Sustainable Energy Management in Data Centers through Collaboration

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Abstract. In the current decade of rapid expansion of ubiquitous data storage and cloud computing services, the demand for data centre services has seen an enormous increase which is resulting in a continuously rising pressure on the environment in terms of energy consumption and greenhouse gas (GHG) emissions. The recently started project, All4Green, explores potential ICT solutions for collaboration amongst data centers, energy providers, and end-users in order to enable energy providers to save CO2 emissions at the very source of energy conversion. This paper presents an overview of objectives and concepts of the research, discussing the so-called data centers' eco-system, the technical approach to collaboration and GreenSLAs as economic incentives.

Keywords: Green IT, Green Data Centre, GreenSLA, Energy Management, Energy Efficiency

1 Introduction: The Problem

The last decade has seen a huge growth in computing. Today many companies "run on data" and the efficient and effective use of this data is an asset that ensures a company's competitiveness and agility. Together with the advent of the cloud computing paradigm this development is resulting in an increasing need for data centers. Unfortunately, data centers require a significant amount of energy (i.e., electricity), consuming about 1.5% of the world's energy supply [6], a share which is projected to even rise in future.

As the pressure on the environment originating in CO2 emissions is thus constantly increasing, the recently established research area of GreenIT is seeking for ways of reducing the energy consumption of or through ICT – with data centers, due to their magnitude of energy consumption, as one major research field.

However, just saving energy in data centers alone might not be enough: it is the energy provider that creates an amount of CO2-emissions depending on the energy sources used to generate electricity. Until now energy providers have fulfilled the energy demand of data centers elastically, organizing the energy conversion according to the needs (in terms of power) of their customers, notwithstanding the means this requires.

The same applies to the relationship between the data centre and their customer: Based on performance oriented service level agreements (SLAs), the data centre delivers its services as and when the end users require them without taking the environmental impact of this service delivery into account.

As long as those two relationships remain untouched, this situation of skyrocketing energy demand and its environmental impact will not change.

The newly established EU-FP7 project All4Green taps on the efficiency potential of viewing the partnership between the data centre (DC), its energy provider (EP) and the data centre end user (EU) as an eco-system which has the option to reduce CO2 emissions considerably if the partners cooperate through a utility negotiation-based collaboration. For instance, during times of unanticipated high energy demand from outside the system, instead of using CO2-intensive energy sources (such as, additional diesel generators) to accommodate this short-term demand peak, the EP can request temporary energy demand capping or decrease from the DC.

We propose a mechanism based on negotiation and rewarding end users, data centers and energy providers who are opting for more environmentally friendly Service Level Agreements (GreenSLA), and are not only taking into account the energy cost, but also the energy source and environmental cost of the services provisioned.

This paper is structured as follows: first we capture findings from related work areas (section 2), then we present an introduction to energy provision and the eco system of EP, DC and EU (section 3). We then explain strategies used to actively shape the energy demand upon the EP's request (section 4), and finally we make an attempt at estimating the impact this collaborative approach might have on the energy supply landscape.

2 Related Work

The shaping of energy consumption in DCs has recently been brought forward through green computing initiatives such as The Green Grid initiative [9], which look not only at the DC infrastructure, but also at the "useful services" in a server (at application-level).

Fit4Green [10] consolidates existing research in the area of federated DC management system engineering, extending it with respect to robust and proactive resource scheduling mechanisms for distributing system load under resource constraints and uncertainty. For these the project capitalizes on results of the research project FIT4Green, which aims at saving 20% of energy at data centre operation through the integration of an energy aware management plug-in on top of the existing data centre framework system[1]. Multi-agent frameworks supporting distributed resource constrained scheduling problems [7,8] are considered as an alternative for improved workload control, which can lead to shaping of energy load. Increasing flexibility in contracting between DCs and ICT end-users, and exchanging energy demand and supply information between energy producers and DCs allows more energy-efficient power management at DCs and at the same time meeting Green-SLAs.

