Industrial demand side flexibility: the case of the metallurgy sector in Spain.

Erick Andres Dorado Galatoire
Electrical Engineering
University of Seville
Seville, Spain
edorado@us.es
0009-0004-8747-8142

Ángel Arcos Vargas
Industrial Organization and Business Management I
University of Seville
Seville, Spain
aarcos@us.es
0000-0002-2250-2533

José Luis Martínez Ramos
Electrical Engineering
University of Seville
Seville, Spain
camel@us.es
0000-0002-3946-9848

***Abstract*—This paper analyzes the current situation of the final electricity demand in Spain, with emphasis on large consumers, and estimates the metallurgy flexibility potential, whose load curtailment capacity could be incorporated in the adjustment services markets to improve the physical operation of the electricity grid. To estimate the metallurgy load curtailment capacity, we use public information from a study carried out in France with the participation of important industrial agents, and actual data from Spain about the annual energy balance, and the sectoral evolution of electricity demand by large consumers, for the period from January 2010 to December 2021. The results show that the final electricity demand by large consumers represents 44.43% of the total final electricity demand in Spain, and metallurgy has the largest weight with an average annual demand of 21 632 GWh, and an estimated average load curtailment capacity of 1.66 GW, 1.61 GW and 1.39 GW for 30 minutes, 2 hours and 8 hours of duration respectively. The incorporation of demand response in electricity markets allows meeting the need for flexibility of the electricity grid, and for metallurgy represents a diversification of its sources of income, which could become an important business opportunity.**

Keywords—electricity demand, flexibility resources, load curtailment capacity, metallurgy.

I. INTRODUCTION

The European Union (EU) is shifting its traditional power system towards a decentralized, digitized and decarbonized one, which requires, new and intelligent solutions to manage the increase of intermittent renewable generation and maintain the operation and security of the electricity system. To achieve these objectives, demand side flexibility (DSF), which is the ability of consumers to change their demand patterns based on external signals, is needed [1].

Some previous research papers quantify the European demand flexibility potential. Gils [2] performs a theoretical analysis including 30 different electricity consumers around all demand sectors, which can shift or curtail their loads by at least one hour and identifies a substantial demand response potential in all demand sectors at the European level (considers 45 countries), obtaining a minimum load reduction of 61 GW and a minimum load increase of 68 GW, available for each hour of the year.

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SmartEN and DNV [1] quantify the potential benefit of DSF by 2030 among the 27 EU members. Based on the inputs and outputs of their market model, they calculate a total of 164 GW of upward flexible power and 130 GW of downward flexible power. Additionally, they have calculated the amount of flexibility that can be activated in the wholesale market, obtaining 397 TWh and 340 TWh of upward and downward flexibility respectively.

Unlike these previous papers, the French Agency for Ecological Transition (ADEME) [3] has developed a report that estimates the industrial and commercial demand response potential of the French metropolitan area, both qualitatively and quantitatively. The most relevant of this report are the case studies were carried out through specific interviews to the industrial and commercial agents involved (30 interviews conducted in total).

The objectives of this work are multiple: to analyze the final electricity demand behavior of the different Spanish economic sectors; to develop an estimate of the metallurgy flexibility potential; and to determine the amount of energy that could be reduced in the adjustment services markets with the incorporation of demand response by metallurgy sector.

The document is structured as follows. Section II provides some relevant information about the current situation of final electricity demand in Spain. Section III describes the data and methodology to calculate the electricity demand by large consumers, and to estimate the metallurgy flexibility potential. Section IV presents the results achieved. Finally, Section V offers the main conclusions and future lines of research.

II. SPANISH ELECTRICITY DEMAND. CURRENT SITUATION

Both data, annual energy balance and sectoral evolution of electricity demand by large consumers, have different taxonomies, so we will homogenize them to make consistency with other international reports.

The annual energy balance prepared by the Ministry for the Ecological Transition and Demographic Challenge (MITERD) is a statistical operation that aims to provide reliable information about the energy situation in Spain [4].

After processing MITERD data from 2010 to 2021[5], it is obtained that the average annual final demand of electricity is 234 143.9 GWh, of which primary sector represents 2.88%,

secondary sector represents 31.19%, tertiary sector represents 34.82%, and residential sector represents the remaining 31.11%. Metallurgy subsector (including ferrous and nonferrous metals), corresponding to secondary (industrial) sector, has the largest weight in the annual final demand of electricity, averaging 22 156.5 GWh, which corresponds to 9.46% of the total final demand of electricity for the period analyzed.

