An Analysis of Contracts and Relationships between Supercomputing Centers and Electricity Service Providers

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ABSTRACT

Increases in peak electricity demands and the growing use of renewable energy — with associated intermittency and variable output — present new challenges to electricity service providers (ESPs). ESPs employ demand charges, variable tariffs and demand response (DR) programs to influence the consumption behavior of consumers to partially mitigate these challenges. Due to their high load and potential flexibility, supercomputing centers (SCs) are increasingly gaining importance in the grid. This paper presents a qualitative study of service contracts between ESPs and SCs in the United States and Europe. From this we extract a contract typology used to understand how, and to what extent, variable tariffs, DR programs, and demand charges are imposed on SCs. Further, we highlight the actions taken by SCs in response to these contractual elements. Finally, we present perspectives on grid integration of SCs to enhance their collaboration with their ESPs to benefit supply stability and resilience.

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1 INTRODUCTION

Electricity service providers (ESPs) face several challenges in maintaining a reliable electricity supply. Peak capacity to accommodate peak power consumption has low investment efficiency [8]. The problem of peak power consumption is exacerbated by the expected electrification of heat production and transport [18]. Another notable challenge is presented by the integration of renewable energy sources, which induce intermittency and variability in output generation [23]. The transmission and distribution grid infrastructure is sized and operated to meet the peak demand needs (kW) of the consumers and to ensure grid reliability. The ESPs design the electricity rate tariffs to these costs by including demand charges which impose a static cost on the consumer based on their peak demand (MW), where a consumer that has peakier load profile shares the higher cost of the investment. Further, DR programs or variable tariff design encourages SC consumers to be flexible in their energy use to reduce high operational costs.

DR offers an economically and environmentally attractive solution for efficient grid management and reliable electricity supply [12]. To address these goals, DR describes changes in the consumption pattern on the demand side in response to incentive payments or changes in the electricity price over time [2]. Similarly, variable tariffs impose differentiated pricing on electricity consumption (MWh) based on the time of use.

Supercomputing centers (SCs) have significant electrical power demands (MW) and substantial annual electricity consumption (MWh). Four major supercomputing centers in the United States had total electrical loads well above 10 MW in 2013 [25]. This load has been steadily growing and is expected to continue to grow in the next decade. The theoretical peak power consumption (that is, feeders entering the facility) of these same sites in 2017 is as high as 60 MW. As the size of computational tasks and the amount of data creation are escalating, a future growth in power consumption of SCs is expected [14]. With exascale computing being established as a common goal between the pioneers in SC design research, our focus is on the TOP 50 SCs, as the power demands of these can be expected to rise - while already having a significant impact on local grid operation. We noted that the electricity use varies significantly among the Top500 list (in the range of 40kW to +10MW). Considering that getting data from SCs is a challenge, we targeted higher energy use sites to highlight the extent of the problem and encourage flexible operations among these SCs where the operational cost savings can be significant. Further, the fast ramping variability in the demand of these SCs can strain the grid power systems and will likely become a electricity rate tariff design. With this approach, the study shall encourage ripple effects of closer relationships among all SCs and ESPs. One of the representative SC, which is 167 on 2015 Top500 list is included to show the characteristics of a smaller site.

We present background on grid challenges as well as some of the measures taken by ESPs to handle these challenges in an effort to inform practitioners in the SC community about the grid

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context in which they operate. We then focus on the relationship between ESPs and SCs by examining the service contracts that exist between ESPs and SCs in the United States and Europe. We use the result of this examination to describe management contexts and experiences of large-scale SCs in both the United States and Europe with respect to the evolving relationship between the SCs and their ESPs. Emerging external factors, such as large-scale SCs' growing power demands, implementation of Smart Grid [13] technologies, and renewable energy source deployments, seem likely to present circumstances under which ESPs and SCs will be forced to develop a closer relationship. That is to say, while the relationship between SCs and their ESPs has traditionally been one-sided, with the ESPs largely driving static and reliable conditions to the SCs, contemporary trends are causing a rethinking of this relationship into a scenario that includes a much higher degree of collaborative interaction. The contractual agreements between SCs and ESPs that this paper examines and analyzes show just the beginnings of these trends. With this paper, we aim at propagating operational experiences of SCs with respect to energy consumption behavior in a grid context to a wide variety of backgrounds about DR, ranging from operations staff to personnel in charge of contract construction and negotiation.

To gather the information necessary for preparing this paper, we conducted a qualitative survey on some of the largest SCs across the United States and Europe. The survey asked SCs to provide information about their responsibility with respect to negotiating their contract with their ESPs and any obligations that they are currently subject to with respect to their power consumption, their power tariffs, and other services they provide toward their ESP. Finally, the survey asked the SCs to describe their outlook with respect to their future relationship with their ESPs and DR participation.

