# CONSUMPTION PATTERNS IN CLIENTS WITHOUT CONSUMPTION DIAGRAM

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## *ABSTRACT*

*In the electrical energy sector, knowing the pattern of consumption of customers and assess their progress over time is vital for planning and operating the network. In 2013, the low voltage (LV), comprised of small businesses, residences and public lighting, represented almost the totality of clients and about half of energy consumed in the Portuguese grid.*

*The problem: As far as the clients connected to the higher voltage levels network are concerned, we know exactly the amount of energy consumed, as they are automatically metered. However, the majority of smaller clients connected to the LV network are read every 3 months, making it impossible to know exactly the amount of energy consumed per client every 15 minutes. Hence, to overcome this problem, LV consumption is estimated through profiles.*

*To address this issue, there were selected representative random samples of the LV population, to ensure the practicability of the consumption analysis of the LV clients. These samples were designed to meet a results' accuracy level defined at start. Besides, they were also stratified by variables with direct influence on the electrical consumption, such as: activity sector, contracted power and annual consumption. Stratification allowed greater efficiency of the estimators used in the inference of these populations, providing greater knowledge on the subpopulations' behavior and avoiding under dimensioning of the samples with strata regarding subpopulations with smaller dimensions. All of these samples have 15' detail data availability, which allows determining the five consumption profiles determined by the regulator: three profiles for standard LV (class A, B and C) (Fig.1), a profile for special low voltage (SLV) and another for public lighting (LV PL). These five profiles are responsible for shaping real or estimated consumptions.*

*The benefits of applying 15' detailed consumption profiles to LV clients are evident in two critical areas of EDP Distribuição (local DSO in Portugal). One, related to the daily data supplied to the wholesale electricity market by EDPD, and other, concerning the representativeness of tariff periods and seasonality in consumption's estimates.*

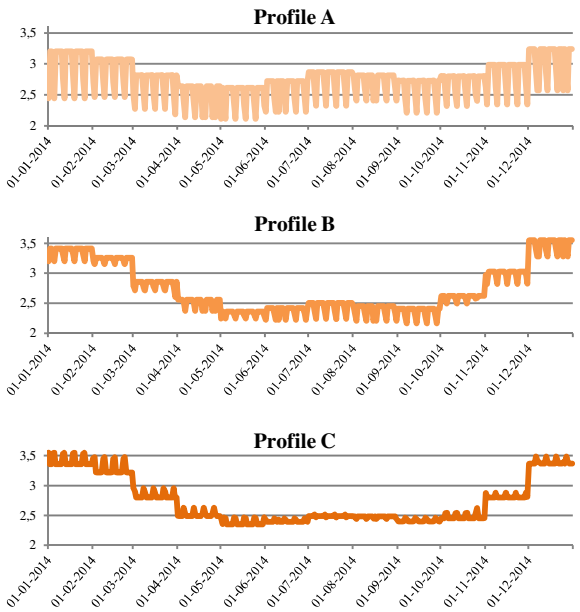


*Figure 1 – LV Profiles per class applicable in 2014.*

*In addition, the mean square error (MSE) was the dispersion tool used to assess the disparities between the consumer's real consumption diagram and the consumer's profile diagram. The results obtained (Fig.2) highlight the idea of a proper fit to the set of customers that comprises each profile.*

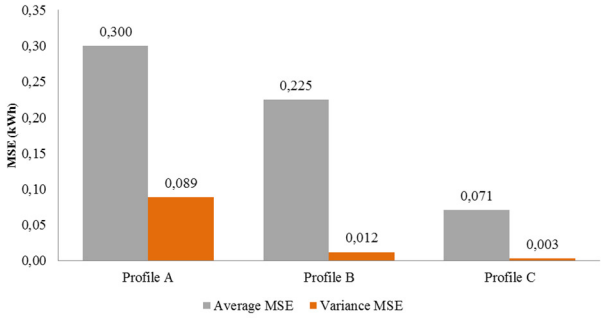


*Figure 2 – Analysis of the Mean Square Error per profile class.*

*Moreover, from an analytical perspective, the samples' results are used in the monthly assessment of the weight of the estimated LV's consumption component, which allows understanding some dynamics associated to the estimation process in the standard LV. Besides, it also provides inputs to the SLV forecast model.*

