Energy Demand
Electricity

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ABSTRACT

This work aims to conceptualise the energy consumption of our work island as well as identify and discuss the corresponding demand sectors and how the consumption is affected by seasonality. It also proposes some demand side management measures, and attempts to predict their possible effects.

I. INTRODUCTION

The electrical network responsible for supplying energy in a region must be able to cover energy needs at any time. The island under study has 50 000 inhabitants who consume electricity in various sectors such as the domestic, non-domestic, agriculture, industry, street lighting and state buildings. Energy consumption in each of these sectors is time-variant, occasionally going through stages where the grid is required to supply more energy. However, it is predictable that energy consumption will be lower in the early hours of the day. The goals of this study are to estimate the energy consumption for this island in each sector and to idealise solutions that will allow its reduction. For this, several load diagrams will be constructed and analysed in order to determine which hours have lower/higher consumption and which sectors require the greatest energy supply. Through this diagram we can propose measures that help to ensure a more levelled-out energy consumption, thus helping to ensure efficient planning of energy production on the island, decreasing the overall required installed capacity and ensuring security of supply.

II. CONSUMPTION DATA

Through data provided by REN [1], we obtained the consumption profile for Portugal for 2018 — this year was chosen since 2020 data would be affected by the current pandemic and due to the fact that we noticed some missing data for the year 2019. Therefore we divided each value by the population and multiplied it by the 50 000 inhabitants of our island. In figure 1 we can analyse the load expected for the case study.

In order to obtain the total consumption, we

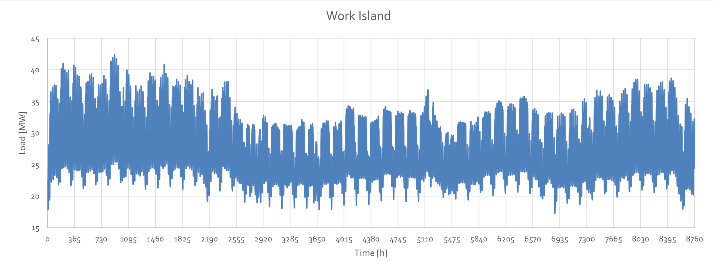

Figure 1

summed up all the values obtained and consequently divided the result by 0.25 - this is due to the fact that our data has been recorded every 15 minutes. By calculating the average power and knowing that the peak power is the maximum value registered, we were able to calculate the load factor ($LF = \frac{AveragePower}{PeakPower}$). The obtained values can be consulted in table I.

Energy (MWh)	248 000
Average Power (MW)	28.27
Peak Power (MW)	42.75
Load Factor	0.661

Table I

A. Seasonal Consumption

Analysis of standard weeks was approached as follows: data was gathered for the previously agreed-upon standard weeks, and separated into weekdays (corresponding to the average of the five weekdays), Saturday and Sunday. The resulting load profiles are shown on graphs 2-4.

According to the seasonal weekly load, it is possible to observe that in the Winter occurs the highest consumption of energy, followed by the Summer and lastly Spring. This is concordant to the higher energy needs for heating and cooling during Winter and Summer, respectively. Regarding the consumption on weekdays, Saturday and Sunday, it is noticeable that the consumption of energy on Sundays is lower than in the weekdays and Saturdays.