SLA as a means to actively influence the environmental impact of DC operation has not been thoroughly tackled in research. Some preparatory work ([11]) has been carried on in the in the area of SLA-based scheduling with the goal to evade SLA breaches by turning them into scheduling algorithms [4]. The power of SLA for environmental objectives has been first recognized by [5] where new SLA parameters trying to catch the CO2 impact of DC operation were introduced – and approach comparable to [3] who integrated CO2 parameters into the quasi-standard for scientific SLA, the WS-Agreement. The concept of GreenSLA was introduced by [1], [2] in the context of energy efficient DC operation.

3 Establishing a Collaboration between Energy Provider, Data Centre and End User

3.1 Energy Provisioning

The Smart Grid is supposed to lead us into an energy efficient era with less overhead in energy production, less wasted energy on the consumer side, and an increased utilization of renewable energy. However, the combined volatility of both, energy supply and energy demand leads to a major challenge: On the one hand, high demands of energy (imposed at peak times) result in the activation of less efficient energy generation. On the other hand, renewable energies are unfortunately based on energy sources that tend to be subject to uncontrollable factors as, e.g., wind or sunlight, and need to be consumed as available.

Energy production can be classified into base load, medium load, peak load, and renewable energy generation (see figure 1) which have different characteristics

[1] www.fit4green.eu

regarding the dynamic adaptation to volatility of demand. These characteristics, in turn, have different impact on CO_2 emissions and power density[2]:

- Peaking power plant:
  - Generation of energy is very expensive and resource intensive (mostly fossil energy sources)
  - Highly responsive to changes in load
  - Pumped-storage hydroelectricity, gas turbines
- Medium load power plant:
  - Medium cost for energy generation
  - Responsiveness to changes in load is moderate
  - Combined gas and steam power plants
- Renewable energy sources
  - Replaces energy sources for base load
  - Wind and solar power
- Base load power plant:
  - Cheap and relatively efficient generation of energy
  - Responsiveness to changes in load is low
  - Nuclear, coal, hydro power

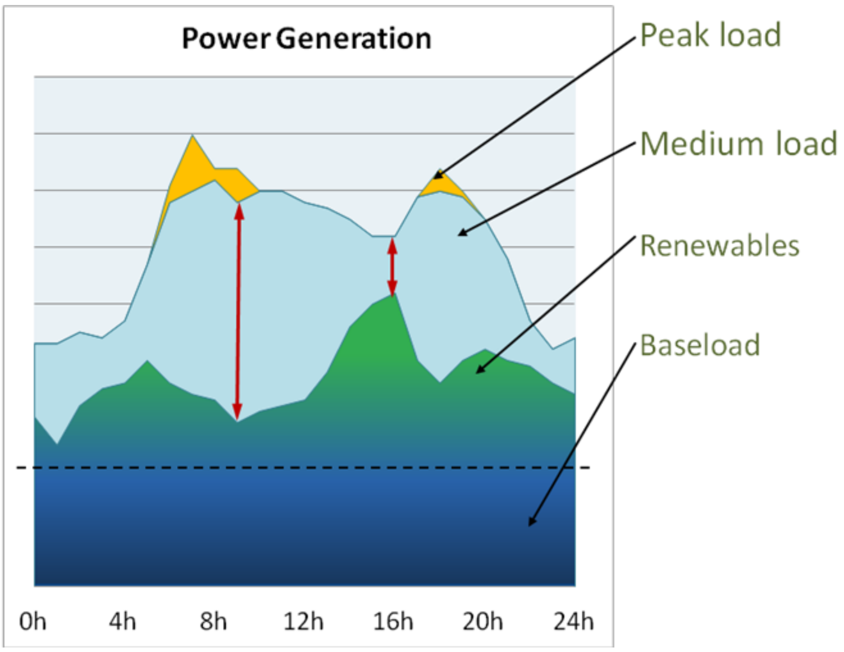

Figure 1: Structure of power generation (Source: Brautsch et al., 2011)

[2] In the first project phase, CO_2 will be the main indicator to assess the impact of the energy conversion process on the environment. However, this measure doesn't capture e.g. the potential risk of nuclear energy. Therefore one research topic is to integrate other output measures into the CO_2 indicator.

