Quantifying the Costs of Demand Response for Industrial Businesses

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Abstract—**This paper quantifies the costs that occur when implementing and using Demand Response (DR) in industrial businesses. Firstly, the three cost categories investments, fixed and variable costs are derived from the literature. Costs of DR with process technologies can be quantified within the literature review. Secondly, findings from 16 semi-structured interviews allow quantifying the costs of DR with cross-sectional technologies. In summary, the paper shows that in terms of process technologies, variable opportunity costs are the most important type of cost, while investments and annual fixed costs are negligible. The opposite applies for cross-sectional technologies. Investments and annual fixed costs are of relevance. Variable costs are rather low. The results of a profitability calculation show that Demand Response can be economical.**

Keywords—Demand Response; Demand Side Management; cost assessment; economic analysis; profitability calculation; cross-sectional technologies

I. INTRODUCTION

The European energy economy is currently undergoing profound structural changes. The Kyoto targets and the European Union's "20-20-20-goals" in particular have a major impact on both energy supply and demand. Until 2020 the European Union has committed to reducing the emissions of greenhouse gases by 20 % relative to 1990. Furthermore, 20 % of energy consumption shall be generated from renewable energy sources. In addition, the European Union is aiming at an increase in energy efficiency by 20 % [1].

One attractive measure that can help to achieve these targets is Demand Response. DR can be described as a short-term change of electrical loads due to a contractual power reserve or as a response to market price signals. This load change can be necessary as a consequence of unscheduled, irregular and extreme events in the energy market, [2] such as power plant outages or too much electricity feed-in from renewable sources. The quantity of research done on the potential of Demand Response has increased drastically over the last few years. However, only few publications have dealt with the costs of Demand Response.

The paper starts with a literature review, followed by a presentation of methodology and questionnaire design. In the end the findings are summarized and analyzed. The demonstrated research project is a part of FfE's project "Merit Order for Energy Storage Systems in 2030" [3].

II. LITERATURE REVIEW

The following paragraphs present the relevant literature.

A. Influencing the consumer load-curve

The literature mentions several measures of influencing the consumer load-curve. The most important actions of changing the shape of the consumer load-curve by means of Demand Response are Peak Clipping, Load Shifting and Valley Filling. Peak Clipping aims at reducing the customer's demand in times of high loads or prices. Load Shifting is the shifting of electricity consumption from high-load or high-price hours to low-load or low-price hours. Valley Filling can be described as the opposite of Peak Clipping, as it increases the electricity consumption during off-peak hours for exploiting low electricity prices [4].

B. Industry sectors for Demand Response

Many publications follow a top-down approach for estimating the technological potential of Demand Response. The literature states that two figures need to be considered when trying to identify attractive sectors for Demand Response: electricity consumption and electricity intensity. The electricity consumption measures the cumulative consumption of electricity in MWh per year. The relation between electricity consumption and the gross value added in Euros (EUR) can be described as electricity intensity. The ratio measures how sensitive a business is about electricity price changes. The higher the ratio, the higher the sensitivity of the production process towards electricity [6].

Fig. 1 visualizes the two figures just described for the ten largest industrial sectors in terms of electricity consumption in Germany in the year 2010. The overall electricity consumption of the respective sectors represents nearly 90 % of the total German industrial electricity consumption of 229 TWh in 2010. The sectors "chemicals", "metal working" and "paper and cardboard" show the highest electricity consumption, totaling 113 TWh. In addition to this, the sectors just mentioned feature the highest electricity intensity. In conclusion, the top-down-approach reveals a high potential for Demand Response in the three sectors described.

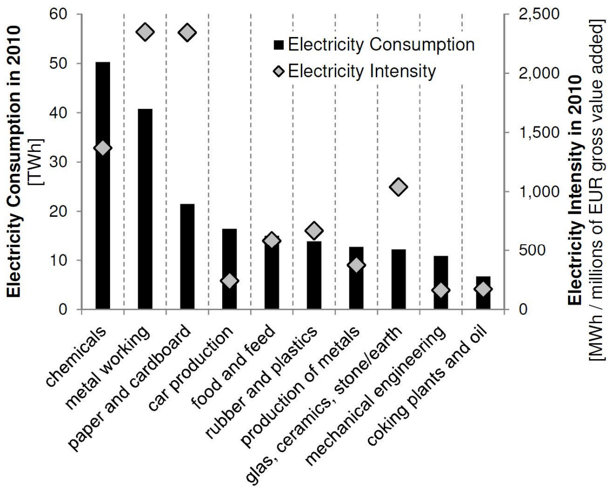

Fig. 1: Energy consumption and energy intensity by sector in Germany [7], [8]