Based on the survey responses, we extract a contract typology in an effort to understand how and to what extent SCs are subject to demand charges, variable tariffs, and DR programs and how SC operation is influenced by these factors. Finally, this paper suggests possible future directions for the interactions between SCs and ESPs based on the analysis of these contractual agreements.

The rest of this paper is organized as follows. Section 2 presents literature related to our study. Section 3 describes the survey that was distributed across 10 large-scale SCs, along with an analysis of the gathered data. Section 4 discusses our findings. Finally, Section 5 presents the paper's conclusion.

2 RELATED RESEARCH

To understand factors in the relationship between ESPs and SCs, which is relevant in forming meaningful collaborations, this paper builds on experiences from three different areas of research.

(1) Research of DR or demand-side management programs in general
(2) Research on DR in the context of data centers
(3) Research on contracts between SCs and their ESPs.

The first concept, invented in the 1980s in the United States, was demand side management [15]. As today, ESPs — in those days vertically integrated organizations — experienced situations where grid stability was threatened and the reasoning was born to use the potential flexibilities of power demand. The idea gained momentum in the early 2000s, first in the United States and then elsewhere. Overviews of currently implemented DR programs are presented in [3, 27], which focus on DR programs in the United States, and in [30] which examines DR in Europe. An examination of these overviews reveals that both the main impact and the great majority of programs are still implemented in the United States. That said, in Europe with Smart Energy Demand Coalition (SEDC), there is a strong coalition that aims at fostering DR, for instance by suggesting ten rules for successful DR [28] and looking into the market maturity for DR approaches in Europe [29]. However, all in all compared to the United States, the resulting adoption is almost negligible. The Federal Energy Regulatory Commission (FERC) estimates that in wholesale markets, DR programs throughout the United States have the potential to reduce peak load by 6.6% [1] whereas for Europe literature speaks of DR's potential instead of an impact realized today (e.g. [10, 17, 31]).

Several papers attempt to identify the theoretical potential of DR to optimize the power system from a modelling perspective [32] give an overview of these research papers. The authors differentiate research that deals with incentive-based versus price-based programs and further categorize work according to the optimization algorithms used. Some works focus on implementation issues surrounding DR, such as the speed of implementing DR or the barriers and challenges of DR [20, 27]. All these works analyse DR programs and reactions to these programs. None of them, alas, looks into concrete contracts between consumers and their ESPs in order to assess the individual scope for power demand management.

Similar notions apply to the second area of related research: DR in the context of data centers (DCs). One of the first studies on the DR potential of data centers was carried through by Lawrence Berkeley National Laboratory [24]. This study resulted in a paper that is the main source of empirical results in later research [16]. Since 2010, a number of papers have dealt with DR with data centers, with most papers considering dynamic tariffs (e.g. [33, 35]) or incentive-based DR approaches like offering ancillary services (e.g. [4, 9, 11, 22]). Also, the emergence of survey papers about DR with data centers shows the growth of this research, for example [21] which classifies the reviewed literature into energy aware scheduling, virtual machine placement, capacity planning and interdisciplinary approaches, with the majority of works dealing with energy aware scheduling.

Only a few studies related to DR with data centers hint at realistic contract issues, such as demand charges that have the potential for turning otherwise moderate electricity bills into huge cost items [4, 34]. The latter study ([34]) in particular goes one step further by presenting research on energy contracts that United States ESPs offer to large industry sites. The result of this research is that the share of the power charge within the electricity bill increases with the ratio of peak versus average power consumption. For the case of colocation data centers, those that do not have the control over the workloads running on the servers in the data center, [19, 26] identify a so-called "split incentive" where the entities who decide on the workload are shielded from the direct consequences of the power bill. In these cases, a special incentive for tenants is needed to encourage them to engage in DR, for example via reverse auctioning which was implemented in contracts with the tenants. One may speculate that in reality, current electricity contracts are not particularly effective at creating a collaborative relationship between DCs and their ESPs. In DR research efforts, the contract between ESPs and consumers is mostly assumed to be either some sort of dynamic pricing or some incentive-based contract such as the ones frequently used in the United States. However, since no real case studies of DR with data centers are reported, these contracts are either not applied to DCs or the incentives lack persuasive power. Therefore, some projects designed contracts that are specifically aimed at enabling data center power flexibility; however, these were not implemented [5, 6].

A previous paper from the EE HPC Working Group [1] [7] examines the relationship between ESPs, charged with the responsibility of supplying efficient and reliable generation, transmission, and distribution of electricity, and SCs, charged with the responsibility of operating energy-intensive performance-oriented computing environments with high system utilization. The paper describes methods and programs employed by ESPs that are key to managing and balancing the supply and demand of electricity. The paper presents survey results from eleven of the biggest SCs in the United States in order to determine the strategies that SCs might use to respond to ESP programs. Coarse-grained power management strategies like energy and power-aware job scheduling, power capping, and shutdown are identified as the most effective strategies that SCs could employ in response to the ESP programs. Overall, however, the survey finds that “the business case for the grid integration of SCs remains to be demonstrated. SCs have concerns that deploying these strategies might have an adverse impact on their primary mission.”