Generally speaking, the quicker the power plants have to react to energy demand spikes, the greater the impact on the environment. The peaking power as the most flexible and least environmentally desirable is generated whenever the energy demand exceeds the planned limit. Today it is exclusively up to the EP (who can also be a producer, an energy trader or a mix of the two roles) to react to sudden increase in energy demand by adding inefficiently produced peak energy to the grid. The potential for closer interaction between energy producers and energy users like DCs is thus not tapped.

3.2 The All4Green Eco-System

In this section, the infrastructure of the grid proposed by All4Green project is presented. Instead of putting the focus of the energy optimization in DCs solely on ICT resources and/or HVAC infrastructure within the DC, All4Green broadens the scope and integrates all players into one eco-system. Within this eco-system, the DC or DC Federation (denoted DCF) has the double role of being the customer of the EP as well as being the supplier of ICT services to their customers. EU/End User represents the demand side of the DC. A typical user aims at minimizing the total costs of computing, i.e. the price paid to DC for computing services, but also has a bias to choose for SLAs that provide more sustainable and more energy-efficient energy usage. It will prefer cheaper, longer term contracts, providing stability for computing services; contracts with DCs with a better reputation, e.g. based on "good history"; contracts which provide better service levels, i.e. higher quality, less execution delays and fewer incidents, and those less binding, i.e., the ones which allow de-commitment without penalties from EU's part but not from DC's part. User propensity for green computing and Green SLAs will encourage DCs that are able to provide Green Computing using renewable energy sources. EP/Energy Provider represents the energy supply side for the DC. Its goals are to acquire a uniform and predictable load for all energy delivered to DC, and in some countries to not exceed its maximum amount of emissions, i.e. a "Green Quota" established by the Government. It tries to apply different strategies to maximize its profit while selecting the most preferred and easily available energy source mix from its suppliers. This is why EP prefers predictable energy loads and uses energy consumption profiles of its DC customers, shared voluntarily as part of energy provisioning agreements, or measured by EP based on monitored Key Performance Indicators. In order to reduce cost, EP tries to avoid power peaks, as this is traditionally the most costly power and involving non-renewable energy sources.

DC/Data Centre acts as provider of computing services and as demand side for the EP. With its specific business model it wants to stay on the market, maximizing turnover, minimizing cost. One sustainability strategy can be to market green products. The DC's workload profile influences its energy consumption profile and it can choose to share this profile with the EP to obtain a discounted energy price for a given energy source provisioned by EP. The DC also employs forecasting to anticipate its own workload profile under different strategies for accepting computing requests.

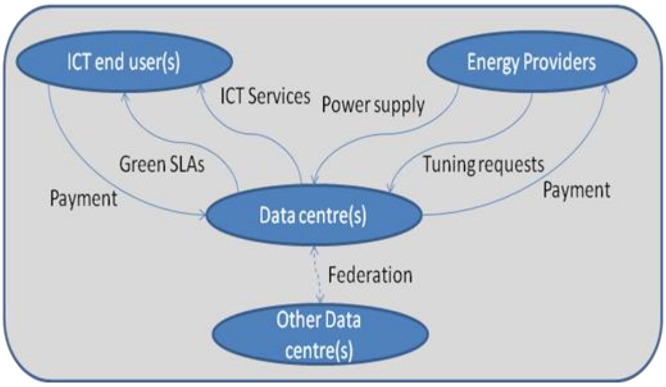

Figure 2. All4Green Eco-System

Figure 2 shows the envisioned relations between the EP, the DCs and the ICT EUs. The communication between the EP and its customers (e.g., the DCs) will be bidirectional, instead of just unidirectional, as it is now. Nowadays, in general there is no (or just a very limited) digital communication between these entities, and the EP only has knowledge about the overall amount of power that was consumed in the past. Thus, the possibilities to send data from the EP to the customers (and vice versa) are very limited. However, for a smart, ecological grid, this is a crucial requirement, since an intelligent distribution and well-planned scheduling of available power resources is not possible without further information about the customer's future needs. Customers that agree to delay some power-consuming tasks for some hours have to be noticed in case that enough energy gets available inside the grid, so they can start their tasks. Of course, the EP cannot send the same signal to all its customers. Otherwise, too many participants might start consuming energy at the same time so that the demands for energy would overwhelm the currently available resources. So, a scheduling approach has to be developed to notify the right subset of consumers at the right time. Additional information about the delayed tasks and the amount of energy a customer usually needs at a specific time of day should be taken into account by the EP.