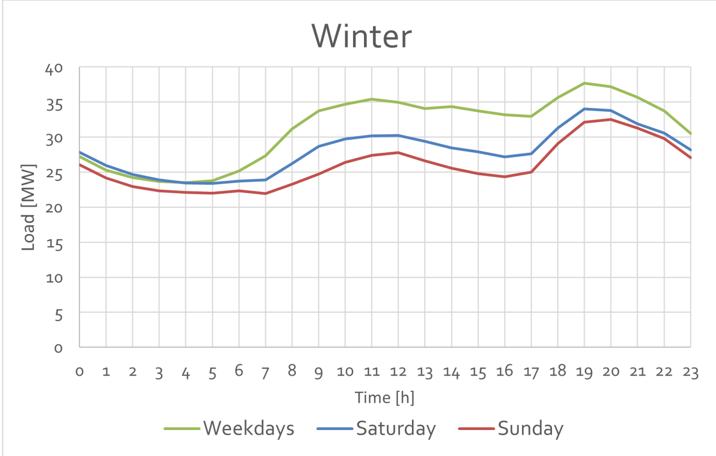

Figure 2

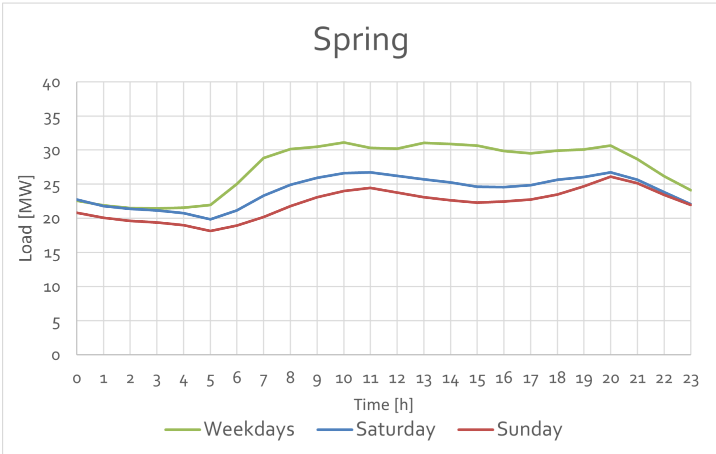

Figure 3

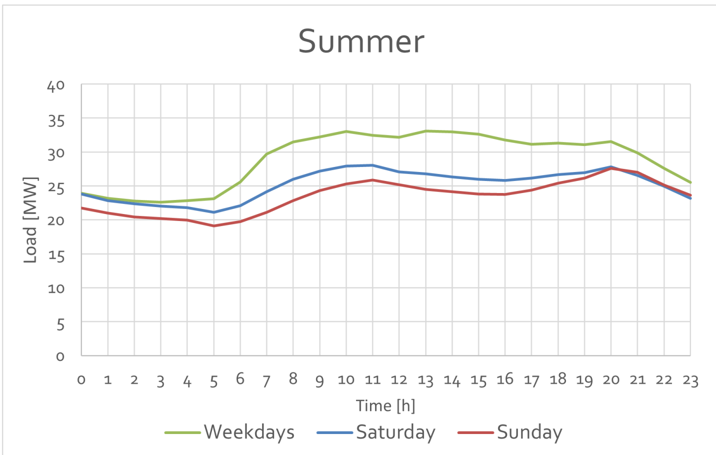

Figure 4

III. ELECTRICITY CONSUMPTION PER TYPE OF CONSUMPTION

We considered that the distribution between the different types of consumption (domestic, non-domestic, industry, agriculture, street lighting, and state buildings) in our island is the same as in Portugal. The data was collected from PORDATA [2] for the year 2017, as it is the latest data. The distribution is presented in figure 5.

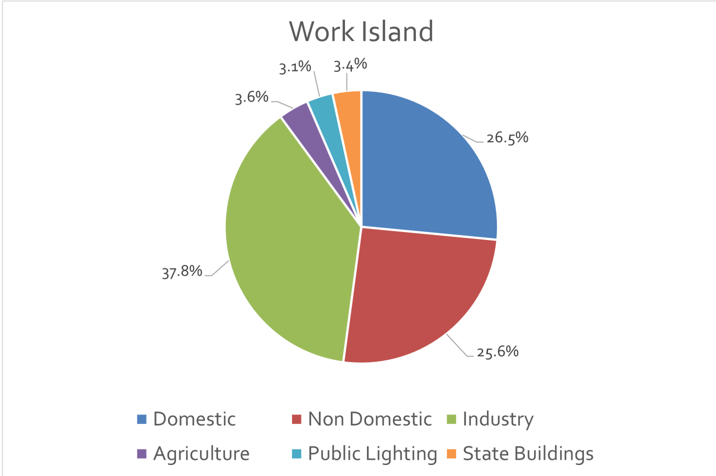

Figure 5

IV. LOAD PROFILE PER SECTOR

In order to determine the effect of possible demand side management measures, we first attempted to build load profiles for each sector. For some, we were able to find sources establishing what shape they should have. For others, we made assumptions based on real data and the rest were based entirely on assumptions. We built an average yearly diagram for each case, as opposed to seasonal diagrams for the sake of simplicity. However, this is not the most realistic approach.