*Last but not least, the proper maintenance of these samples ensures a valuable support for the calculation of the consumptions' profile and, subsequently, an increase of accuracy in the estimates. In a near future, the experience and consolidation of the results obtained will allow us to walk towards the application of dynamic profiles.*

## INTRODUCTION

This paper highlights the relevance of LV profiles for the electricity sector as a whole. In the first chapter, it is described the problem that originated the necessity for the creation of such profiles. The second chapter mentions the methodology and the studies that originated each LV profile. The third chapter focuses on the benefits of the LV profiles in concrete scenarios, namely: the electricity wholesale market, tariff periods and analyses of consumption's estimates evolution. Lastly, in the fourth chapter, the main conclusions of the paper are drawn, as well as future perspectives and innovations under this field.

## PROBLEM

In Portugal, the amount of energy consumed every 15 minutes is known for the clients connected to the higher voltage levels (Very High Voltage – VHV 150 to 400kV; High Voltage – HV 60kV and Medium Voltage – MV 6 to 15kV). Each of these clients connected to the VHV, HV and MV levels has a meter installed that stores consumption information every 15 minutes.
However, in the Low Voltage (LV) level, most of the LV clients are only locally read every three months. In order to solve the lack of information for each 15', consumption profiles are applied to LV measurements. But what are the bases for the creation of such profiles?

## METHEDOLOGY

Due to the absence of 15 minute remotely metered information in most of the LV clients, a representative sample of the totality of the LV clients was set. This sample was created so that the consumption patterns of the clients of the sample would illustrate the consumption of all LV customers.
The appropriate sampling plan to the problem required the specification of a probability sample. Such model implies the ability to statistically determine the accuracy and reliability of the results obtained in the estimation from the sample's data. Furthermore, a probability sampling requires the availability of a sampling frame that identifies all the elements of the target population. This list, comprised only by LV clients, was ensured by EDP.
As the sample was conditioned by the existence of segments or subpopulations with both different dimensions and heterogeneous consumption levels, it was used the stratified sampling method to address this issue. This way, it was possible to set comparable precision levels for the results of the several segments.
As a matter of fact, several authors point out that the stratified random sampling has some notable advantages over simple random sampling. Among these advantages, Vilares and Coelho [1] highlight:

- Accuracy improvement of the population parameters estimators;
- Presence of each subpopulation in the sample, even those with smaller size;
- Possibility of excluding extreme samples, particularly those samples associated to larger segments.

The stratified sampling method involves dividing the population into mutually exclusive and exhaustive subpopulations denominated strata. In each stratum, a simple random sample without replacement is selected. Regarding the partition of the population, there were chosen attributes or variables with potential impact on electricity consumption. Consequently, for the LV level, the stratification variables used were activity sector, annual consumption and contracted power. For Special LV, stratification was based on the activity sector, the annual consumption level and the consumption's cycle.
Tables 1 and 2 display the population parameters, the sample sizes and the respective global and subpopulation maximum margins of error, considering those parameters.