C. Technologies for Demand Response

Generally, this paper differentiates between cross-sectional and process technologies. The term "cross-sectional technologies" describes loads that occur in the majority of industrial businesses, regardless of which sector it is in. In contrast, process technologies are specific to certain industry sectors or production processes. Table I summarizes the technologies that are potentially attractive for Demand Response from the literature. In terms of process technologies, the reviewed literature mainly focuses on the potentials of energy intensive industrial processes from the sectors listed above. Within the brackets, the sector of the particular process technology is listed.

When assessing suitable technologies for Demand Response, several technological restrictions have to be taken into account. In [6] six parameters that help to evaluate the potential of a technology for Demand Response are mentioned. The load-changing potential measures the maximum changeable power in MW. The duration of load-changing specifies the time a technology can provide load-changing capability. The maximum amount of load-changing periods per year has to be taken into account as well. Also important is how long the minimal time period between two Demand Response calls has to be. Furthermore, the shut-down and run-up speed needs to be considered. The last important parameter is the size of storage facilities that help to operate loads in a flexible way.

TABLE I. CROSS-SECTIONAL AND PROCESS TECHNOLOGIES FOR DEMAND RESPONSE [5], [6], [9], [10], [11]

Cross-sectional technologies	*Process technologies*
• Space and process heating • Air conditioning and process cooling • Compressed air • Ventilation • Electric lighting • Materials handling • Pumps • IT (Servers) • On-site generation systems	• Air fractionation (chemicals) • Chloralkali electrolysis (chemicals) • Aluminium electrolysis (metal working) • Copper and zinc electrolysis (metal working) • Mechanical pulp preparation (paper) • Electric arc furnace (metal working) • Cement mills (stone/earth) • Wastewater treatment (water management)

D. Marketing Demand Response

Demand Response capacity can be integrated in the markets in different ways – this paper focuses on the German markets. On the one hand electricity exchanges are attractive for offering Demand Response; on the other hand Demand Response load can be placed in the markets for balancing power [12]. Another possible way of selling Demand Response capacities is compensating deviations from the schedules of balancing accounts [10].

Electricity exchanges can be subdivided into derivatives and spot markets. Due to their long-term planning horizon, derivatives markets are not attractive for Demand Response. In contrast, spot markets are suitable for selling Demand Response capacities. Spot markets in turn consist of two different markets. Electricity is traded 12-36 hours ahead of delivery in the form of hourly contracts at Day Ahead markets. At Intraday markets, 1 hour and 15 minute contracts can be traded until 45 minutes before delivery.

When marketing Demand Response in these two markets, the Demand Response provider has the opportunity to generate profits by taking advantage of price-spreads between different hours of the day. In practice this marketing strategy would be suitable for Load Shifting. In reality, however, Intraday trading is difficult to implement. Matching the Demand Response capacities with Intraday trading in order to compensate schedule deviations is a major challenge for industrial businesses, in particular due to a lack of appropriate IT systems.

Balancing power is used by the Transmissions System Operators (TSO) for stabilizing the power frequency of the grid at the desired level of 50 Hertz. TSOs thus utilize positive and negative balancing power. Positive balancing power helps stabilize the power frequency by increasing power generation or reducing power consumption. Negative balancing power works in precisely the opposite way: consumption is increased or generation capacities are shut down [13]. Balancing power is traded in three qualities: primary, secondary and tertiary frequency control. Technically the three types differ mainly in terms of activation time and in the process of an actual use of balancing power.

For Demand Response the markets for secondary and tertiary frequency control are of economic interest. Primary reserve would be of commercial interest as well, but the prequalification conditions are practically unachievable. In terms of Demand Response, negative balancing power could be provided by starting up technologies in hours of low demand and high renewable feed-in. On the other side, positive balancing power can be offered by throttling or shutting down unnecessary plants in times of high demand and low power generation.