In addition, according to data from the Spanish system operator, Red Eléctrica España (REE), the energy generated at generation side busbars from 2010 to 2021 was 263 875.2 GWh as annual average; therefore, there have been losses of 29 731.3 GWh in the electricity grid, equivalent to 11.27% of the total energy generated.

Complementing the above information, the system operator REE periodically publishes the sectoral evolution of electricity demand by large consumers, under the name of Electricity Network Index (IRE). The data analyzed refer to consumers with type 1 and 2 measurements, which according to the unified regulation of measurements points of the electricity system [6] are: type 1 measurement points correspond to costumers whose contracted power is equal to or greater than 10 MW; type 2 measurement points correspond to costumers whose contracted power is equal to or greater than 450 kW.

III. Materials and Methodology

A. Electricity demand by large consumers

The IRE indicator shows the evolution of electricity demand by medium and large consumers. The system operator REE receives these measurements from distribution system operators (DSO), but they are not final until 10 months have elapsed [7]. To minimize the impact on the consolidation of information, REE selects a sample of consumers for each sector defined with their respective National Classification of Economic Activities (CNAE) code, in such a way as to ensure the representativeness of the sample compared to the total universe for definitive measurements [8].

The analysis developed uses the corrected data of the IRE indicator [9] from January 2010 to December 2021. These data have a monthly resolution and are expressed as a percentage, showing the variation with respect to the results of the base year, which corresponds to 2010 as it is the first full year since REE has stable measurements. To determine the behavior of the final electricity demand by large consumers, it is necessary to know the groupings used in the IRE indicator [10]: there are 3 main sectors (industry, services and other activities), in turn, each sector has different subsectors (e.g. consumer goods, intermediate goods and capital goods for the industrial sector), and finally, each subsector has different sub-subsectors that are defined with their CNAE code. Table I shows all the sectors and subsectors of these activities with their respective percentage share in electricity demand for 2010 (base year of the IRE indicator).

To transform the above percentages of participation in terms of energy, the final metered demand for 2012 is used, which was 101 777.0 GWh [8]. According to the information published in the IRE indicator, the year 2012 had a total demand by large consumers equal to 99.01% with respect to the base year, therefore, doing the inverse exercise, the total energy consumed in 2010 is calculated, which would be equal to 102 791.9 GWh. As a next step, the percentage share of each sector, subsector and sub-subsector (detailed in Table I) is used to calculate the energy consumed by each of them in 2010. Subsequently, the monthly percentage variation of the database until December 2021 is applied.

After a preliminary analysis, it is observed that the sum of the sub-subsectors does not coincide with the total of its corresponding subsector, the sum of the subsectors does not coincide with the total of its corresponding sector, and the sum of the sectors does not coincide with the total electricity consumed by large consumers.

To correct this situation, firstly, the total electricity consumed by large consumers is take as a valid and accurate measure. As a next step, the results of each sector are adjusted proportionally in such a way that the sum equals the total demand by large consumers. Subsequently, the results of each subsector are adjusted proportionally in such a way that the sum equals the total demand of each corrected sector respectively. Finally, the results of each sub-subsectors are adjusted proportionally in such a way that the sum equals the total demand of each corrected subsector respectively.

B. Metallurgy flexibility potential estimation

In Table I, the industrial sector has the largest share in the final electricity demand with 68.6%. In turn, the intermediate goods subsector has the largest weight within the industrial sector with 51.8%, and the metallurgy sub-subsector accounts for almost half of this subsector, with a share of 23.71% among all large consumers.

Metallurgy is the technique of obtaining and processing metals from metallic minerals. In the case of Spain, this economic activity is classified as CNAE 24 and includes the following activities [11]: manufacture of basic iron, steel and ferroalloy products; manufacture of tubes, pipes, hollow sections and steel accessories; manufacture of other products by primary transformation of steel; production of precious metals and other nonferrous metals (aluminum, lead, zinc, tin, copper); smelting of metals.