*Table 1 – Standard low voltage customers' sample parameters.*

| Segment | Class | Population | | Annual Consumption in 2012 | | Sample | Margin of error |
|---|---|---|---|---|---|---|---|
| Client type | Domestics | 4.811.494 | 86,3% | 9.619.903.613 | 68,8% | 2.028 | 1,6% |
| | Hotelary | 31.839 | 0,6% | 482.266.077 | 3,4% | 661 | 8,0% |
| | Industry | 58.576 | 1,1% | 364.950.818 | 2,6% | 763 | 8,8% |
| | Others | 675.223 | 12,1% | 3.515.902.561 | 25,1% | 1.708 | 4,2% |
| Power class | <=3,45 kVA | 2.963.058 | 53,1% | 3.494.010.999 | 25,0% | 1.223 | 2,1% |
| | >3,45 and <=6,90 kVA | 1.779.743 | 31,9% | 4.387.633.427 | 31,4% | 1.029 | 2,2% |
| | =10,35 kVA | 392.707 | 7,0% | 1.410.400.482 | 10,1% | 702 | 3,8% |
| | =13,80 kVA | 154.815 | 2,8% | 863.504.768 | 6,2% | 659 | 5,2% |
| | >=17,25 kVA | 286.809 | 5,1% | 3.827.473.393 | 27,4% | 1.547 | 4,5% |
| Consumption class | Less than 500 kWh | 1.569.185 | 28,1% | 248.766.307 | 1,8% | 961 | 7,5% |
| | Between 500 and 1500 kWh | 1.339.771 | 24,0% | 1.312.014.493 | 9,4% | 723 | 3,3% |
| | Between 1500 and 3000 kWh | 1.383.831 | 24,8% | 3.001.168.156 | 21,5% | 793 | 2,0% |
| | Between 3000 and 7140 kWh | 980.157 | 17,6% | 4.241.856.445 | 30,3% | 1.101 | 2,0% |
| | Greater than 7140 kWh | 304.188 | 5,5% | 5.179.217.668 | 37,0% | 1.582 | 3,7% |
| **TOTAL** | | **5.577.132** | | **13.983.023.069** | | **5.160** | **1,58%** |

*Table 2 – Special low voltage customers' sample parameters.*

| Segment | Class | Population | | Annual Consumption in 2012 | | Sample | Margin of error |
|---|---|---|---|---|---|---|---|
| Client type | Domestics | 518 | 1,5% | 25.065.761 | 0,8% | 49 | 10,1% |
| | Hotelary | 2.999 | 9,0% | 334.582.947 | 10,3% | 336 | 5,7% |
| | Industry | 6.765 | 20,2% | 580.709.324 | 17,9% | 530 | 6,4% |
| | Others | 2.565 | 7,7% | 250.081.387 | 7,7% | 265 | 11,0% |
| | Services | 20.589 | 61,6% | 2.057.923.556 | 63,4% | 1.624 | 3,5% |
| Consumption class | Less than 7140 kWh | 2.567 | 7,7% | 7.057.480 | 0,2% | 521 | 6,9% |
| | Between 7140 and 50000 kWh | 11.246 | 33,6% | 314.511.377 | 9,7% | 581 | 3,5% |
| | Between 50000 and 100000 kWh | 8.743 | 26,1% | 633.248.631 | 19,5% | 474 | 1,8% |
| | Greater than 100000 kWh | 10.880 | 32,5% | 2.293.545.487 | 70,6% | 1.228 | 3,8% |
| Cycle | Daily cycle | 24.473 | 73,2% | 2.031.899.006 | 62,6% | 2.108 | 2,7% |
| | Weekly cycle | 8.963 | 26,8% | 1.216.463.969 | 37,4% | 696 | 5,7% |
| **TOTAL** | | **33.436** | | **3.248.362.975** | | **2.804** | **2,72%** |

In order to obtain the best compromise between the accuracy of results and the sample size, the sample's distribution through the various strata was made using a systematic algorithm. This algorithm was designed to ensure not only the sample's optimal distribution, but also its diversity on a number of features that were not explicitly considered in stratification.

## Sample's Maintenance

The desired consumption's analysis is based on a research methodology which equates to a longitudinal study: for a fixed randomly selected units' set, there are two or more measurements in time.

Besides, given that the clients' population is dynamic, the samples are subject to both loss of units, in this case due to the activation/inactivation of old/new clients, and profile changes. Subsequently, subpopulations are self-reconfigured in some way, and they require periodic assessment and rectification, in order to ensure the representativeness of the respective samples.

The update of the LV consumption's samples is made in an annual basis and comprises performing statistical analysis to identify the necessary adjustments to the samples, with the purpose of restoring the representativeness of the samples at the level of the correspondent populations' strata.