III. Costs Of Demand response

This chapter deals with the costs that occur when implementing and using Demand Response. In general, costs arise for two parties: the industrial business that delivers Demand Response and the system operator or another third party that creates the infrastructure required to launch Demand Response [14]. Due to the focus of this paper, costs for system operators or other Demand Response program operators will not be taken into consideration any further. Table II summarizes the findings with regard to the different types of costs from the literature. The costs are subdivided into investments, fixed and variable costs. These will be discussed in detail below.

A. Investments

For enabling suitable plants to deliver Demand Response capacity, several investments have to be made. The business has to install measurement and control technologies. Furthermore, software has to be set up in order to enable load controlling in a centralized way. Moreover, investments in communication technology are required [5], [10]. It has to be added that investments for measurement, control and software technologies might be dependent on the type of Demand Response service offered (e.g. balancing power, Intraday trading, etc.). A Demand Response strategy has to be developed which causes investments as well. This strategy evaluates which technologies are suitable, in the context of a cost-benefit-analysis, for participating in Demand Response programs, and under which circumstances [14]. Where appropriate, investments occur as a consequence of purchasing storages that enable the delivery of Demand Response.

Paulus and Borggrefe [6] state that investments regarding process technologies are very low for industrial businesses. This is due to the fact that measurement, control, software and communication technologies are often already in use in many businesses. For the same reason, in [10] investment costs are estimated to be 1 EUR/kW.

B. Fixed costs

Fixed costs occur regularly and independently from actual Demand Response activations. In [10] fixed costs are subdivided into information, transaction and control costs. Information costs result from gathering information for consolidating decisions. Transaction costs are incurred by communication and control costs arise due to the planning and controlling of processes involved in Demand Response. These three types of fixed costs therefore mainly cause costs in terms of personnel. In addition, fixed costs may result from data exchange between the business and a Demand Response Aggregator [6].

It is assumed that in practice, fixed costs for Demand Response are negligible in terms of process technologies. One reason for this is that communication infrastructure and a manned control room are already available within most businesses [6].

TABLE II. Types of costs for implementing and operating Demand Response [5], [6], [10], [14]

Investments	*Fixed costs*	*Variable costs*
• Measurement and control technology • Software • Communications technology • Demand Response strategy • Storages	• Information costs • Transaction costs • Control costs	• Opportunity costs (value of lost load) • Storage costs • Personnel costs • Maintenance costs • Inconvience costs • Efficiency losses • Fuel costs

C. Variable costs

Should an actual Demand Response activation take place, variable costs need to be considered. The U.S. Department of Energy describes the variable costs as opportunity costs [14]. It can be assumed that opportunity costs mainly occur for process technologies because cross-sectional technologies do not necessarily have a direct impact on the output of the business. Reference [10] differentiates between opportunity costs resulting from Peak Shaving events and opportunity costs as a consequence of Load Shifting. Peak Shaving of process technologies may have an impact on the output of the production process, and thus the opportunity costs can also be described as "value of lost load". A good measure for the "value of lost load" is the gross value added. In contrast, Load Shifting only causes opportunity costs resulting from the time shift of the process. The lost output can be produced later and thus does not have to be considered. However, Load Shifting causes storage costs resulting from the actual use of the storage as well as losses that arise throughout the storage period.

When curtailing loads, personnel costs are of relevance due to changed workflows that may for instance make overtime payments necessary. Moreover, it is possible that Demand Response activations cause additional maintenance costs for the affected plants. Also, costs of inconvenience and efficiency losses due to partial load operation may arise. Finally, fuel costs may be of relevance for the case that on-site generation units are used to provide Demand Response capacity [5], [14].

IV. Methodology

This section describes the methodology of the survey that was conducted.

A. Research approach and scope

As opposed to the top-down approach which was used in the literature, the survey is based on a bottom-up approach. This means that a questionnaire is designed to collect data from industrial businesses. This approach seems to be appropriate due to the fact that electricity consumption and intensity do not appear to be the only important measures for identifying suitable industrial sectors. Cross-sectional technologies in particular do not necessarily have a strong impact on the electricity intensity and the overall electricity consumption of an industrial business. Focusing on electricity-intensive companies would thus mean excluding businesses that do not use electricity-intensive process technologies but instead have a potential in the field of cross-sectional technologies. For these reasons the scope of a bottom up approach seems to be more broad and therefore more suitable to the aims of the survey.