Another paper [25] presents a survey of European SCs in an effort to compare and contrast the perspectives of European centers to those in the United States. It was hypothesized that due to higher cost of electricity as well as greater use of renewables, European SCs would have more experience with DR than SCs in the United States. An unexpected conclusion of the paper is that SCs in the United States reported being more open to cooperating and deploying DR strategies than their European counterparts. “However, it was apparent that some SCs in Europe engage in collaboration with their ESPs in order to ensure minimal fluctuations as well as for forecasting of deviations from normal power consumption patterns.” This finding resulted in the necessity to give more attention to the contractual situation of SC in order to find out what fosters and what limits power flexibility in data centers, specifically in SCs.

3 SURVEY AND RESULTS

The survey “HPC power contracts and grid integration” was completed by ten SCs in the United States and Europe in 2016. We decided to target the large SCs in Europe and the United States. Large was operationally defined as those that have supercomputers that are/could be in the Top50 of the Top500 List. The geographic restriction to Europe and the United States was based on an interest to build upon prior work. We did not attempt to reach SCs in industry, rather restricted our study to those in either government or academic institutions.

We decided to use open-ended questions as opposed to multiple-choice questions. The reason for this decision was the concern that ESP contracts are all unique and multiple-choice questions would be too restrictive.

Invitations to participate were sent to 10 sites, which was 30% of the Top50 government/academic sites in Europe and the United States. Overall, the response rate to the survey was approximately 50%. Some answers were elaborated further through bilateral interviews. Four SCs from the United States were included: Oak Ridge National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and the National Center for Supercomputing Applications. From Europe, six sites were surveyed: the European Centre for Medium-Range Weather Forecasts (United Kingdom), the Swiss Supercomputing Center (Switzerland), the Leibniz Supercomputing Center, the High Performance Computing Center in Stuttgart, the Juelich Supercomputing Center, and the GSI Helmholtz Center (all four from Germany). The participating sites and their associated country of residence is summarized in Table 1. As described in Section 2, prior work suggested differences between Europe and the United States in that "SCs in Europe engage in collaboration with their ESPs in order to ensure minimal fluctuations as well as for forecasting of deviations." However, the suggested difference was based on unsolicited comments from Europeans and not a specific question asked of all sites. The current work specifically asked this question of all sites and discovered that there was not a difference between SCs in Europe and the United States. Furthermore, the survey results did not show any geographic trends.

Interview Site	Country
European Centre for Medium-range Weather Forecasts	England
GSI Helmholtz Center	Germany
Jülich Supercomputing Centre	Germany
High Performance Computing Center Stuttgart	Germany
Leibniz Supercomputing Centre	Germany
Swiss National Supercomputing Centre	Switzerland
Los Alamos National Laboratory	United States
National Center for Supercomputing Applications	United States
Oak Ridge National Laboratory	United States
Lawrence Livermore National Laboratory	United States

Table 1: Interview sites labeled with country of residence.

3.1 Survey Questions

Each of the sites were presented with the questions listed in this section. The sites answering the questions where not provided with these motivations behind the questions.

3.1.1 Contract Negotiation Responsibility. To understand who is responsible for negotiating the electricity service contract, the first question asked:

> In your institution, who is responsible for negotiating the contract between your HPC facility and your ESP? (“Institution” means, for example, the facility

[1] https://eehpcwg.llnl.gov

> itself or an organization to which the HPC facility belongs.) What role do you play, if any, in this contract negotiation?

Understanding how SCs participate in and/or influence the negotiation of their contracts may be important. Intuitively, the more the SC participates in the actual negotiation with the ESP, the greater the likelihood that the contract would be tailored to the needs and abilities of the SC.

3.1.2 Details on Pricing Structure. To understand the details on the pricing structure of the SC's electricity service contract, the second question asked:

> Could you elaborate on the details of the pricing structure of your electricity? What are the basic pricing components? (Note: We do not need information on the actual price the HPC center pays for electricity. We are interested in the type of pricing program they are enrolled in.)

Knowing what sort of tariffs exists among SCs can help to understand the degree to which SCs already participate in DR-like programs and how they act in this context.

3.1.3 Obligations Towards the ESP. To understand what obligations the SCs might have with their ESP, the third question asked:

> Do you have any obligations towards your ESP, e.g. a contractually agreed power band or requirement to deliver power profiles? (These obligations are characterized by being static and "pre-smart grid" in the sense that no real-time communication is needed between ESP and HPC center. Examples include limits for allowed variability in consumption and fixed consumption limits.) What is your incentive towards committing to these obligations? (Reduction in electricity price, direct payments, legislation, ...)