# BENEFITS

The sample's representativeness described in the previous chapter enables a sustainable construction of the 5 profiles determined by the regulator: three for standard LV (Table 3), one for SLV and another for LV PL. These profiles are responsible for shaping real or estimated consumptions.

*Table 3 – Standard LV clients' characteristics per profile class.*

| Class | Contracted Power | Anual Consumption |
|---|---|---|
| A | >13,8 kVA | - |
| B | =<13,8 kVA | >7.140 kWh |
| C | =<13,8 kVA | =<7.140 kWh |

The application of consumptions' profiles has several benefits for the players on the electricity wholesale market. Not only the Distribution System Operator, DSO, and the Transmission System Operator, TSO, but also the retailers and the clients are benefited from the application of these profiles. In the following 3 chapters there will be presented particular cases of the Portuguese electricity system in which the benefits of the application of consumptions' profiles are highlighted.

## The relevance of consumption profiles

Currently, the standard LV level clients' consumptions are locally and periodically read, which offers them a low resolution. The representative sample of this segment allows to build annual profiles based on real data, which cover seasonality of the summer and winter periods.

Furthermore, the main purpose of using LV profiles is estimate consumptions with the highest precision possible. This way, the DSO can, on the one hand, rise the clients' satisfaction level through the correct billing of their consumptions, and on the other hand, reduce the accounting distortion in the financial and energetic reports. For this reason, consumptions profiles are annually approved and published by the regulator (ERSE, in the Portuguese scenario).

## Electricity Wholesale Market

In order for the market to function properly, all the consumptions data, as well as all the Special Regime Productions data must be supplied to the market operator and to the retailers operating on it.

All the tension levels consumptions are gathered in a single file for each company operating in the market. Then that file is sent both to the retailer itself and to the market operator, who receives information concerning all the companies. These data are provided by EDP, daily, and each file contains information for every 15'.

The LV profiles play a crucial role in this field, as they

offer form to the LV and SLV meter readings. Moreover, the LV profiles make it possible for all market players to have 15 minutes load curves of their LV clients. Besides, the profiles also allow that the market operator has all the inputs necessary to make the balancing of the electricity system. In order for the system to be balanced, the amount of energy entering the distribution network has to match the amount of energy that is being consumed, plus the energy lost on the network itself, Figure 3.

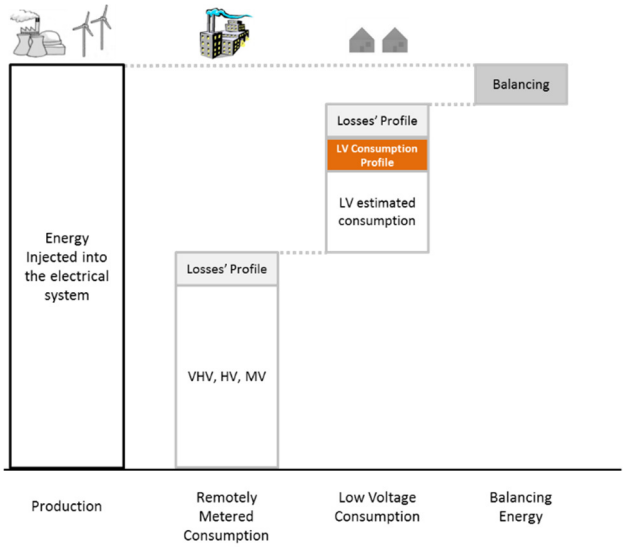


*Figure 3 – Energy balance of the electrical system.*

From the retailers perspective, the LV profiles are vital for the so called market operation. The LV profiles allow retailers to have a daily file with 15 minute's detail of the consumption of all of their clients. This aggregated file is used by retailers to make their forecasts and, consequently, the offers in the different market sessions, either the day-ahead market or the intraday market.
The accuracy of the forecasts made by retailers in the different market sessions is determinant to avoid the generally high costs of the denominated balancing mechanism, which in some cases is perceived as a penalty imposed by the system operator on the purchase price of balancing energy.
All in all, retailers rely heavily on the consumption data supplied by EDP Distribuição to minimize the effects of the balancing mechanism and, consequently, the losses on their financial income. Particularly, the effect of LV profiles in the final data is of utmost relevance, as they allow the 15 minute detail information for the LV level.