The study carried out by ADEME [3] indicates that metallurgy is a highly concentrated sector in France, with its electricity demand being around 18 TWh (10.9 TWh for ferrous metals, and 7.2 TWh for nonferrous metals) and an approximate contracted power of 3.5 GW for 2013. Additionally, from the specific interviews conducted with each of the participants from the metallurgy sector (three ferrous metals companies, one aluminum company and one zinc company), it was determined that their electricity demand is evenly distributed among thermal, electrolysis and motor uses.

TABLE I.
PERCENTAGE SHARE OF FINAL ELECTRICITY DEMAND. 2010.

Large consumers	***(%)***
Industrial sector	68.6
Consumer goods – CNAE 10/11/12/14/15/18/21/21/32	*9.0*
Intermediate goods	*51.8*
Metallurgy – CNAE 24	23.71
Rest – CNAE 13 16 17 19 20 22 23	28.09
Capital goods – CNAE 25/26/27/28/29/30/33	*7.8*
Services sector	23.3
Other activities	8.2
TOTAL	100

Source: REE [10]

Table II summarizes the participation share of these activities, both for the ferrous and nonferrous metals sectors, and Table III shows the average installed power in each demand type and the estimate load curtailment capacity for 30 minutes, 2 hours and 8 hours respectively.

The model developed in this document uses the information from ADEME study in the following way: as a first step, the participation share of electricity demand in metallurgy activities are applied to the electricity consumed by ferrous and nonferrous metals industries in Spain; as a second step, the average installed power in each demand type is calculated based on the operating hours; and as a third step, the percentages of the estimate load curtailment capacity for 30 minutes, 2 hours and 8 hours presented in Table III are applied to the average installed power calculated in the previous step for each demand type.

TABLE II.
PARTICIPATION SHARE OF ELECTRICITY DEMAND IN METALLURGY ACTIVITIES. FRANCE, 2013.

Metallurgy	***Ferrous (%)***	***Nonferrous (%)***
Thermal	53.21	-
Electrolysis	-	70.83
Motors	44.58	26.96
Others (air conditioning, lighting)	2.21	2.21
TOTAL	100	100

Source: ADEME [3]

TABLE III.
INSTALLED POWER AND PERCENTAGES OF THE ESTIMATE LOAD CURTAILMENT CAPACITY IN EACH DEMAND TYPE. FRANCE, 2013.

Type	***P_i (GW)***	***Curtail 30' (GW)***	***Curtail 2h (GW)***	***Curtail 8h (GW)***
Thermal	1.29	0.84 (65%)	0.84 (65%)	0.84 (65%)
Motors	1.45	0.32 (22%)	0.32 (22%)	0.29 (20%)
Electrolysis	0.64	0.22 (34%)	0.19 (30%)	0.04 (6%)
Others	0.13	0.02 (15%)	0.01 (8%)	0.01 (8%)
TOTAL	3.50	1.40	1.36	1.18

Source: ADEME [3]

IV. ANALYSIS AND RESULTS

A. *Electricity demand by large consumers*

This subsection analyzes the results obtained from the final electricity demand by large consumers in Spain. Firstly, we regroup the sub-subsectors presented in the IRE indicator report (from the other activities sector, the extractive and construction sub-subsectors are extracted and added to the industrial sector), to make a comparison with MITERD data. Table IV shows the behavior of electricity demand by large consumers in Spain, from 2010 to 2021. It is obtained that the average annual final electricity demand by large consumers is 104 039.45 GWh, of which the industrial sector represents 69.57%, the services sector represents 23.96%, and the other activities sector represents the remaining 6.47%. The final electricity demand by large consumers represents 44.43% of the total final electricity demand in Spain.

Up to this point, it can be observed that the IRE indicator groups in the metallurgy sub-subsector both the ferrous and nonferrous metals industries; however, the MITERD data have these two activities separated, with the denomination of "iron and steel" and "nonferrous metals" respectively. To describe the evolution of these two demand sub-subsectors in terms of the total demand value recorded in the IRE indicator, we applied a factor to proportionally relate it to the total demand that appear in MITERD data for each one. See Fig. 1.