There is a range of obligation an SC can have towards their ESP with respect to managing their demand. The range spans from no obligations to very tightly coupled obligations.

3.1.4 Services Provided to ESP. While obligations are contractual constraints imposed on SCs, services are opt-in programs that the SCs choose to participate in. To understand whether SCs offer any DR services to their ESP, the fourth question asked:

> Do you offer any kind of services for your ESP? (These services are characterized by two-way communication, where a consumer reacts to a signal sent by the ESP. Examples include load capping, powering up backup generators, etc.) What is your incentive for offering these services? (Reduction in electricity price, direct payments, legislation, ...)

This question extends the concept of obligation to one where the SC is actively offering one or more services to the ESP.

3.1.5 Future Relationship with your ESP. To understand the future relationship between the ESC and SC in an evolving environment, the fifth question asked:

> How do you envision your future relationship with your electricity provider? (Tighter, for example by selling local generation capacity? Looser, for example by being self-sufficient with respect to electricity?)

An understanding of how SCs see the evolution of the grid and in particular the emerging relationship with their ESPs combined with information on their current relationship, which has been investigated in the previous questions, is useful in the context of describing the SC readiness towards the transition.

3.1.6 DR Potential. To understand the potential for DR participation from the perspective of the SCs, the last question asked:

> Imagine your ESP offered a DR program on a voluntary basis. That is, it will ask you to shift or reduce some load in exchange for some incentive.
>
> - Is there some part of the load that you can reduce (or increase) for a certain time-span (e.g., an hour) without negatively impacting on your operations or your users/customers. How much load do you estimate (very roughly) you could shift? And what incentive would you expect for this effort?
> - In case the ESP would like you to shift more power load this would result in some kind of cost for your organization. We are trying to understand the trade-off between cost in an HPC centre and the benefit for the power system. Therefore we would like to know what kind of incentive — if any — you would expect for shifting load that is linked with a tangible impact on your users/customers.

The motivation for this question was to better understand how responsive SCs are to DR and what kinds of incentives would have to be created or barriers removed in order to change behavior.

3.2 Contract Typology

The survey found that in general, power contracts are large and complex. Without a common nomenclature, comparing contracts and experiences with procurement across sites would be cumbersome. To this end this section presents a novel typology of the constituent parts of SC electricity service contracts and how these components relate to demand-side management, DR, and energy efficiency. There are three branches within the typology diagram: tariffs, demand charges, and other. Each of these branches are described below. While the cost of electricity is influenced by location-specific service fees and taxes, these are not included in the typology as they cannot be generalized. An overview of the typology can be seen in Figure 1.

3.2.1 Energy Mapped to kWh. Tariffs map to a price per kWh and were found to be one of a) fixed, b) based on time-of-use (TOU), or c) dynamically variable. The fixed kWh tariff describes a situation where the price of electricity is fixed throughout a contractual period. Fixed kWh tariffs encourage energy-efficiency measures, but do not provide an incentive for demand-side management.

The time-of-use tariff describes a situation where the kWh price of electricity varies across some known and contractually defined time period. These variations include ones related to seasonal pricing and day/night pricing. Time-of-use tariffs encourage static demand-side management. Because these tariffs are fixed in time, they are different from dynamically variable tariffs.

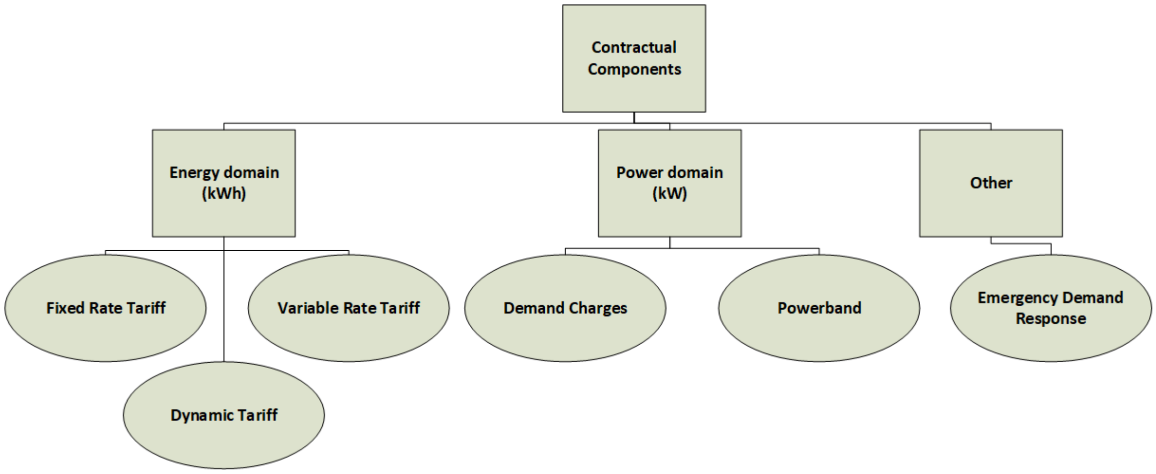

Figure 1: Overview of contract typology.