Firstly, a draft questionnaire was developed. This was used as the basis for discussion with experts who have already conducted research in the field of Demand Response. Furthermore, selected businesses were asked to fill out the draft questionnaire and report questions that are not clearly understandable. By implementing the notes of the experts and businesses into the questionnaire, a final version was created. The questionnaire focuses on Demand Response with cross-sectional technologies. This decision was made because process technologies were already analyzed in the literature.

B. *Design of the questionnaire*

The first part of the questionnaire investigates which cross-sectional technologies within the particular industrial business are suitable for Demand Response. This helps to understand and evaluate the gathered information on the costs of Demand Response. The cross-sectional technologies from Table I were used as a basis for the questions (except on-site generation systems).

The investments section starts off with a qualitative question regarding investments that would be necessary for the participating business. This allows for analysis of the participant's general willingness to make the investments. Furthermore, the industrial businesses are asked to assess the personnel costs that occur when deriving the Demand Response strategy. At the end of the first section the willingness to invest in storage systems for Demand Response and the need for other investments are determined.

With regard to annual fixed costs, the industrial businesses are asked to estimate annual personnel costs. Moreover, the participants must evaluate annual fixed costs that result from data exchange. In addition, the participants are asked in a more explorative way if they could think of any other annual fixed costs that would occur when operating Demand Response.

The third section of the economical part of the questionnaire consists of questions dealing with variable costs. For each cross-sectional technology, the participant can choose if one of the following variable costs would occur during a Demand Response activation: personnel costs, efficiency losses, inconvenience costs, storage losses or other variable costs. The questionnaire differentiates between boosting or starting up and throttling or shutting down cross-sectional technologies. Furthermore, the industrial businesses are asked to quantify the variable costs where possible.

C. *Execution and sample*

The survey was carried out with 16 industrial businesses via on-site (6) and telephone interviews (10). The contacted medium-sized and large-scale enterprises are members of FfE's Learning Energy Efficiency Networks (LEEN) in Germany. The survey was conducted in conjunction with the research project "Merit Order for Energy Storage Systems in 2030" [3], which aimed at figuring out the techno-economical potentials of Demand Response with cross-sectional technologies. The data collected was subject to the restriction that the production process and the output of the businesses remain unaffected by the Demand Response calls.

D. *Generation of additional data*

In addition to the information gathered from the industrial businesses, the survey is flanked by three other research approaches. Where necessary, expert estimates by FfE's researches were carried out. This applies in particular to identifying required measurement and control technologies. Market prices for these technologies were quantified by Internet research and by using FfE's database. Additionally, an interview with an employee of a Demand Response Aggregator was conducted in order to quantify and verify different kinds of costs.

V. FINDINGS

This section summarizes the findings of the survey.

A. *General findings*

The industrial businesses were asked to name suitable cross-sectional technologies for Demand Response. Within 13 of 16 interviewed businesses, ventilating systems were considered to be appropriate for being throttled or shut down for periods between 15 minutes and half an hour. Refrigerating machines can be operated in a flexible way in 9 industrial businesses (throttling, shutting down, boosting or starting up for 30 minutes up to two hours). 8 interview partners specified that they could dim or partly switch off lighting systems for one, four or eight hours. In 5 businesses, heating circulating pumps are suitable for Demand Response. Heat pumps and electrical hot water preparation were mentioned in two businesses. Band-conveyors of a building company that operates quarries can be used for Demand Response as well. Fig. 2 summarizes the findings.

Regarding investments, 7 businesses are generally willing to invest, while 8 are not. This depends in large part on the availability of suitable plants for Demand Response and the required payback periods of the businesses. Three quarters of the interview partners are not willing to invest in additional storage systems to enable participation in Demand Response programs.

