which allow the evaluation of the homogeneity of the concessions (or possible groupings of concessions) in terms of costs, regardless of their characteristics.

The models were estimated using the Translog function, since it is the most appropriate to a situation where unit prices of the productive factors are equal, based on the data considered from a single operator (Kumbhakar et al, 2015).

In this model, costs vary with the number of clients and the inverse of the population density.

[3] For details concerning the econometric analysis adopted by ERSE for this task, please refer to chapter 4 of the main study.

The number of transformers was the variable used to allocate non-specific costs, which consisted mostly of operating costs.

Finally, the study proceeded to the actual grouping of the existing areas, seeking to assemble neighboring areas with uniformity both in terms of unit costs and efficiency, with no less than 600 thousand clients overall.