The dynamically variable tariff describes a situation where the kWh price of electricity is subject to real-time communication between the consumer and the provider. Dynamically variable tariffs encourage a specific type of demand-side management known as DR [2].

3.2.2 Power Mapped to kW. Other contract components are not mapped to kWh, but were found to be mapped to the magnitude of peak power consumption in the SCs. For contracts with a demand charges component, part of the electricity price is determined based on the peak consumption of a consumer across a billing period. For example, in a case with three 15 MW peaks in a billing period, demand charges are calculated based on these peaks and added to the electricity bill after the billing period. In the next billing period, if the peaks are 12 MW instead, the demand charges are lowered accordingly. Such demand charges are typical in power billing for industrial sites and, due to similarities in load characteristics, also for supercomputing centers.

Some sites that participated in the survey were subject to a powerband. A powerband dictates electricity consumption boundaries (upper and, optionally, lower). Consumption outside the specified powerband limits is associated with high additional electricity costs. Thus, powerbands may be considered as a variation over demand charges with upper- and lower limit and continuous sampling of consumption as opposed to measuring a fixed number of peaks to calculate prices for demand charges.

Demand charges and powerbands encourage demand-side management, but are not DR (real-time) programs. While this does not reflect the degree to which SCs are able to change their consumption in response to DR real-time signals, it does show that methods for demand-side management are relevant at a majority of the sites.

3.2.3 Other. While most of the components identified in the contracts mapped to either kWh or kW, there were some exceptions. The survey identified emergency response program elements in some contracts. In a DR context, these services constitute Emergency DR programs, a specific type of incentive-based DR program which imposes a reduction in consumption or a consumption up to a certain limit in order to preserve grid reliability[2]. However, as opposed to commercial DR programs, these are mandatory and imposed upon the SCs.

3.2.4 Application of Contract Typology. Table 2 is a synthesis of the survey results based on the contract typology. The table reflects that fixed kWh tariffs are a dominant component of SC's service contracts with their ESPs. Eight of the ten sites had a fixed kWh tariff in their contracts. The variable "Time-of-use" tariff was seen in three out of the ten sites while two SCs have at least some aspect of their contract with a dynamically variable tariff, where pricing is determined based on real-time market conditions. As can be seen from the table, two of the sites have both a fixed and a variable rate component. While this may seem counter intuitive, the reason is that a variable service-charge is applied on top of their fixed rate tariff depending on the time of use. Further, table 2 shows that five out of the ten sites are subject to a powerband as a mandatory obligation. Eight of the ten sites surveyed had a demand charge component in their contract. Finally, two sites mention that they offer mandatory services to their ESP to be executed in case of a grid emergency.

3.3 Responsible negotiating parties

Based on the survey results, we identified three actors who could take main responsibility for negotiation of electricity procurement contracts. These are *supercomputing centers*, *internal organizations*, and *external organizations*. The *supercomputing center* actor works within the SC organization and is the responsible negotiating party (RNP) for the SC. Only one of the ten sites surveyed has the supercomputing center as the RNP. This SC is part of a larger organization, but the data center site is geographically isolated from the larger organization. This SC previously had an *internal organization* actor negotiate the contract and expects to return to more of an *internal organization* actor with the next contract revision.

The *internal organization* actor is the RNP for multi-function sites, such as a university or government organization. In these

[2]https://www.pjm.com/ /media/markets-ops/dsr/end-use-customer-fact-sheet.ashx

	Demand Charges		Tariffs (kWh-domain)			Other	RNP
	Demand Charges	Powerband	Fixed	Variable	Dynamic	Emergency DR	
Site 1	√		√	√			External
Site 2	√	√	√				Internal
Site 3	√		√			√	Internal
Site 4	√				√		Internal
Site 5	√	√	√				Internal
Site 6		√	√				SC
Site 7	√	√			√	√	Internal
Site 8					√		Internal
Site 9	√	√	√	√			External
Site 10			√				External

Table 2: Summary of survey results.

cases, a "site" would include the SC as well as other buildings. The site may have other scientific equipment that consumes as much or even more electricity and with higher peak power draw than a supercomputer. The *internal organization* actor often operates near the SC, and may have some insight as to their operational characteristics, although domain knowledge is not fully represented. The majority of SCs surveyed operate within this type of situation (six out of ten).