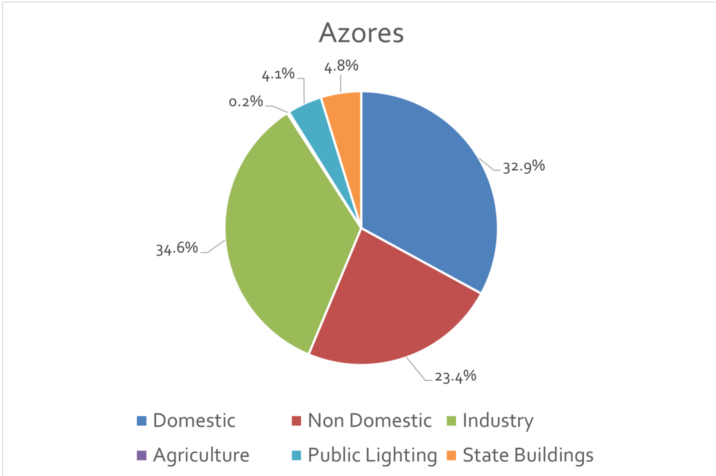

Figure 6

A. Yearly consumption per sector

Once again we resorted to PORDATA to acquire yearly electricity consumption data for each sector from 2017 [2], as it is the most recent available, more specifically for Continental Portugal, for the sake of consistency with previous values. We considered that average consumption per capita would be the same, and so adjusted for population size. Results are shown in table III in the annexes, which includes data for the Azores archipelago for comparison.

As previously mentioned, we did not use data for the Azores island because we were unable to find load diagrams for the archipelago, so we relied on data for Continental Portugal in order to obtain more consistent results. Nonetheless, a comparative analysis may be useful, as it is likely that our island would behave more similarly to Azores than to Continental Portugal. Comparing figs. 5 and 6 (fig. 5 is the same as for Continental Portugal), we may note that contributions from industry, non-domestic and agriculture are a smaller percentage of the total in Azores when compared to Continental Portugal, and agriculture in particular becomes negligible in Azores. This means that the contribution from domestic consumption will play a larger role. This observation should be taken into account when analysing the potential effect of demand side management measures.

Dividing the yearly consumption for each sector by 365, we got the average daily consumption, which will be used ahead.

B. Domestic and industrial sectors

One paper [3] shows a typical load diagram for the domestic and industrial sectors as a fraction of the maximum load for each sector, as shown in figure 7.

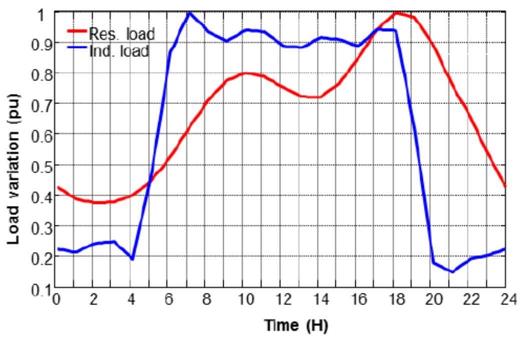

Figure 7

Through the total annual consumption for each sector, it was possible to determine the average energy consumption spent per day in each of the sectors through the following formula.

We first reproduced an approximate version of these diagrams, still as a fraction of maximum load ($f = \frac{load}{load_{max}}$). We then considered that:

$$\text{Average daily consumption} = \int_{day} load = \\ = \int_{day} f \times load_{max} = load_{max} \int_{day} f \quad (1)$$

Rearranging,

$$load_{max} = \frac{\text{Average daily consumption}}{\sum_{day} f \times \Delta t} \quad (2)$$

This way, we were able to calculate the average power for each sector and each hour, and build our load diagram with actual power values. These results suppose that we won't face a major decrease on our load if everyone in the island transition to a non-electric heat distribution system.