## Other Applications

In addition to the benefits above emphasised, the sample has also an important role in the energy balance analysis of the distribution network, particularly in Special Low Voltage and standard Low Voltage.
The data of the SLV's sample, when extrapolated to the population, has a higher resolution (upscaling) compared to the existing readings. Besides, this data is also useful as an input to the models that allow to understand both the dynamic behaviour and the consumption's forecast of the LV level. The consequent output of these models offers a guideline to the elaboration of the company's budget and investment plans.
The standard LV segment, due to its characteristics, has a strong estimated component in its consumption and therefore it is vital to monitor its development. Comparing the estimated consumption of the standard LV population with the sample's value extrapolated to the same universe, one may easily understand if in a given period the weight of the estimated component is above or below the actual standard LV's consumption. As an example, Figure 4 illustrates that the month of October 2014 has faced a consumption's over-estimation.

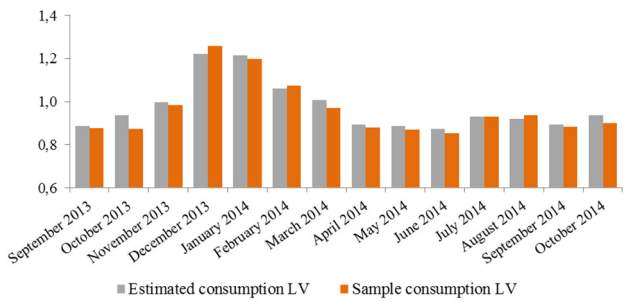


*Figure 4 – Comparison between estimated and extrapolated consumptions of the sample for the standard LV segment.*

## CONCLUSION

In conclusion, this paper highlighted the relevance of the representativeness of the LV sample in the construction of the LV profiles. Additionally, it was also mentioned the benefits of these profiles for the agents of the electrical sector. The main focus is that the profiles provide the retailers crucial information for their market operation.
Moreover, Table 3 demonstrated the three standard LV's profiles class. However, as one may note, these 3 classes are too broad and results of recent studies showed that it would be advantageous for the electrical sector to narrow those classes. These studies converge to a contracted power segmentation solution, as the one in Table 4.

*Table 4 – Possible segmentation for Standard LV clients' per contracted power.*

| Profile Class | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Contracted Power (kVA) | 1,15 | 2,3 | 3,45 | 4,6 | 5,75 | 6,9 | 10,35 | 13,8 | 17,25 | 20,7 | 27,6 | 34,5 | 41,4 |

A segmentation such as the one in Table 4 will be implemented in a very near future.
Nevertheless, in a not so far future, the electrical sector will walk towards the implementation of dynamic profiles. As one may have noted through the reading of

this paper, the profiles reported are annual and stationary. The future, though, is about to provide a challenging route in this area. As a matter of fact, the inclusion of variables such as the temperature and the consumptions of previous days will offer profiles a dynamism that is considered profitable to the electrical system as a whole. The introduction of these so-called dynamic profiles will challenge all agents of the wholesale electricity market, but the gains arising from the introduction of these profiles, namely their adaptable characteristic, will overcome the necessary changes that the sector will face. Such changes will also have a deep impact in the informatics systems, since the new adaptive algorithm will require more storage and processing capability from the machine itself. Within this field, big data will certainly provide some answers that are expected to clear the path to the massive introduction of dynamic profiles.

All in all, dynamic profiles are unquestionably giving the first steps towards their implementation, which is seen as an overall improvement for the electric sector as a whole.

## REFERENCES

[1] Vilares M.J., and Coelho P.S., 2011, *Satisfação e Lealdade do Cliente*, Escolar Editora, Lisboa, Portugal.