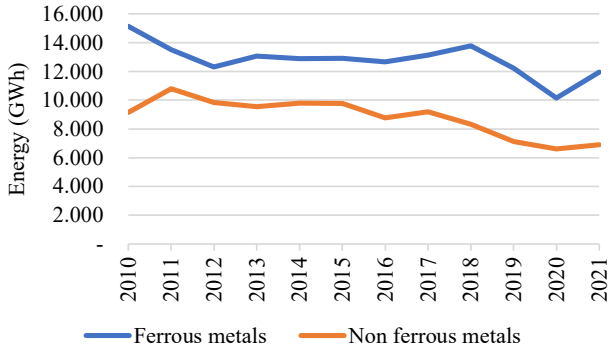

Fig. 1. Electricity demand. Ferrous and nonferrous metals. Spain.

TABLE IV. ELECTRICITY DEMAND BEHAVIOR BY LARGE CONSUMERS IN SPAIN. 2010-2021.

Large consumers (GWh)	***2010***	***2010 to 2021***			***2021***
		Mean	***Min***	***Max***	
Industrial sector	73 246.93	72 378.21	66 910.50	75 646.03	70 538.05
Metallurgy – CNAE 24	*24 299.85*	*21 632.32*	*16 759.18*	*25 951.82*	*18 856.79*
Chemical and petrochemical – CNAE 19/20	*9 715.84*	*10 999.74*	*9 715.84*	*12 166.38*	*9 717.69*
Nonmetallic minerals – CNAE 23	*6 702.70*	*6 835.92*	*5 828.77*	*7 968.44*	*7 968.44*
Transport equipment – CNAE 29	*3 321.30*	*3 418.81*	*2 822.16*	*3 746.80*	*2 822.16*
Machinery – CNAE 25/26/27/28/30/33	*4 680.48*	*4 772.51*	*4 342.35*	*5 200.02*	*4 798.58*
Extractive industries – CNAE 05/06/07/08/09	*1 743.97*	*2 015.91*	*1 743.97*	*2 186.36*	*2 168.32*
Food, beverages and tobacco – CNAE 10/11/12	*7 289.60*	*8 071.58*	*7 289.60*	*9 244.17*	*9 244.17*
Pulp, paper and graphic arts – CNAE 17/18	*6 038.07*	*5 653.64*	*5 304.11*	*6 038.07*	*5 501.70*
Wood and wood products – CNAE 16/31	*1 415.05*	*1 423.99*	*1 231.90*	*1 687.82*	*1 687.82*
Construction – CNAE 41/42/43	*1 128.46*	*1 023.90*	*905.17*	*1 128.46*	*943.50*
Textile and leather products – CNAE 13/14/15	*1 045.84*	*1 012.45*	*895.67*	*1 078.73*	*993.60*
Not elsewhere specified – CNAE 21/22/32	*5 865.78*	*5 517.44*	*5 042.07*	*5 887.72*	*5 835.28*
Services sector	24 005.30	24 931.44	23 186.50	26 049.79	24 791.87
Other activities – CNAE 01/02/03 35/36/37/38/39	5 539.68	6 729.80	5 539.68	7 601.85	7 420.43
Total electricity demand by large consumers	**102 791.90**	**104 039.45**	**97 349.07**	**108 687.86**	**102 750.35**
Total final electricity demand in Spain	244 802.20	234 143.90	219 654.60	244 802.20	227 880.50
Participation share by large consumers on total demand (%)	*41.99*	*44.43*	*44.32*	*44.40*	*45.09*

B. Metallurgy flexibility potential estimation

This subsection analyzes the results obtained from the metallurgy flexibility potential estimation in Spain. An average load curtailment capacity of 1.66 GW, 1.61 GW and 1.39 GW have been calculated for 30 minutes, 2 hours and 8 hours of duration respectively, observing that processes involving thermal and motor demands can maintain their load curtailment capacity from 30 minutes to 8 hours, however, electrolysis and air conditioning demands see this load curtailment capacity slightly reduced at 2 hours and practically null for 8 hours. Fig. 2 shows the evolution of these variables, with monthly resolution, from January 2010 to December 2021.

To evaluate the results obtained, the activation delay of the load curtailment capacity in metallurgy demand, which is usually one and a half hours, must be considered [3]. Therefore, the participation of these flexibility resources is ruled out for the balancing markets such as secondary regulation, tertiary regulation, and deviation management, and for the real-time security technical constraints market; being more propitious its activation in the daily security technical constraints market.