For this, a digital connection between DC and EP is needed

- to send notifications regarding available energy resources from the energy provider to the DC.
- to send notifications from the EP to the DC in case there is an energy shortage in the grid and to ask the customer to reduce its consumption
- to tell the EP which amount of energy will be needed in the near future and for how long. Additional information that supports scheduling could also be included, e.g., how urgently the energy will be needed then.
- to tell the EP how much energy is locally buffered (e.g. by the

UPS) and could possibly be used by the data centre itself (e.g., by switching off the UPS as backup-energy or as energy storage in case the grid state is getting critically low/high).

For planning purposes, up-to-date information will be needed. This gets even more important when renewable energy sources should be used by the providers. Short-term fluctuations of the amount of produced power complicate the prediction of available energy. To deliver energy in a timely manner to its customers, the EP also needs to receive up-to-date information from the customers.

Scheduling is not only done by the EP. Inside a DC, some non-urgent tasks can be delayed. Another way of raising or reducing the amount of needed energy is to migrate workload to federated DCs located in, e.g., another country or region. For instance, tasks are moved to a place where enough energy is currently available - meaning: It is more energy efficient to move jobs to where they can be done, instead of moving energy to where it is needed.

Furthermore, a DC that hosts workload for its ICT EUs, might introduce a new kind of green contracts (GreenSLAs, see section 4.2). EUs that agree to accept a limited QoS reduction for their hosted services might get better pricing conditions.

4 Strategies for Shaping the Energy Demand in Data Centers

There are several energy saving techniques that have been successfully applied in DCs [10] and amongst others can be used to shape the demand in a DC or a DCF in order to comply with requests from an EP. Additionally, in order to exploit the full potential of the envisioned collaborative approach, economic incentives are being developed that foster the collaboration between DC and EU and also instigate the cooperation between DC and EP.

4.1 All4Green Energy Shaping Techniques

This section contains several techniques for energy load shaping in a DC.

Dynamical Server consolidation. A dynamic measure to reduce energy consumption is to consolidate servers that are not used at their normal capacity into fewer ones, with a better utilization. Thus freed, unused servers can be shut down. When load will grow, some of these servers will be restarted (FIT4Green approach) [12] [13]

Server Virtualization. Virtualization helps consolidate workload on fewer physical servers.s.

Workload migration across a federation of data centers. The solution of workload migration is particularly interesting when the transfer of tasks takes place between geographically dispersed nodes, which are subject to different geographical characteristics (cold vs. warm climate) and availability of energy sources (wind power instead of coal).

Other techniques. The main problem faced by DC is a dynamic workload demand with abrupt peaks of energy consumption, followed by lower than average demand (outside working hours, at night and during week-ends). Through adapting mid-term workload planning to energy supply planning, peaks can be avoided.

Cooling. The cooling infrastructure can serve as energy buffer: At times of high energy supply (through wind, sun) the temperature in the DC can be reduced beyond what is necessary. This buffer can be utilized in times of scares energy. Moreover, thermal "debts" can be created by allowing the temperature to rise up to a certain extent – these debts can then be paid back with renewable energy.

UPS. In the event of power shortages or even periods of energy peaks, Uninterruptible Power Systems (UPS) can be started. They can function for systems independently or in parallel with EP power-generating system, for as long as the energy provided by EP is insufficient for all active servers and virtual machines at DC, and after the energy consumption peak is over, they can be stopped again.

Negotiation as workload coordination mechanism. The actors in the DC ecosystem can participate in a multi-party negotiation to shape the energy demand in the DC. Separate DC-EP and DC-EU negotiations can take place, with different frequencies and for different objectives: DC-EP negotiation take place weekly or monthly to establish the energy source mix and price per KWh that the DC needs to pay to EP (based on the average energy load demand in the previous period, and the stability/uniformity of the consumption profile). DC-EU negotiations take place monthly or periodically as agreed upon in the SLA and aim at establishing the maximum computing delays for a given computing task cost.t.