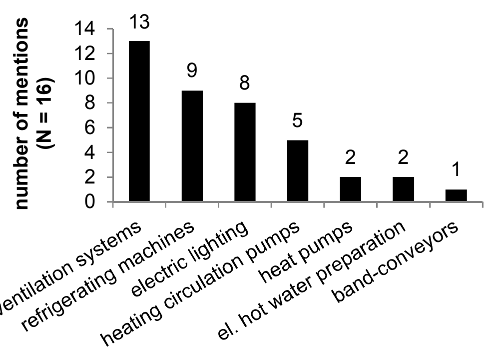

Fig. 2: Suitable cross-sectional technologies for Demand Response (interview result) [3]

B. *Quantifying the investments*

Investments can be subdivided into plant-independent and plant-dependent investments. Plant-independent investments have to be made whenever Demand Response is implemented in an industrial business. Plant-dependent investments are dependent on the type and the number of plants.

Plant-independent investments

Fig. 3 shows the answers regarding the personnel costs that occur as a consequence of deriving a Demand Response strategy. The majority of the interview partners estimated an amount of 4,000 to 6,000 EUR. For instance, 6,000 EUR would be caused by three employees with an hourly wage of 50 EUR working for five days. The comparatively high amounts of 30,000 and 36,000 EUR were estimated by major enterprises. Here, far more employees have to be consulted for the development of a Demand Response strategy. For most companies, 6,000 EUR seems to be a realistic amount.

In the field of communication technology, an industrial business has to invest in a communication box. This device receives commands from a Demand Response Aggregator and forwards them to the central building control system of the industrial business. That way plants can be switched by an external entity. The investment for this communication box was valued at 3,000 EUR. This amount was determined on the basis of an expert estimate with FfE's researchers and a telephone call with an employee of a Demand Response Aggregator.

Plant-dependent investments

Within the survey, 13 businesses stated that investments in control technology are necessary. This partially contradicts the results of the on-site interviews. Here, it could be observed that the control technology that is needed for Demand Response is often already installed. In the case of missing control technology, expert estimates by FfE's researchers show that electric contractors or relays have to be retrofitted in order to shut down or start up plants. For boosting or throttling plants, investments in frequency converters have to be made. In order to dim electric lighting, dimmable ballasts are necessary.

The results of the Internet research show that prices for electric contractors are between 6 and 9 EUR per kW. Prices for frequency converters do not increase linearly with the electrical power. For instance, frequency converters for 10 kW cost around 2,000 EUR, while for 100 kW the amount increases to 7,000 EUR. A frequency converter for 500 kW requires an investment of 30,000 EUR; dimmable ballasts cost around 100 EUR per illuminant.

12 industrial businesses stated that measurement technology has to be retrofitted in order to take part in Demand Response programs. On each plant a measurement device that monitors the current power consumption has to be installed. Including hardware costs and installation by a technician, this investment is estimated at 1,000 EUR per plant. This amount was also determined on the basis of an expert estimate by FfE's researchers and a telephone call with an employee of a Demand Response Aggregator.

Furthermore, integrating the plants into the central control system is essential. This allows switching loads in an automated way. It might be that the plants are already integrated in the central control system. In that case only a reprogramming of the central building control system would be necessary. The programming costs for the first plant are estimated to be at 1,000 EUR. It can be assumed that this investment drops to 250 EUR per plant from the second plant on. This is due to the fact that the programming code of the first plant can be copied without major adjustments. The assumptions are based on an expert estimate by FfE's researchers. The estimation could be validated within one on-site interview.

C. *Quantifying the fixed costs*

The industrial businesses were asked to quantify the annual fixed personnel costs. Fig. 4 summarizes the answers. The majority of the businesses said that they would have to invest 2,000 – 5,000 EUR per year. The comparatively high amounts were again estimated by major enterprises. For most businesses it can be assumed that in the first year of operating Demand Response, 5,000 EUR have to be calculated for personnel costs. Due to learning effects, the fixed personnel costs can be reduced to 2,000 EUR from the second year on.

Regarding the annual fixed costs caused by data exchange, eight businesses answered that no costs will be incurred, as existing data lines can be used. Two interview partners calculate 500 EUR for annual fixed costs, while three businesses expect that data exchange will cost 1,000 EUR per year. In one interview an amount of 5,000 EUR was mentioned; two businesses did not answer the question. For this paper it is assumed that no costs occur as a consequence of exchanging data.