In Operating Procedure 3.2 for Technical Constraints [12], bid offers of demand response units is not considered. Fig. 3 shows the upward energy acquired in phase I of the daily security technical constraints market with monthly resolution, from January 2015 to December 2021 [13].

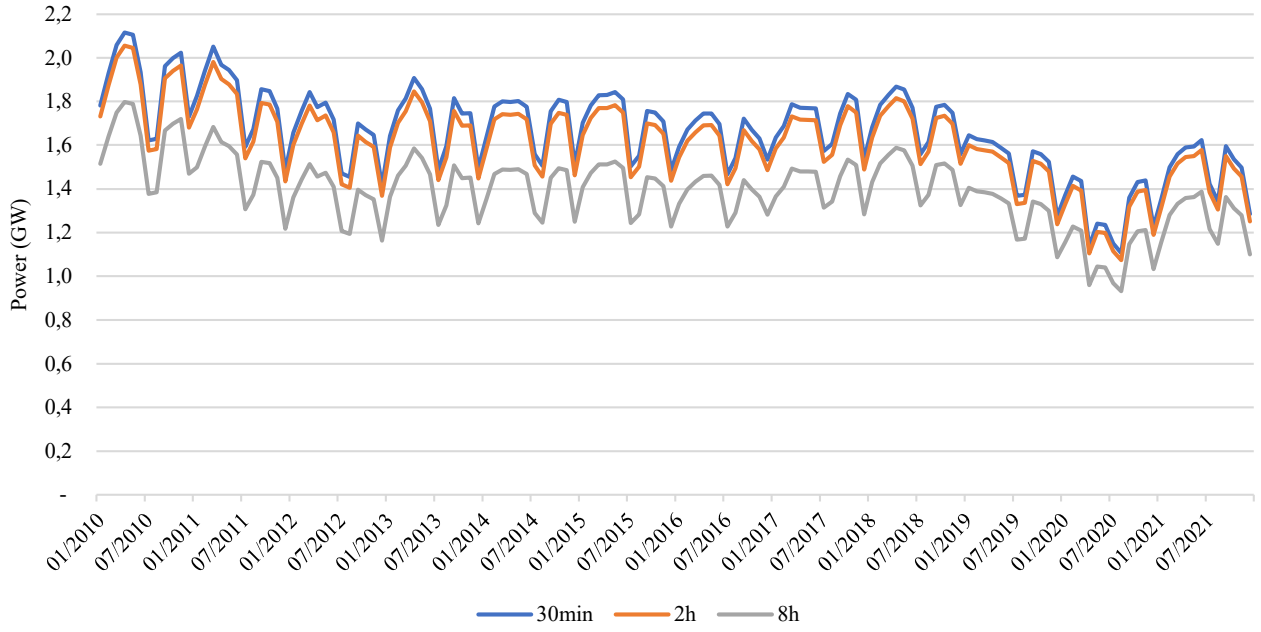

Fig. 2. Metallurgy load curtailment capacity estimation. Spain. 2010-2021.