4.2 All4Green Energy Shaping Incentives

The technical collaboration approach introduced above offers a high potential for the optimization of energy provision. Within the traditional legal and economic boundaries however, this potential remains untapped to a great degree: On the one hand full elasticity of electricity supply between EP and DC has been an undisputed principle until now, on the other hand strict performance guarantees between DCs and their customers limit the scope for energy shaping measures in the DC.
This is why All4Green explores strategies that aim at economically supporting the technical options offered by the collaboration tool. A powerful leverage to do this are the contracts between EP and DC as well as between DC and EUs.

There is a bundle of different energy tariffs a business can choose from for the contract with its EP. Most of these are a combination of a baseline tariff that depends on the connected power and a variable component that depends on the kWh consumed.

In All4Green however this rationale of elastic supply is inverted: The EP needs options to require the collaboration from the DC in clearly specified boundaries. This calls for new energy tariffs that foster this collaboration by giving the EP the right to trigger energy shaping activities at the site of the DC. Such a contract will contain the definition of triggering events, but also limitations for the EP, for instance with regard to the number of triggering events per week or month and with regard to magnitude of the DCs activities. At the same time the contract must offer a trade-off for the DC, most likely in the form of a novel pricing system that connects the DC's electricity cost to the intensity of the realized collaboration – thus rewarding the DC if it reacts positively to the triggering event.

However, also on the side of the DC, the scope of technical cooperation is limited due to performance guarantees the data center has given to its customers through their contracts. The guarantees between DC and customer are contained in the service level agreements (SLA), which are the technical parts of IT service contracts.

Until recently these SLA were biased toward sheer performance and availability orientation, no matter at what cost for the natural environment. This resulted for instance in SLAs based on the TIER I-IV categories that guarantee a certain standard of access (e.g. 24-7-365) and infrastructure redundancy. For certain applications, be it mission critical prototype test or medical simulations, performance will always be the most important requirement. There are other applications, however, that are not critical in the same way, be it regularly done back-up jobs or the processing of monthly billing data in a company. For these, in the context of All4Green, GreenSLA will be offered that trade the possibility of slight performance degradation against e.g. monetary incentives and a certified "greenness" of the IT service.

To this end, we define a GreenSLA as a SLA between a service provider and its customers that offers an extended scope for energy shaping measure to the service provider

- by replacing traditional performance parameters through allowed performance scopes
- by introducing novel energy performance parameters as classifying elements,
- keeping track of collaboration efforts from both DC and end-customer, and
- by offering incentives to the customers to agree to performance modifications and collaboration.

If a customer of a bank, e.g., agrees to such a GreenSLA, the fees for her bank account will be reduced – at the expense of an increased waiting time for bank services like transferring money etc.This concept was first introduced in the context of energy saving measures in DCs [1],[2]. In All4Green it will be used in a different way – not only helping to reduce the energy consumed by DCs without caring for adaptation processes at the EP's site, but by supporting the DC in actively shaping its energy demand: the goal "reduce energy consumption originating in costumer/applications specified in GreenSLA" is replaced by the goal "support DC's energy shaping efforts" under certain performance constraints.

5 Impact

All4Green aims at reducing the energy consumption accountable to the DC industry through a really upheaval approach. This is an objective which in turn, if reached, may significantly benefit the global energy consumption picture. As a matter of fact, in 2008 the European DC consumption was estimated at 50 TWh, expected to rise to 100TWh by 2020, roughly the same as the electricity consumption of Portugal. So, the project targets an area where obtaining results can have a relevant impact on overall sustainability.

Up to date, the energy saving (or emission saving) goals have been pursued through sectorial approaches, where each of the involved actors put forth its own instruments and action plans, looking at a reduction of its own consumption which didn't take into account nor tried to exploit the interactions with the other players of the DC supply chain. Nevertheless, acting in self-standing way can't avoid the occurrence of boundary and/or abnormal operation conditions, which, even if transient, can have a significant negative impact on the big energy consumption picture. Demand peaks are one of the most common and simple cases in point: peak energy conversion is ineffective ("rich" in CO_2 and "poor" in efficiency terms). For instance, to produce 1MW from diesel fueled equipment (typically used during peak loads) requires approx. 250ltr/h, which means about 700 kg CO_2 /h emission.