Finally, the *external organization* actor is the RNP for more than one (typically) multi-function site. Such sites can span multiple geographic regions and can span unrelated legal or functional entities. The *external organization* actor is sufficiently removed from the SC that operational characteristics and domain knowledge is minimal. This is the case for three of the ten sites surveyed. Of these sites, 2 sites have the U.S. Department of Energy as their external organization actor.

Although there are differences between SCs as to who has the main responsibility for contract negotiations, several sites had knowledge about details in their power contract. Other sites acquired this knowledge as a direct consequence of participating in the survey conducted as part of this paper.

3.4 ESP and SC Interaction

SCs are focused on addressing the needs of their users as well as specific institutional missions. As a result, SCs are primarily concerned with ensuring high system utilization due to the large amount of investment made to procure and maintain high-performance computing hardware relative to the cost of electricity. While the SC sites did generally adhere to demand charges and powerbands specified in their contracts, they did not see much if any opportunity for shedding or shifting electricity consumption in a DR program, as this would compromise SC operation to some degree. From the interviewed sites, while 3 sites are on a time-based dynamic tariff, they do not employ any DR strategies to manage electricity costs. The survey does show, however, that other incentives, such as "being good neighbors" and similar policies could influence SCs to change their electricity demand in response to external events. By being good neighbors, SCs act proactively as allies towards the ESPs by reporting (i.e. via phone) maintenance periods, benchmarks and other events which make their power consumption deviate significantly from default operation. Such measures could lead them to influence their own role in future grid scenarios, as it fosters dialogue between the ESP and the SC.

Six of the ten SCs communicate swings in load to their ESPs. Some SCs provide this communication by contract while others do it as part of a good business relationship.

4 DISCUSSION

The results of the survey show that service contracts between ESPs and SCs include aspects that generally encourage energy efficiency as well as demand flexibility, but do not include sophisticated dynamic DR. The results also further confirm and explain the reluctance of SCs to adopt strategies that would enable demand flexibility. Overall, the economic incentive offered through tariffs and DR programs is not high enough to alter operation strategies in SCs, due to high hardware depreciation costs. With these thoughts in mind, we believe that SCs should continue to focus on energy efficiency in order to reduce job costs with respect to demand charges and powerbands. However, as mentioned in the beginning of this paper, the landscape is evolving due to increasing peak electricity demands on the consumption side and the increase in renewable energy in the generation portfolio. Here, SCs should consider designing and potentially implementing contingency planning for power management in collaboration with their ESP in order to minimize impact to users during contingency periods.

SCs with direct responsibility of electricity procurement could have extended options to influence the design of their power procurement contracts. As an example, the Swiss National Supercomputing Centre (CSCS) put their electricity procurement through a public procurement process. In this process, CSCS used external experts to identify a model for a power procurement contract that would suit the needs of CSCS. This included removing demand charges (an element of their existing contract), defining a requirement for an energy supply mix which included 80% electricity from renewable generation as well as defining a formula for calculating electricity price, where 4 variables where left to the ESPs to decide, thereby defining their bids on the power contract. This way, the management at CSCS have transformed from being a passive electricity consumer into one, which is actively engaged with their ESP, to ensure a power contract which adheres to operational requirements, reduces cost and adheres to on-site policies with respect to energy mix.

Keeping in mind the experiences of sites such as CSCS could act as a driver for sites who are not directly involved in the electricity procurement process. They can see potential in providing input for their own negotiation by influencing the responsible party - or even taking on the responsibility themselves, keeping in mind that this does require some on-site resources.

While SCs who are not directly involved with electricity procurement do not have as sophisticated measures in controlling their procurement contract, options do exist for these sites.The Electricity Procurement contract of the Los Alamos National Laboratory Supercomputing Center (LANL SC) is negotiated at an institutional level by their Utility Division. They have on-site generation and participate in generation and voltage control programs through coordination with their Balancing Authority. LANL SC have identified DR potential in their general office buildings and see opportunities in providing DR services in the 15 min to 1 hour timescale. The drivers in this context is the facilitation of more (on-site) renewable energy, avoiding penalties for additional power and a reduction in demand charges. This approach can be extended into leveraging variable prices described in electricity tariffs to achieve lower costs while positively impacting the grid operation. While no existing economic incentive fosters this need, the actions of SCs may be crucial in maintaining a stable and resilient power supply in a future Smart Grid. By being proactive, SCs can address these challenges in a timely manner and have an influence on their future role from the perspective of the ESP, thereby potentially avoiding superimposed constraints which we see emerging to some degree already today. In this context it is worth noting that SCs often have sophisticated power management tools at their disposal. Further, SCs are able to exhibit rapid changes in their electricity power use, which could be of great benefit to grid operators. While this does not explicitly address challenges faced by ESPs, this enables them to use SCs indirectly to mitigate these, as they can expect demand-side responses to incentive payments or variable tariffs.