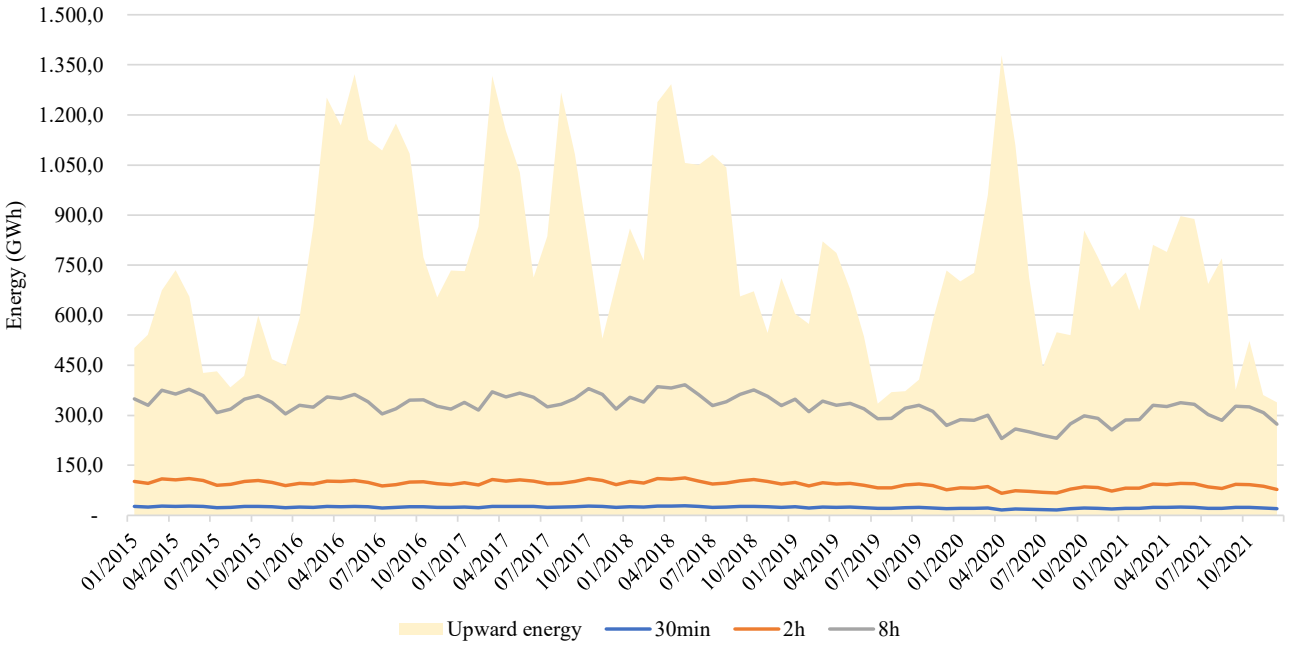

Fig. 3. Upward energy phase I of the daily security technical constraints market and avoid energy by metallurgy load curtailment capacity. Spain. 2010-2021.

This variable is compared with the energy that could have been avoided with the application of the metallurgy load curtailment capacity, for a duration of 30 minutes, 2 hours and 8 hours respectively. The application of this load curtailment capacity is done once a day, due to the time required for its activation and to not stop the production process repeatedly.

According to the public data of the System Operator Information System (ESIOS) [14], the costs for upward energy in phase I of the daily security technical constraints market, from 2015 to 2021, were 872.69 M€ in annual average, 553.90 M€ the minimum in 2019, and 1 056.02 M€ the maximum in 2021. The costs for downward energy in phase II of the daily security technical constraints market, from 2015 to 2021, were 419.95 M€ in annual average, 271.86 M€ the minimum in 2015, and 617.37 M€ the maximum in 2021. Given that the metallurgy load curtailment capacity can replace the need to acquire upward energy from the generation units in phase I and avoid the downward energy balance in phase II, the costs observed in this market represents an interesting business opportunity.

V. Conclusions

The final electricity demand by large consumers, from January 2010 to December 2021, represents 44.43% of the total final electricity demand in Spain, situation that gives signals to encourage this demand sector for the development of flexibility resources to improve the physical operation of the electricity grid.

Metallurgy has the largest weight in final electricity demand, averaging 21 632 GWh/y, which corresponds to 20.79% of the total demand by large consumers, from January 2010 to December 2021.

The calculation of metallurgy load curtailment capacity is based on the study carried out in France with the participation of major industrial players and is transposed to the Spanish case using actual data about annual energy balance, and the sectoral evolution of electricity demand in large Spanish consumers.

The previous time required for the activation of the metallurgy load curtailment capacity is usually one and a half hours, which would rule out its participation for the balancing markets such as secondary regulation, tertiary regulation, and deviation management, and for the real-time security technical constraints market.

The ability to curtail demand by metallurgy is more appropriate for the daily security technical constraints market, replacing the need to acquire upward energy from generation units and, consequently, obtaining benefits for the Spanish electricity system by increasing the number of participants in this market and promoting greater competition.

The costs of the solutions in the daily security technical constraints market, for upward energy in phase I and downward energy in phase II, were 872.69 M€ and 419.95 M€ respectively, on annual average from 2015 to 2021; these costs represent an important business opportunity to implement load curtailment capacity by the metallurgy and an interesting possibility of diversification to its sources of income.

For future research, the generation units that participate the most in the daily security technical constraints market can be identified, to know their geographic location and determine which companies in the Spanish metallurgical industry have a similar location to be able to apply their potential load curtailment capacity in this market.

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