All4Green wants to minimize the negative impact of the above cases by developing technologies supporting an active cooperation among all the ecosystem actors (EPs, DC operators, and EUs), with the common purpose to control energy demand, and by this means obtain an overall energy saving around 10% for the system as a whole. This saving doesn't overlap with the ones you can achieve through self-standing improvements, on the contrary adds on to that, and can in general be applied even to ecosystems where ICT equipment, DC facilities and/or energy sources have not reached an intrinsic good level of efficiency yet.

A second positive effect of All4Green is to increase the percentage of renewable energy that can be fed into the electricity grid. Nowadays, to some degree due to their reduced constancy and predictability, solar or wind energy produced cannot be fully utilized because the power supply voltage is already at maximum. In Germany, for instance, a solar power plant with more than 100MW connection power is legally required to be detachable due to grid stability issues! Through the joint demand control mechanisms offered by All4Green, this problem can be much better tackled.

In terms of energy consumption management on the DC side, All4Green can positively impact two areas:

1. It can provide verifiable and transparent methods of measuring energy performance, by developing new metrics that encompass the whole value network aggregating ICT EU, DC and EP (and subsets thereof). These metrics will be developed in a way to show if the energy savings (triggered via technical changes, or economic incentives within the eco-system like Green-SLAs), materialize as real reductions of inputs of energy carriers into the technical and economic metabolism.

2. It can offer quantifiable and significant reduction of energy consumption and CO2 emissions, achieved through ICT. The reduction of energy consumption that can be achieved through ICT depends largely on:

- The freedom DCs have in performing local optimizations by using Green-SLAs as contracts between ICT users and DCs. Inside ordinary DCs 10% to 20% energy savings can be realized during certain time periods, particularly by DCs offering services to geographically concentrated users, on top of traditional strategies/policies already in place (that work with standard SLAs).
- The reduction of energy demand from non-renewable sources at the very beginning of the energy value chain: savings that can be transported to the origin of energy conversion are magnified from the environmental perspective. The collaboration between DC and power provider can result in a temporary 10%-20% reduction of the DC energy demand, typically by delaying or slowing down some activities, to help power providers manage energy consumption peaks.
- The ability to “migrate” workload across the DCF can reduce the transport needs of energy from remote providers, and thus avoid the 10% energy transport overheads.

If this vision is projected to all the European DCs (a very strong assumption), this would mean that through a well-working collaboration mechanism within the DC eco system, the huge amount of roughly 2000 t CO2e could be avoided by integrating the necessary energy consumption into the base or medium load instead of “producing” extra inefficient and dirty peak load energy which is about what 20.000 German families consume in those 2 hours![3]

6 Summary and Conclusions

This paper has presented a novel idea to face current and future problems caused by the ongoing energy transition. While more and more regenerative energy is produced and the production of nuclear power may be reduced in the future, new technologies are needed to keep the power grid stable.

The arising problems of energy production have been discussed in detail in this paper and the collaboration between energy producers, energy consumers, and finally their end-customers has been identified as feasible approach to customize energy demand with respect to the dynamic supply of energy. Especially, the energy-related eco-system of data centers has been looked at in detail, consisting of the energy provider, the data center and the end-customer of the data center. The paper has presented mechanisms as virtualization, consolidation, federation of data centers, and management of cooling systems and UPS that are able to achieve a high flexibility of energy demand within the data center. This flexibility can be used by the energy provider to adjust energy demand to the current availability of regenerative energy and to shave peaks in power demand to keep the power grid in a stable situation.

Furthermore, the paper has discussed incentives (as green SLAs) that are necessary to enable the needed collaboration within the energy-based eco-system of the data center. Finally the paper has discussed the possible impact of the suggested approach and presented the possible positive outcomes of the project All4Green.

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