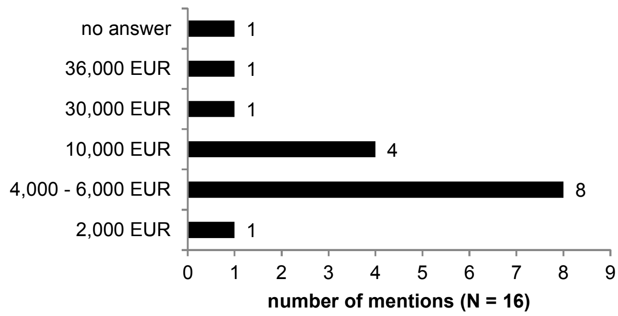

Fig. 3: Investment for Demand Response strategy (interview result)

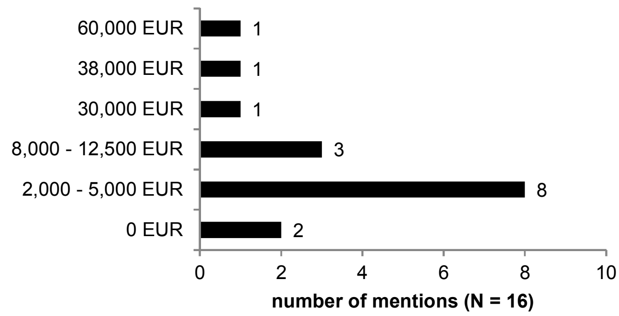

Fig. 4: Annual fixed personnel costs (interview result)

D. *Quantifying the variable costs*

In terms of variable costs, it turned out that only personnel costs can be quantified. Many industrial businesses indicated that they want to decide whether plants are switched or not before every single Demand Response activation. Thus variable personnel costs have to be considered. As a rough estimate, the personnel costs amount 8 EUR per Demand Response activation (50 EUR hourly wage, 10 minutes average decision-making time).

Variable costs due to efficiency and storage losses were mentioned for several technologies. Some interview partners pointed out that these costs can be neglected due to the short period of time of a Demand Response activation. Inconvenience costs as a result of a loss of comfort were mentioned for nearly all cross-sectional technologies. Quantifying this type of variable costs is not possible. When boosting or starting up plants, additional costs for purchasing electricity may occur. This is of relevance if the need for electricity is shifted to hours with higher electricity prices as a result of a Demand Response activation. Additional costs of electricity cannot be generally quantified, but instead differ from case to case.

VI. Calculation of Profitablity

The costs quantified above were transferred into a profitability calculation. A base scenario was developed in order to investigate whether Demand Response with cross-sectional technologies makes sense from an economical perspective. The core assumptions of the base scenario are:

- 10 years project calculation period, 8 % interest rate
- Three plants for Demand Response with 250 kW in total
- 250 production days, each with two eight hour shifts
- At most one Demand Response activation of 30 minutes per shift, thus in total one hour of availability time for balancing power per day
- 100 Demand Response activations of 30 minutes per year (12.5 MWh of marketable electricity per year)
- Average market prices for secondary and tertiary reserve in Germany and EPEX Intraday spot market of 2012 (prices from 6 a.m. to 22 p.m. were considered)
- No investments for control technology necessary

It turned out that the base scenario is not profitable within the discussed markets (capital values < 0). However, it is conceivable that Demand Response with cross-sectional technologies becomes profitable (capital values ≥ 0) in the markets for balancing power if at least one of the following three sensitivities increases: electrical power offered, availability time offered or level of market prices. If the electrical power offered increases to at least 600 kW, an economical operation within the market for positive tertiary reserve would be possible due to the high level of energy prices. If the availability time increases to 2,600 hours, the market for negative secondary reserve becomes attractive due to its high capacity fees. If balancing power prices would rise for instance to a capacity fee of 3.47 EUR/(MW·h) and an energy price of 430.73 EUR/MWh, the capital value would amount zero EUR.

VII. Conclusion

Based on a literature review, three types of costs could be derived: investments, annual fixed costs and variable costs. The literature shows that investments and annual fixed costs are negligible in terms of process technologies because most businesses already have the necessary technology and infrastructure to conduct Demand Response. In contrast, investments and annual fixed costs are important for Demand Response with cross-sectional technologies. Variable costs for cross-sectional technologies are rather low compared to a loss of production potentially caused by the use of process technologies. The profitability calculation conducted showed that Demand Response can be profitable for industrial cross-sectional technologies bigger than 600 kW or availability times of more than 2,600 hours. Alternatively, higher market prices would enable an economical operation.

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