C. Public lighting

One report from EDP Distribuição [4] sets the usual hours for public lighting for each season, as can be seen on figure 10 in the annexes. For our load diagram, we considered the average of the four seasons. The power installed in lighting was calculated by dividing the energy consumed annually in public lighting by the hours of annual lighting.

D. Non-domestic, Agriculture and State Buildings

Having found no information on the average load profiles of these three sectors, we have had to "guesstimate" most of it. In any case, contributions from agriculture and state buildings are quite small and so will not play a very important role in demand side management. But the same cannot be said of the non-domestic sector. For this, the largest peak was considered to be near lunchtime, since both shops and restaurants are functioning, with a slightly smaller peak near dinnertime, and an overall high load factor for most of the day, due to the working hours of both shops and office buildings.

Agriculture was considered to be near-constant, as there seems to be no reason for these loads not to level out throughout the day. State buildings were considered to be similar to the non-domestic sector, but with more restricted working hours.

E. Estimated load profile per sector

Put together, these estimated load profile for each sector add up to the load profile seen on figure 8. This does not exactly match the load profile of the real data shown above, but it is a decent approximation and can serve as a visual guide in determining demand side management measures.

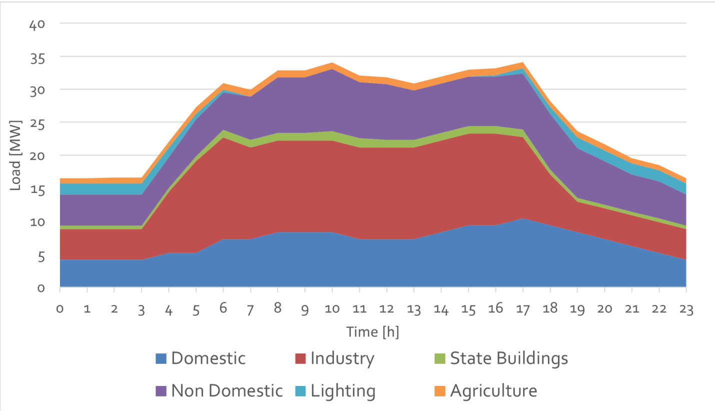

Figure 8

V. DEMAND SIDE MANAGEMENT

Demand side management measures can be split into two categories: measures which aim to reduce overall consumption, and measures which aim to shift some loads to different times, when demand is lower. The first include:

- Increasing the energy tariff [€/kWh], thus forcing users to lower their consumption in order to save money
- Reducing the power contracted by consumers, enforcing better management of energy usage.
- Daylight Saving Time, which is the practice of changing the clocks typically by 1 hour — setting them forward by one hour in Spring so that the sun sets at a later clock time, allowing for better use of sunlight and decreasing electricity usage. In Autumn, clocks are set back by 1 hour to return to standard time. This is not a measure we can implement that can help us reduce consumption, as it is already implemented in most countries. However, periodically, discussions seem to rise again on whether Daylight Saving should be abolished. The fact is that its effects seem to depend on many factors, including latitude, climate but also cultural habits of the population. In many cases, it tends to have a very small impact and in many cases even a negative one. The impact is further diminished as LED lighting gets more and more common, so we might indeed soon see the end of Daylight Saving. [5]

The application of the first two measures could be poorly received by the consumers. So, a more reasonable approach to decrease energy consumption can be conceptualised, in the form of load shifting measures. These include:

- Bi- or tri-hourly tariffs — classification of different time slots into different categories based on average demand, and attribution of different electricity prices accordingly. This encourages consumers to schedule non-time-sensitive loads on hours when demand is low, thus helping with “peak shaving” and “valley filling” that is, decreasing demand on peak hours and increasing demand on off-peak hours, levelling out consumption and helping it to fit energy production, thus avoiding large power surges and a large expense in energy production.
- Demand response — assigns an active role to the consumer, by shifting their consumption into off peak hours and/or reducing it during peak hours. This benefits both the consumer, since the rate of electricity during off peak hours is lower, resulting in lower energy

expenses, and the power grid by ensuring a more stable supply.