5 CONCLUSION

Faced with challenges from growing peak electricity demand on the consumer side and from a more volatile and intermittent supply of power, ESPs increasingly apply demand charges, variable tariffs, and DR programs in an effort to alter consumption side behavior. Thereby, they aim to mitigate peak demands while ensuring effective utilization of the intermittent electricity generation resulting from renewable energy sources. These approaches enhance the relationship between the supply side and demand side and offer both challenges and opportunities on both sides of the meter. The relationship between ESPs and SCs, as large electricity consumers, is particularly interesting due to the potential impact of consumption patterns in SCs on local grid state. This paper explores the relationship between these two parties in order to understand if and how SCs are subject to demand charges, variable tariffs, and DR and how this influences their operation. Further, this paper attempts to understand drivers for influencing SC behavior and identify actions for SCs in response to these contractual elements. We conducted a qualitative survey of ten SC sites across the United States and Europe and have extracted a contractual typology to describe the common elements we see in SC electricity procurement contracts. We applied the typology to the survey results to find that fixed tariffs, demand charges and powerbands where common elements in power procurement contracts, while variable- and dynamic elements are rare less common. We describe management experiences of large-scale SCs in the context of their electricity procurement contracts, and find that while demand charges and the associated concept of powerbands does influence SC operation, variable tariffs have little to no influence on SC operation. We also find that commercial DR programs are absent in SC electricity procurement contracts. This conclusion falls in line with the analysis of the survey results. In lue of these findings, SCs should continue to focus on energy efficiency to reduce impact of demand charges. While the economic incentive in performing demand-side management in response to variable tariffs or DR programs is likely too low to accommodate the costly depreciation on hardware in SCs, electricity procurement contracts are likely to continue their evolution in response to increasing peak electricity demand and renewables in the generation portfolio. As a consequence, SCs with direct negotiation responsibility over their power procurement contracts should seek to influence the implementation of these elements in their own contracts. We show CSCS as an example of how this process can yield a direct economic benefit to the supercomputing site. For facilities with indirect responsibility over the electricity procurement process, the aim should be to move closer to the decision process. As for the SCs in general, we foresee a future need for contingency planning, where specific actions can be applied in SC operation, to adhere to grid conditions. In our future research we want to aggregate knowledge of demand-side management in SCs and combine that with knowledge on grid management, to form suggestions for contingency plans in SCs. This approach will enable SCs to perform impact analysis of contingency planning on their operation in an effort to prepare for more sophisticated grid integration.

REFERENCES

[1] 2006 assessment of DR and advanced metering. Tech. rep., Federal Energy Regulatory Commission, 2006.

[2] 2012 assessment of DR and advanced metering. Tech. rep., Federal Energy Regulatory Commission, 2012.

[3] Aalami, H., Moghaddam, M. P., and Yousefi, G. Demand response modeling considering interruptible/curtailable loads and capacity market programs. *Applied Energy 87*, 1 (2010), 243–250.

[4] Aksanli, B., and Rosing, T. Providing regulation services and managing data center peak power budgets. In *Proceedings of the conference on Design, Automation & Test in Europe* (2014), European Design and Automation Association, p. 143.

[5] Basmadjian, R., Botero, J. F., Giuliani, G., Hesselbach, X., Klingert, S., and De Meer, H. Making data centres fit for demand response: introducing greensda and greensla contracts. *IEEE transactions on smart grid* (2016).

[6] Basmadjian, R., Niedermeier, F., Lovasz, G., De Meer, H., and Klingert, S. Greensdas leveraging power adaption collaboration between energy provider and data centres. In *Sustainable Internet and ICT for Sustainability (SustainIT), 2013* (2013), IEEE, pp. 1–9.

[7] Bates, N., Ghatikar, G., Abdulla, G., Koenig, G. A., Bhalachandra, S., Sheikhalishahi, M., Patki, T., Rountree, B., and Poole, S. Electrical grid and supercomputing centers: an investigative analysis of emerging opportunities and challenges. *Informatik-Spektrum 38*, 2 (2015), 111–127.

[8] Bayliss, C. R., Bayliss, C., and Hardy, B. J. *Transmission and distribution electrical engineering*. Elsevier, 2012.

[9] Berl, A., Klingert, S., Beck, M. T., and de Meer, H. Integrating data centres into demand-response management: a local case study. In *Industrial Electronics Society,*

IECON 2013-39th Annual Conference of the IEEE (2013), IEEE, pp. 4762–4767.

[10] Chardon, A., Almén, D., Lewis, D. P. E., Stromback, J., Château, B., et al. Demand response: a decisive breakthrough for europe. Tech. rep., Capgemini, 2008.