A. Shiftable load per sector and shiftable percentage of the total load

One paper [6] used Portugal as a case study in order to model the possible impacts of demand response. Among other things, this study claims that the domestic sector accounts for shiftable loads that represent 9% of the total load, non-domestic (tertiary sector) accounts for 6% and industry 5%. We considered that this data is more useful when presented in the form of percentage of each sector, so we used data from PORDATA to help us calculate this. For sectors not mentioned in this study, once more we had to do an educated guess: we considered public lighting to be not flexible at all, state buildings to be as flexible as the tertiary sector, and agriculture to be highly flexible — as mentioned above, there seems to be no good reason to have to water plants at a specific time rather than a couple of hours earlier or later.

Even if the assumptions made for these three sectors are not quite accurate, the impact from the three will not be very large on the full picture.

Results are shown on table II.

	% of the sector that is shiftable
Domestic	35.5
Non Domestic	23.1
Industry	13.1
Agriculture	80.0
Public Lighting	0.0
State Buildings	23.1

Table II

Using the values on this table, we calculated, via a weighted average, the percentage of total load that is deferrable for each hour of the day. Once again, we should really highlight that these are extremely optimistic numbers. We should look at these numbers as a ceiling for the shiftable loads - that is, reaching these numbers in reality would not be easy, and a more realistic approach, with non-extreme measures, is likely to result in much smaller numbers - likely below 10% at any given time. Nonetheless, our results can be seen on figure 9.

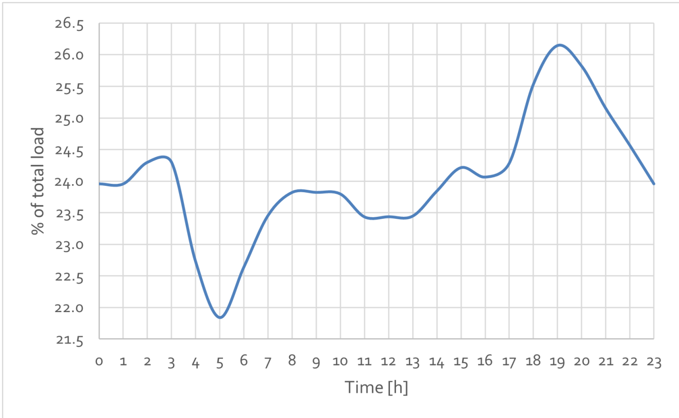

Figure 9

VI. CONCLUSION

The study allowed us to determine an annual energy consumption of 248 000 MWh, i.e., 4.95 MWh per inhabitant. Peak and average powers are 42.75 and 28.27 MW, respectively.

The season with the lowest energy consumption is Spring/Autumn. Sundays and the period of 0 to 6 a.m. present the lowest consumption for all seasons.

Main consumers are Industry and Domestic sectors with a percentage of use of 37.8% and 26.5%, respectively. The sector that represents the lowest percentage of energy consumption is Public Lighting (3.1%).

VII. ANNEXES

	Yearly electricity consumption [kWh]			
	Azores	Portugal	Island	% of total
Domestic	243 396 178	12 562 138 813	61 077 189	0.2633
Non-domestic	172 587 107	12 130 113 847	58 976 681	0.2542
Industry	255 535 508	17 906 713 219	87 062 540	0.3753
Agriculture	1 736 104	1 695 304 091	8 242 578	0.0355
Public lighting	30 354 274	1 465 936 392	7 127 391	0.0307
State buildings	35 314 186	1 613 938 149	7 846 976	0.0338
Total	738 923 357	47 716 459 410	231 997 692	1

Table III

Figure 10

[1] REN, "Perfis de consumo," (2018).

[2] PORDATA, "Consumo de energia eléctrica: total e por tipo de consumo," (2017).

[3] T. Tran-Quoc, X. Le Pivert, M. Saheli, and O. Beaude, 2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe) (2012), 10.1109/isgteurope.2012.6465704.

[4] EDP Distribuição, "Manual de iluminação pública," (2016).

[5] M. C. Brito, "O consumo de energia e a mudança na hora | Faculdade de Ciências da Universidade de Lisboa," (2021).

[6] J. Anjo, D. Neves, C. Silva, A. Shivakumar, and M. Howells, Energy **165**, 456–468 (2018).