[11] Cioara, T., Anghel, I., Bertoncini, M., Salomie, I., Arnone, D., Mammina, M., Velivassaki, T.-H., and Antal, M. Optimized flexibility management enacting data centres participation in smart demand response programs. *Future Generation Computer Systems 78* (2016), 330–342.

[12] Clausen, A., Ghatikar, G., and Jørgensen, B. N. Load management of data centers as regulation capacity in denmark. In *Green Computing Conference (IGCC), 2014 International* (2014), IEEE, pp. 1–10.

[13] Farhangi, H. The path of the smart grid. *IEEE power and energy magazine 8*, 1 (2010).

[14] Feng, W., Strohamier, E., Scogland, T., and Bates, N. Trends in energy efficient supercomputing. https://eehpcwg.llnl.gov/pages/conf_sc17a.htm, 2017. Birds of feather.

[15] Gellings, C. W., and Chamberlin, J. Demand-side management, 1988.

[16] Ghatikar, G., Ganti, V., Matson, N., and Piette, M. A. Demand response opportunities and enabling technologies for data centers: Findings from field studies. Tech. rep., Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States), 2012.

[17] Gils, H. C. Assessment of the theoretical demand response potential in europe. *Energy 67* (2014), 1–18.

[18] Iacovella, S., Lemkens, K., Geth, F., Vingerhoets, P., Deconinck, G., D'hulst, R., and Vanthournout, K. Distributed voltage control mechanism in low-voltage distribution grid field test. In *Innovative Smart Grid Technologies Europe (ISGT EUROPE), 2013 4th IEEE/PES* (2013), IEEE, pp. 1–5.

[19] Islam, M. A., Mahmud, H., Ren, S., and Wang, X. Paying to save: Reducing cost of colocation data center via rewards. In *High Performance Computer Architecture (HPCA), 2015 IEEE 21st International Symposium on* (2015), IEEE, pp. 235–245.

[20] Kim, J.-H., and Shcherbakova, A. Common failures of demand response. *Energy 36*, 2 (2011), 873–880.

[21] Kong, F., and Liu, X. A survey on green-energy-aware power management for datacenters. *ACM Computing Surveys (CSUR) 47*, 2 (2015), 30.

[22] Liu, Z., Wierman, A., Chen, Y., Razon, B., and Chen, N. Data center demand response: Avoiding the coincident peak via workload shifting and local generation. *Performance Evaluation 70*, 10 (2013), 770–791.

[23] Lund, H., and Münster, E. Management of surplus electricity-production from a fluctuating renewable-energy source. *Applied Energy 76*, 1 (2003), 65–74.

[24] Mares, K. Demand response and open automated demand response opportunities for data centers. *Lawrence Berkeley National Laboratory* (2010).

[25] Patki, T., Bates, N., Ghatikar, G., Clausen, A., Klingert, S., Abdulla, G., and Sheikhalishahi, M. Supercomputing centers and electricity service providers: A geographically distributed perspective on demand management in europe and the united states. In *International Conference on High Performance Computing* (2016), Springer, pp. 243–260.

[26] Ren, S., and Islam, M. A. Colocation demand response: Why do i turn off my servers? In *ICAC* (2014), pp. 201–208.

[27] Singh, S. N., and Østergaard, J. Use of demand response in electricity markets: An overview and key issues. In *Energy Market (EEM), 2010 7th International Conference on the European* (2010), IEEE, pp. 1–6.

[28] Smart Energy Demand Coalition. A demand response action plan for europe-regulatory requirements and market models. Tech. rep., 2013.

[29] Smart Energy Demand Coalition. Mapping demand response in europe today. Tech. rep., 2014.

[30] Torriti, J., Hassan, M. G., and Leach, M. Demand response experience in europe: Policies, programmes and implementation. *Energy 35*, 4 (2010), 1575–1583.

[31] Torriti, J., Hassan, M. G., and Leach, M. Demand response experience in europe: Policies, programmes and implementation. *Energy 35*, 4 (2010), 1575–1583.

[32] Vardakas, J. S., Zorba, N., and Verikoukis, C. V. A survey on demand response programs in smart grids: Pricing methods and optimization algorithms. *IEEE Communications Surveys & Tutorials 17*, 1 (2015), 152–178.

[33] Wang, R., Kandasamy, N., and Nwankpa, C. Data centers as demand response resources in the electricity market: Some preliminary results. In *Intl. Workshop on Feedback Computing* (2012).

[34] Xu, H., and Li, B. Reducing electricity demand charge for data centers with partial execution. In *Proceedings of the 5th international conference on Future energy systems* (2014), ACM, pp. 51–61.

[35] Yao, J., Liu, X., and Zhang, C. Predictive electricity cost minimization through energy buffering in data centers. *IEEE Transactions on Smart Grid 5*, 1 (2014), 230–238.